INNOVATION ENCOURAGING PUBLIC PROCUREMENT IN CIVIL ENGINEERING

Different roads leading to different Romes

Bart Lenderink

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Bart Lenderink
born on the 23rd of October 1989
in Apeldoorn, the Netherlands

This dissertation has been approved by:

Supervisors:

Prof.dr.ir. J.I.M. Halman

Dr. J.T. Voordijk

Prof.dr.ir. A.G. Dorée

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Summary

Innovation encouraging public procurement strategies are highly relevant as a means to address the increasing societal and environmental challenges we are facing now and in the near future. As the largest user of raw materials and a major contributor to CO2 emissions, the civil engineering industry has a significant impact on these challenges. Small improvements in this industry can already have a significant effect on the Sustainability Development Goals (SDG's) set by the United Nations (United Nations, 2020). Moreover, the civil engineering industry plays an essential role in improving our ability to cope with the negative effects of climate change and ensuring the upkeep of public infrastructure with limited budgets in the years to come. As such, the development and improvement of more sustainable and cost-effective solutions in civil engineering is essential for addressing these societal and environmental challenges.

Large public clients have a major influence on the extent to which innovations can be developed and implemented within civil engineering projects and programmes. In fact, contractors and other suppliers are highly dependent on these clients to provide incentives and suitable conditions within public tenders for projects and programmes for innovations to flourish. Yet, despite their potential influence on innovation, public clients are often reluctant to actively encourage innovation in public tenders for civil engineering projects and programmes. A possible explanation for this reluctance is a lack of knowledge with respect to the use of innovation encouraging strategies within public procurement.

This research focusses on the use of public procurement to encourage innovation in civil engineering projects and programmes, and aims to contribute to addressing the substantial societal and environmental challenges withing the field of civil engineering. The main research question of this study is:

What are the main options for public clients to stimulate innovation through public procurement in civil engineering projects and programmes?

This main research question is divided into four sub-questions, each corresponding to one of the chapters in this thesis:

1. What reasons, approaches and methods for stimulating innovation through public procurement can be found in literature?
2. How can the implementation of innovations be encouraged and assessed in public tenders for the award of civil engineering projects?

3. What determining factors and mechanisms influence the successful development and implementation of radical innovations within civil engineering projects?
4. How to select an effective innovation-encouraging procurement strategy for specific projects or programmes in the field of civil engineering?

A qualitative research approach was selected based on the exploratory and explanatory nature of the research questions in combination with limited existing theoretical and empirical knowledge on the use of innovation encouraging public procurement in the field of civil engineering.

Chapter 2 of this PhD thesis provides an answer to the first sub-question by presenting a structured literature review on different concepts, rationales and approaches for encouraging innovation through the use of public procurement. The initial findings of the literature review showed that a wide range of different concepts and abbreviations are used in academic articles and policy documents to describe the phenomenon of stimulating innovation though public procurement. Moreover, they pointed out that these concepts and abbreviations are associated with different reasons and methods used for stimulating innovation, which can make it difficult for public organizations to decide why, how and to which extend they will encourage innovation through public procurement. The literature review addresses this problem in three ways. First, it provides a review on the different streams of literature, dichotomies and typologies with respect to encouraging innovation through public procurement. Second, it discusses various approaches on an individual level and comparing them in a structured overview. Third, it provides guidance on the suitability of these approaches in different situations. Based on this literature review we found that one of the main ways to differentiate these approaches is to separate them into three categories based on the categorization of the OECD (2011).

1. Regular procurement, which can be made more innovation-friendly;
2. Strategic procurement of innovations, where public clients demand new technologies products and services to address a specific need or societal challenge;
3. Procurement of R&D services.

Chapter 3 provides an answer to the second sub-question, by presenting a design-oriented study in which a method to trigger and assess innovations in tenders for bridge projects is developed, implemented and evaluated. Encouraging innovation

in civil engineering projects and programmes can contribute to achieving policy goals, addressing societal challenges and obtaining specific objectives. Despite their potential, innovations are rarely included in the scope of tender assignments and the evaluation of tender offers. An explanation for this is the perceived difficulty by public clients to trigger and objectively evaluate innovations in the award of tender assignments. To address this problem a new method to trigger and assess innovations in tenders was developed, implemented and evaluated within a bridge project. Using this method tenderers were explicitly requested to include up to three innovations in their tender offer for this project, which were assessed in the evaluation of the tender offers. The findings of this study indicate that it is possible to trigger and assess innovations in tenders for civil engineering project in line with procurement regulations and their underlying values. Furthermore, the study showed three main ways to encourage innovation within tenders for civil engineering projects:

- Provide incentives to tenderers for including innovations as part of their tender offer;
- Provide solution space within the description and requirements of tender assignments to allow for the inclusion of innovations by tenderers;
- Use innovation as a selection criterion in shortlisting tender candidates to determine which candidates are invited to submit a tender offer for the civil engineering project.

Chapter 4 provides an answer to the third sub-question, by presenting the results of an in-depth case study on how a public client managed to develop and implement a radical green innovation in a civil engineering project. The use of integrated project delivery methods can be an effective way to encourage incremental innovation in regular civil engineering projects. However, for encouraging the development and implementation of radical innovations in such projects the unilateral allocation of the innovation risks to the main contractor is undesirable since these risks are more difficult to assess and manage. This is due to the significant gap between required and acquired technological knowledge and skills which need to be bridged involving large inherent uncertainties during the implementation of such innovations in a project. The case study results led to the identification of three essential factors for the successful development and implementation of a radical green innovation in this project:

1. Government championship, through a proactive participation of the public client in the initiation, development and realization phases of the project and the willingness of the public client to bear innovation risks;

2. The application of innovation risk management strategies and the availability of a fall back option;
3. The establishing of favourable organizational and relational conditions.

A review of the literature revealed that each of these factors could be traced back to existing literature. Yet, this study revealed that it was the well-considered conjoint application of these three factors by the public client which explained the successful implementation of the radical innovation in this civil engineering project.

Finally, chapter 5 provides an answer to the fourth sub-question by presenting a typology and guidelines for selecting innovation encouraging procurement strategies in the field of civil engineering. Furthermore, a multiple case study is presented which is among the first to classify different types of initiatives with respect to the use of innovation-encouraging procurement strategies in the field of civil engineering. A significant amount of research has been carried out on how public clients can encourage innovation through the procurement of goods and services and the development of dichotomies and typologies in this area reflect this. However, there is still a lack of knowledge on which procurement strategies and tendering methods can be effectively used to encourage specific types of innovation within larger public initiatives such as civil engineering projects and programmes. The developed typology in this study uses three factors to distinguish different types of civil engineering initiatives with respect to encouraging innovation through public procurement:

1. The scope and time frame of the intended project or programme;
2. The degree of innovation that needs to be realized in the specific project or programme;
3. The intended level of cooperation/competition in the client-contractor relationship.

In addition to the typology, a general guideline is developed and proposed for the selection of an effective innovation-encouraging procurement strategy. In this guideline six coherent procurement strategies are described with respect to the proposed procurement methods in relation to the type of initiative and desired client-contractor relationship.

Based on the conducted research presented in this PhD thesis, chapter 6 provides a discussion on the scientific contributions of this PhD thesis. First, it contributes to the debate on how the terms innovation and innovativeness can be operationalized. In specific, these terms were adapted to in the specific context of innovation in bridge project allow for the assessment of innovation in tender offers in such a project.

Second, it contributes to the debate on how different types of innovation can be encouraged through public procurement. In specific, this study is among the first to study the mechanisms that affect the development and realization of radical innovations in a civil engineering project. Third, it contributes to the debate on how the government can encourage innovation in the field of civil engineering. In specific, the study has combined insights from three streams of literature to develop a typology on civil engineering initiatives with respect to the selection of public procurement strategies for encouraging innovation. Furthermore, a guideline is developed for the selection of innovation encouraging procurement strategies based on literature and a multiple case study of 8 civil engineering projects and programmes.

This PhD thesis also has important implications for public clients of civil engineering project and programmes. First, in line with previous research the results of this research indicate that procurement decisions of public clients have a decisive influence on the extent to which innovation is likely to occur within civil engineering projects and programs. As such, this research stresses the essential role public clients play in encouraging innovation within the sector. Second, the results show that innovation encouraging procurement strategies can be used by clients for different purposes, such as achieving policy goals, addressing societal challenges or obtaining specific goals within a project or program. Third, the results of this research indicate that the selection of an effective innovation-encouraging procurement strategy in particular depend on three factors with respect to the civil engineering project or programme at hand: 1) the scope and expected timeframe, 2) the intended degree of innovation to be realized, and 3) the type of client-contractor relationship. A careful consideration of these factors in combination with the use of the developed guidelines can aid public clients in selecting an effective innovation encouraging procurement strategy. Lastly, the results indicate that the conjoint application of three factors favours the realization of radical innovations within civil engineering projects: 1) government championship, through a proactive role of the public client in all stages of the project, 2) the deliberate application of risk management strategies and inclusion of a fall-back option, and 3) the establishment of favourable organizational and relational conditions.

Samenvatting

Het gebruik van innovatiegerichte inkoopstrategieën is een belangrijk instrument voor het adresseren van belangrijke maatschappelijke opgaves op het gebied van duurzaamheid en milieu. De bouw/infra sector heeft vanwege zijn bijdrage aan de uitstoot van CO_2 emissies en als grootste verbruiker van natuurlijke grondstoffen een grote invloed op deze maatschappelijke opgaves. Kleine verbeteringen in deze sector kunnen daarom substantieel bijdragen aan het behalen van de duurzame ontwikkelingsdoelen (Sustainable development goals) van de Verenigde Naties. Daarnaast speelt de bouw/infra sector een essentiële rol in het klimaatbestendig maken van onze leefomgeving. Dit om de negatieve gevolgen van klimaatverandering tegen te gaan. Een andere belangrijke uitdaging is het op peil houden van de staat van de fysieke infrastructuur binnen de beschikbare budgetten in de komende jaren. Hiertoe is het ontwikkelen, verbeteren en toepassen van meer duurzame en kosteneffectieve oplossingen binnen de civiele techniek van groot belang.

Grote publieke opdrachtgevers hebben een aanzienlijke invloed op de mate waarin innovaties binnen civiele projecten en programma's tot stand komen. De reden hiervoor is dat aannemers en leveranciers in hoge mate afhankelijk zijn van de prikkels en mogelijkheden die door publieke opdrachtgevers geboden worden om innovatieve oplossingen in hun aanbieding op te nemen. Ondanks hun potentiële invloed, blijken publieke opdrachtgevers helaas vaak terughoudend te zijn om binnen civiele projecten en programma's, innovatie actief via publieke inkoop te stimuleren. Een mogelijke reden hiervoor is een gebrek aan kennis en ervaring met betrekking tot het gebruik van innovatiegerichte inkoopstrategieën.

Dit promotieonderzoek richt zich op het gebruik van innovatiegerichte inkoopstrategieën binnen civieltechnische projecten en programma's en heeft tot doel om een bijdrage te leveren aan het oplossen van maatschappelijke opgaves op het gebied van duurzaamheid en milieu. De hoofdvraag van dit onderzoek is:

"Wat zijn de belangrijkste opties voor publieke opdrachtgevers om innovatie te stimuleren via publieke inkoop in civiele projecten en programma's?"

Voor het beantwoorden van deze hoofdvraag zijn er vier deelvragen opgesteld, die elk in een apart hoofdstuk in dit proefschrift worden behandeld:

1. Welke redenen, aanpakken en methodes worden er in de literatuur beschreven voor het stimuleren van innovatie door middel van publieke inkoop?
2. Hoe kan de toepassing van innovaties worden gestimuleerd en beoordeeld binnen publieke aanbestedingen voor civiele projecten?
3. Welke mechanismes beïnvloeden de succesvolle ontwikkeling en toepassing van radicale innovaties binnen civiele projecten?
4. Hoe kan een effectieve innovatiegerichte inkoopstrategie worden gekozen voor specifieke civiele projecten en programma's?

In dit onderzoek is gebruik gemaakt van een kwalitatieve onderzoekaanpak vanwege het verkennende en verklarende karakter van de onderzoeksvragen en ook de beperkte beschikbaarheid van theoretische en empirische kennis op het gebied van innovatiegericht inkopen binnen de civiele techniek.

Ter beantwoording van deelvraag 1, wordt in hoofdstuk 2 een gestructureerd literatuuronderzoek beschreven waarin verschillende concepten, redenen en aanpakken voor het stimuleren van innovatie via publieke inkoop worden behandeld. Een eerste scan van de literatuur laat zien dat er een groot aantal verschillende concepten wordt gebruikt voor het bevorderen van innovatie door middel van publieke inkoop. Daarnaast laat deze scan zien dat de gebruikte concepten en bijbehorende afkortingen veelal worden geassocieerd met verschillende methodes en redenen voor het stimuleren van innovatie. Ook worden concepten en afkortingen door elkaar gebruikt. Dit kan bij publieke opdrachtgevers tot verwarring leiden bij het bepalen in hoeverre, op welke manier en voor welke doelen zij innovatie via publieke inkoop willen en kunnen stimuleren. In hoofdstuk 2 wordt dit probleem op drie manieren uitgewerkt. Ten eerste wordt een overzicht gegeven van de verschillende stromingen, dichotomieën en typologieën met betrekking tot innovatiegericht inkopen. Ten tweede worden de verschillende aanpakken individueel besproken en gecategoriseerd in een gestructureerd overzicht. En ten derde worden aanbevelingen gedaan over de mate waarin het gebruik van verschillende typen innovatiegerichte inkoopstrategieën passend is in verschillende situaties. Een belangrijke bevinding van het uitgevoerde literatuuronderzoek is dat de categorisatie van de OECD (2011) een waardevolle kapstok biedt voor het categoriseren van de verschillende typen inkoop met betrekking tot innovatie. Hiertoe wordt in hoofdstuk 2 een onderscheid gemaakt tussen:

1. Reguliere inkoop, die meer innovatievriendelijk gemaakt kan worden;
2. Strategische inkoop van innovaties, waarbij publieke opdrachtgevers nieuwe technologieën, producten en diensten uitvragen voor het adresseren van een specifieke behoefte of maatschappelijke uitdaging;
3. Inkoop van onderzoek- en ontwikkeldiensten (R&D).

Ter beantwoording van deelvraag 2, wordt in hoofdstuk 3 een methode beschreven die ontwikkeld is voor het uitvragen en beoordelen van innovaties bij het aanbesteden van brugprojecten. Het stimuleren van innovatie in civiele projecten en programma's kan significant bijdragen aan het behalen van beleidsdoelen, het adresseren van maatschappelijke opgaves en het halen van project specifieke doelen. Desondanks wordt de toepassing van innovaties zelden specifiek binnen civiele projecten uitgevraagd en/of meegenomen bij het beoordelen van de inschrijvingen. Een mogelijke verklaring hiervoor zijn de problemen die ervaren worden bij het uitvragen en objectief beoordelen van innovaties bij het aanbesteden van overheidsopdrachten. Daarom is specifiek voor het uitvragen en het beoordelen van de innovatiegraad en de schaal van innovaties een nieuwe methode ontwikkeld. De methode is vervolgens toegepast en geëvalueerd bij de aanbesteding van een nieuwe brug. Bij deze eerste toepassing werden inschrijvers gevraagd om maximaal drie innovaties in hun aanbieding op te nemen. De beoordeling van deze innovaties werd vervolgens als onderdeel meegenomen in de selectiebeoordeling van de inschrijvingen. De bevindingen van deze studie wijzen erop dat het met de nieuw ontwikkelde methodiek mogelijk blijkt om innovaties binnen civiele projecten uit te vragen en deze op objectieve wijze te beoordelen. Daarnaast worden in hoofdstuk 3 drie belangrijke manieren beschreven om binnen aanbestedingen voor civiele projecten innovaties te stimuleren:

- Het bieden van prikkels aan inschrijvers voor het opnemen van innovaties als onderdeel van hun inschrijving;
- De eisen en de scope van de opdracht dusdanig specificeren zodat er aan inschrijvers oplossingsruimte wordt geboden voor het opnemen van innovaties in hun inschrijving;
- Het gebruik van innovatie als één van de nadere selectiecriteria om te bepalen welke gegadigden worden gevraagd om een inschrijving te doen.

Ter beantwoording van deelvraag 3 wordt in hoofdstuk 4 een casestudie beschreven en geanalyseerd over de wijze waarop een publieke opdrachtgever de ontwikkeling

en toepassing van een radicale groene innovatie binnen een civieltechnisch project heeft weten te realiseren. Het gebruik van geïntegreerde contracten kan een effectieve methode zijn voor het stimuleren van de toepassing van incrementele innovaties. Echter, voor het stimuleren van radicale innovaties is het eenzijdig alloceren van de innovatierisico's naar de hoofdaannemer onwenselijk aangezien deze risico's in vergelijking met incrementele innovaties veel lastiger in te schatten en te managen zijn. Dit komt door het significante gat tussen de benodigde en reeds behaalde technische kennis en vaardigheden die moeten worden overbrugd en de grote risico's die gemanaged moeten worden bij het ontwikkelen en implementeren van dergelijke innovaties. Op basis van de uitgevoerde casestudie was het mogelijk om drie essentiële factoren te identificeren die nodig zijn voor het succesvol ontwikkelen en implementeren van een radicale groene innovatie:

1. Een duidelijke trekkersrol voor de overheid door het proactief deelnemen als opdrachtgever in de initiatie-, de ontwikkel- en de toepassingsfase van het project en het door de opdrachtgever bewust willen dragen van innovatierisico's;

2. Het toepassen van een aantal effectieve strategieën voor het managen van de innovatierisico's en het opnemen van een terugvaloptie in de uitvraag;

3. Het tijdens de ontwikkeling en uitvoering van het brugproject scheppen van organisatorische en relationele condities die gunstig zijn voor de ontwikkeling en toepassing van innovaties.

Uit het in hoofdstuk 4 uitgevoerde literatuuronderzoek blijkt dat elk van bovenstaande factoren terug te vinden is in de bestaande literatuur. Een belangrijke opbrengst van dit onderzoek is echter dat de bewust gecombineerde toepassing van deze drie factoren door de publieke opdrachtgever een doorslaggevende voorwaarde bleek te zijn voor de succesvolle ontwikkeling en toepassing van de radicale innovatie in dit civiele project.

Ter beantwoording van deelvraag 4, worden in hoofdstuk 5 een typologie ontwikkeld en richtlijnen uitgewerkt voor het kiezen van een innovatiegerichte inkoopstrategie voor civiele projecten en programma's. Als basis hiervoor is er een meervoudige casestudie uitgevoerd. In de meervoudige casestudie zijn verschillende typen civieltechnische projecten en programma's geanalyseerd met betrekking tot het gebruik van innovatiegerichte inkoopstrategieën. Er is in de afgelopen decennia een significante hoeveelheid onderzoek gedaan naar het stimuleren van innovatie via de publieke inkoop van goederen en diensten. Dit heeft geleid tot diverse

dichotomieën en typologieën. Er bleek echter nog steeds een gebrek aan kennis over welke inkoopstrategieën en tender methodes op een effectieve manier gebruikt kunnen worden om specifieke typen innovaties te stimuleren binnen de context van publieke projecten en programma's. De nieuw ontwikkelde en in hoofdstuk 5 beschreven typologie maakt gebruik van drie dimensies om verschillende typen civiele initiatieven te categoriseren met betrekking tot het stimuleren van innovatie via publieke inkoop:

1. De scope en looptijd van het beoogde project of programma;
2. De mate van innovatie dat gerealiseerd moet worden binnen het project of programma;
3. De beoogde mate van samenwerking/competitie in de opdrachtgever-opdrachtnemer relatie.

In aanvulling op de typologie is er een generieke richtlijn ontwikkeld voor het selecteren van een effectieve innovatiegerichte inkoopstrategie. In deze richtlijn worden zes coherente inkoopstrategieën beschreven met betrekking tot het gebruik van tender methodes in relatie tot het type initiatief en de beoogde opdrachtgever-opdrachtnemer relatie.

In hoofdstuk 6 wordt ingegaan op de wetenschappelijke bijdragen van dit proefschrift. Ten eerste draagt het onderzoek bij aan het debat over hoe de termen innovatie en innovativiteit kunnen worden geoperationaliseerd. De definities van deze termen worden in dit onderzoek zodanig geoperationaliseerd dat deze gebruikt kunnen worden voor het beoordelen van innovaties als onderdeel van inschrijvingen voor brugprojecten. Ten tweede draagt het onderzoek bij aan het debat over hoe verschillende typen innovaties kunnen worden gestimuleerd via publieke inkoop. Daarbij is dit één van de eerste onderzoeken waarin de mechanismen worden bestudeerd die van invloed zijn op de ontwikkeling en realisatie van een radicale innovatie binnen een civieltechnisch project. Ten derde draagt dit onderzoek bij aan het debat over hoe de overheid innovaties kan stimuleren binnen de civiele techniek. Hiertoe worden er inzichten uit drie literatuurstromen gecombineerd voor de ontwikkeling van een typologie van civieltechnische projecten en programma's met betrekking tot het selecteren van een publieke inkoopstrategie voor het stimuleren van innovatie. Daarnaast zijn er richtlijnen ontworpen voor het selecteren van een innovatiegerichte inkoopstrategie.

Het proefschrift heeft ook belangrijke implicaties voor publieke opdrachtgevers van civieltechnische projecten en programma's. Ten eerste laten de resultaten van dit

onderzoek zien dat publieke opdrachtgevers een doorslaggevende invloed kunnen hebben op de mate waarin innovatie zal plaatsvinden binnen civiele projecten en programma's. Ten tweede laten de resultaten zien dat innovatiegerichte inkoopstrategieën voor verschillende doeleinden gebruikt kunnen worden door opdrachtgevers, zoals het behalen van beleidsdoelen, het aanpakken van maatschappelijke uitdagingen en voor het behalen van specifieke doelen binnen projecten en programma's. Ten derde wijzen de resultaten van het onderzoek erop dat de keuze van een effectieve innovatiegerichte inkoopstrategie in grote mate afhangt van drie factoren met betrekking tot het civiele project of programma dat voorhanden ligt: 1) de scope en verwachte looptijd, 2) de mate van innovatie dat naar verwachting gerealiseerd moet worden, en 3) de beoogde mate van samenwerking/competitie in de opdrachtgever-opdrachtnemer relatie. Het zorgvuldig overwegen van deze factoren in combinatie met het volgen van de ontwikkelde richtlijnen kan publieke opdrachtgevers helpen bij het kiezen van een effectieve innovatiegerichte inkoopstrategie. Tot slot wijzen de resultaten van het onderzoek uit dat voor het succesvol realiseren van een radicale duurzame innovatie, een initiërende, proactieve trekkersrol door de publieke opdrachtgever gedurende alle fasen in het project onontbeerlijk is. Van de publieke opdrachtgever wordt daarbij verwacht dat deze de vereiste gunstige organisatorische en relationele condities schept en een effectieve risicomanagement strategie weet uit te werken bestaande uit een evenwichtige risicoallocatie-balans tussen opdrachtgever en opdrachtnemer(s) en het opnemen van een terugvaloptie in de uitvraag.

Contents

Chapter 1

1 Introduction

The world is increasingly confronted by several substantial sustainability challenges, which are related to three global trends: industrialization, population growth and urbanization (United Nations General Assembly, 2015). The first and foremost sustainability challenge is climate change, and the major effects it has on the environment we live in today and in the future. The global rise in temperature caused by greenhouse gas emissions is leading to: (a) increased sea levels, (b) larger variations in temperature and (c) the more frequently occurrence of extreme weather events such as droughts, floods, storms and heavy precipitation (IPCC, 2021).

Three other substantial sustainability challenges are: scarcity of natural resources (George, Schillebeeckx, & Liak, 2018), environmental pollution, and waste production. "The global material footprint grew from 73.2 billion tons in 2010 to 85.9 billion tons in 2017" (United Nations, 2020). The current use and disposal of natural resources cannot be sustained by the planet and has detrimental effects on the environment (United Nations, 2020). Some important examples are: mining of rare metals (Ali, 2014), use of fossil fuels (Covert, Greenstone, & Knittel, 2016), large scale deforestation (Finer et al., 2018), overfishing (Zhou, Smith, & Knudsen, 2015), and the production of solid waste (Hoornweg, Bhada-Tata, & Kennedy, 2013), plastics (Borrelle et al., 2020), electronics (Wang, Zhang, & Guan, 2016) and other hazardous materials that end up in the environment.

The civil engineering and construction industry has a major impact on these sustainability challenges and the environment we live in. This industry accounts for 6% of the global GDP, and most other industries rely heavily on the built environment as an asset to produce their economic and societal value (World Economic Forum, 2016). Moreover, the industry is the largest user of raw materials and is responsible for producing 23% of the global carbon emissions which contribute to climate change (Huang, Krigsvoll, Johansen, Liu, & Zhang, 2018). In addition, construction, renovation and demolition activities generate a significant share of the solid waste that is produced around the world (Yuan & Shen, 2011). As a result of this, small changes in this industry can have a significant effect on the Sustainable Development Goals (SDGs) developed by the United Nations (United Nations, 2020).

Three major sustainability challenges for the civil engineering industry are to: (a) significantly reduce its CO2 emissions (Huang et al., 2018), (b) increase the reuse of materials (van den Berg, 2019), and (c) decrease the production of solid waste (World Economic Forum, 2016; Yuan & Shen, 2011). Furthermore, there is a strong need to adapt the built environment to improve its ability to cope with the negative effects of climate change, such as the increased occurrence and severance of droughts, floods, storms and heavy precipitation (IPCC, 2021). Another challenge is the more intensive use of public infrastructure which is putting additional strain on existing public infrastructure. This in turn leads to a more frequent need for large scale renovations and maintenance of existing infrastructure in the years to come (van Belzen, 2021; Wientjes et al., 2016). Addressing these challenges will require incremental product and process innovations, as well as, the development and implementation of more substantial innovations where current solutions appear to be ineffective.

1.1. Innovation in civil engineering and construction

The civil engineering and construction industry has often been criticized for a lack of innovation (Dorée & Holmen, 2004; Egan, 1998; Loosemore & Richard, 2015; Xue, Zhang, Yang, & Dai, 2014). This view is negatively biased to some extent since innovativeness is traditionally measured through the amount of R&D expenditures and many innovations in the civil engineering and construction originate from other industries (Gambatese & Hallowell, 2011). Nonetheless, there are several characteristics which can explain why innovation tends to be less common in this industry compared to other industries. The first is the project-based mode of production, focussing on one offs or small batches of final products, which makes it relatively difficult to earn back investments into product innovations in comparison to the mass production of products (Lindblad & Guerrero, 2020; Rutten, Dorée, & Halman, 2009). Second, the supply chains in the industry are relatively fragmented and can be regarded as a "loosely coupled" system in which temporary coalitions work together to realize specific projects. As such, additional efforts into inter-organizational cooperation are important to successfully develop and implement innovations in this industry (Rutten et al., 2009). Third, the physical scale, expected life span and complexity of the produced systems lead to additional requirements for innovations in this industry (Slaughter, 1998). As such, the potential for failure, the failure mode, and options for repair and modifications over time of innovations in civil engineering need to be thoroughly investigated and assessed.

1.2. The role of the public client in encouraging innovation

The government plays a key role in encouraging innovation in civil engineering. Caerteling, Halman, and Dorée (2008) describe four ways through which the government can influence innovation in general. The first way is public funding of research and development activities which can result in innovations. The second way is government championship by providing technical assistance, political support and human resources to firms which are working on innovations. The third way is influencing the appropriability of innovations by changing the conditions which effect the extent to which firms are able to profit from innovations. Some examples of appropriability conditions are laws and regulations on intellectual property rights, standards and taxes. The fourth way is the use of public procurement to stimulate the development and implementation of innovations in civil engineering projects and programmes.

As a public client, government organizations have a major influence on the extent to which innovations can be developed and implemented within the field of civil engineering (Lindblad & Guerrero, 2020; Loosemore, 2015; Rose & Manley, 2012). The market of civil engineering can be characterised as a market with several large contractors and many sub-contractors, a large number of small public clients and only a few large public clients which have a dominant market position. This market structure in combination with the way public tendering works results in a high dependency of contractors and suppliers on larger public clients to provide incentives and suitable conditions for innovations to flourish. In fact, if these public clients do not specify their tender assignments in a way that alternative solutions can be offered, and/or significantly value quality and innovation in the assessments of bids, innovation is unlikely to occur in this industry. Unfortunately, public clients are often reluctant to encourage innovation and in many cases still focus on lowest price while evaluating tenders for civil engineering projects (Loosemore & Richard, 2015).

Several basic guidelines for encouraging innovation through public procurement are well known and widely described in literature. For example: (1) to focus on quality and price instead of lowest price only; (2) to accept alternative solutions; (3) the advantages of using performance-based specifications instead of prescriptive specifications and; (4) advantages of using integrated project delivery methods over the standard design-bid-build delivery method (Blayse & Manley, 2004; Eriksson et al., 2019). However, there is still a significant lack of knowledge on how different public procurement strategies and tendering methods can be used to effectively

encourage innovation within the context of civil engineering (Arnoldussen, Groot, Halman, & Van Zwet, 2017).

Since many different concepts and approaches for encouraging innovation through public procurement are used within literature and practice, it remains difficult for public clients to decide how, why and to what extent they will encourage innovation through public procurement. Second, there is a lack of knowledge on how innovations can be triggered and assessed within tenders for civil engineering projects. Third, most strategies and tendering methods for encouraging innovations discussed in civil engineering literature focus on stimulating incremental innovations. As such, knowledge on how to encourage the development and implementation of radical innovations within civil engineering projects remains limited. Fourth, there is still a lack of knowledge on how to select a procurement strategy and tendering methods for effectively encouraging innovation within specific projects or programmes.

1.3. Research aim and objective

The **aim of** this research is to contribute to addressing the substantial sustainability challenges within the field of Civil Engineering. In addition, it aims to contribute to improving the use of innovation encouraging public procurement within the field of civil engineering.

The main **objectives in** this research are:

- to investigate how public clients can effectively encourage innovation through public procurement in civil engineering initiatives
- to provide managerial and policy recommendations for improving the use of innovation encouraging procurement strategies and tendering methods

1.4. Research questions

The main research question of this study is:

"What are the main options for public clients to stimulate innovation through public procurement in civil engineering projects and programmes?"

This main research question is divided into four sub questions, each corresponding to one of the chapters in this thesis:

1. What reasons, approaches and methods for stimulating innovation through public procurement can be found in literature?
2. How can the implementation of innovations be encouraged and assessed in public tenders for the award of civil engineering projects?
3. What determining factors and mechanisms influence the successful development and implementation of radical innovations in civil engineering projects?
4. How to select an effective innovation-encouraging procurement strategy for specific projects or programmes in the field of civil engineering?

1.5. Overall research approach and philosophy of science

A qualitative research approach was selected based on the exploratory and explanatory nature of the research questions in combination with limited existing theoretical and empirical knowledge on the use of innovation encouraging public procurement in the field of civil engineering. Qualitative research approaches are better suited for answering open questions, as well as exploring and gaining an in-depth understanding of complex phenomena (Eisenhardt & Graebner, 2007). Quantitative approaches on the other hand are better suited for answering closed-ended questions and finding general patterns and relations from large samples which are representative of wider population.

This research was performed from a realism philosophy of science, which like pragmatism provides a middle ground between positivistic and relativistic philosophies of science (Van de Ven, 2007). Realism assumes there is a real world out there independent of our cognition (objective ontology), but our abilities as individuals to understand this world are severely limited. Based on our limited ability to understand this world, realism assumes that there are no predefined or predetermined methodologies or criteria to objectively judge the truthfulness of our knowledge (subjective epistemology). Rather, the validity of knowledge is based on consensus within the scientific community and the standards they use to reach this consensus. This research was performed within the field of social science. Sound logical arguments and empirical evidence are used to substantiate claims in this field (Van de Ven, 2007). Furthermore, triangulation across convergent, inconsistent and contradictory data is used to increase the validity of knowledge.

1.6. Research methods

Chapter 2: Identifying the reasons, approaches and methods for stimulating innovation through public procurement in literature

The first chapter of this thesis provides a structured literature review on different concepts, rationales and approaches for encouraging innovation through public procurement in general. Over the last two decades many articles and policy documents have been written on the use of public procurement as a tool to encourage innovation. A preliminary review of this literature showed that many different concepts are used across these article and policy, each with its own rationales and methods for encouraging innovation, and that an overview on these concepts, rationales and methods was still missing.

A systematic literature review is performed, which distinguishes the major streams of literature and discusses the various concepts, terms and abbreviations as well as dichotomies and typologies used in literature. Furthermore, a structured overview of different approaches for encouraging innovation through public procurement is presented and initial guidelines for the selection of a suitable approach are provided.

Chapter 3: Developing, implementing and evaluating a method to trigger and assess innovation in tenders for civil engineering projects

The second chapter presents a design-oriented study in which a method for triggering and assessing innovations in tenders for civil engineering projects is developed, implemented and evaluated. Encouraging innovation in civil engineering projects can contribute to achieving policy goals of the public client, addressing societal challenges and meeting the aims and objectives of the client. Despite their potential, innovations are rarely included and evaluated in the tenders for civil engineering projects, which could be explained by the perceived difficulty of public clients to trigger and objectively assess innovations in the award of projects.

To address this problem, a method for triggering and assessing innovations in tenders is developed, implemented and evaluated. For this a cyclical design approach is used based on Wieringa (2014) and van Aken, Chandrasekaran, and Halman (2016). In the first step a literature study is performed to investigate: 1) why it is particularly difficult to objectively assess innovations in tenders for civil engineering projects. Furthermore, the problem context of a bridge project, in which the client aimed to include multiple innovations, is investigated. In the second step the

innovation typology of Garcia and Calantone (2002) is tailored to create a method for ranking innovations based on their degree of innovation, as well as, the scale level on which the innovations are implemented in the tender offers. In the third step the design is evaluated through discussions with the procurement team of the bridge project. In steps four and five the developed method is implemented and evaluated within the bridge project.

Chapter 4: Identifying the mechanisms that affect the development and implementation of substantial innovations within civil engineering projects

The third chapter provides an in-depth case study on how a public client managed to develop and implement a radical green innovation in a civil engineering project. Two decades ago a trend started towards the use of integrated project delivery methods to improve the constructability of projects and stimulate innovation. This works well for incremental innovations. However, for radical innovations with more significant innovation risks the unilateral allocation of these risks to the main contractor is undesirable as these risks are more difficult to assess and manage due to their inherent uncertainties.

An in-depth case study is performed to investigate the application of an alternative client-led approach for the development and application of a movable bridge deck of bio-based materials in a new to be build movable bicycle bridge. According to Yin (2013) and Eisenhardt and Graebner (2007) the use of single case studies is highly suitable for studying unusually revelatory cases or extremely exemplar cases. This investigated project can be characterised as a "world's first" innovation project and is selected due to its unique characteristics which will allow the generation of insights on the procurement of innovative projects with relatively low technology readiness levels.

A semi structured interview approach is adopted to interview the involved staff from the public client, the engineering company supporting the client, the contractor, the producer of the innovative bridge deck and other tenderers. These interviewees, who held important managerial positions in the project, also provided project, procurement and concept contract documents. These documents enable us to refine the description of the characteristics of the project, the procurement approach and tendering methods that was followed including the used contractual arrangements with respect to the goals of the project. Furthermore, the interviews and documents provide valuable information with respect to the role of the public client, the use of

strategies to manage the innovation risks and collaboration between all parties in the project. The interviews are recorded, transcribed and sent back to the interviewees for feedback. Furthermore, Atlas ti is used for the data analysis and a workshop is organized to validate the research findings and analysis with the interviewees.

Chapter 5: Developing a typology and providing guidelines for selecting innovation procurement strategies and tendering methods to effectively encourage in civil engineering initiatives.

In the fourth chapter a typology is developed for the selection of a procurement approach with respect to innovation in civil engineering projects and programmes. Encouraging innovation through public procurement can lead to improved performance, contribute to organizational and policy goals as well as addressing substantial societal challenges. However, there is still a lack of knowledge on how to select procurement approaches and tendering methods to effectively encourage innovation in civil engineering projects and programmes.

This study presents a typology for selecting a procurement approach with respect to innovation. Furthermore, the study includes a multiple case study of eight different cases which are conducted to gain insights into the factors that influence the effectivity of innovation-encouraging procurement strategies and methods. Lastly, the insights acquired during the literature review, the multiple case study and the typology development are used to derive a general guideline for the selection of an innovation-encouraging public procurement strategy for different types of initiatives (project or programme).

The main strength of typologies is that they can be used to identify and understand relationships between combinations of independent and dependent variables rather than only separate independent and dependent variables, which makes them very suitable for midrange theory development (O'Raghallaigh, Sammon, & Murphy, 2010). The development of the typology is based on the insights on typology development from the literature (Niknazar and Bougault, 2017; Shenhar and Dvir, 1996). Furthermore, the development follows the steps proposed by O'Raghallaigh et al. (2010) in their paper on theory-building using typologies:

1. Define the purpose and limit the domain of the typology. Identify and define the concepts used in the typology:
    a. Key constructs;
    b. Ideal types.

2. Describe the logic which explains the relationships between the ideal types and the dependent variable(s).
3. Make predictions and propose suggestions for future research.

The cases are analyzed from the perspective of public clients who initiated an innovation-encouraging procurement strategy to fulfil the aims and goals of a specific project or programme. This with the aim to increase knowledge on how the use of innovation-encouraging procurement strategies are related to the characteristics of the specific projects and programmes.

1.7. Research outline

Figure 1 provides an overview of the chapters within this thesis and how they are related to the main and sub research questions.

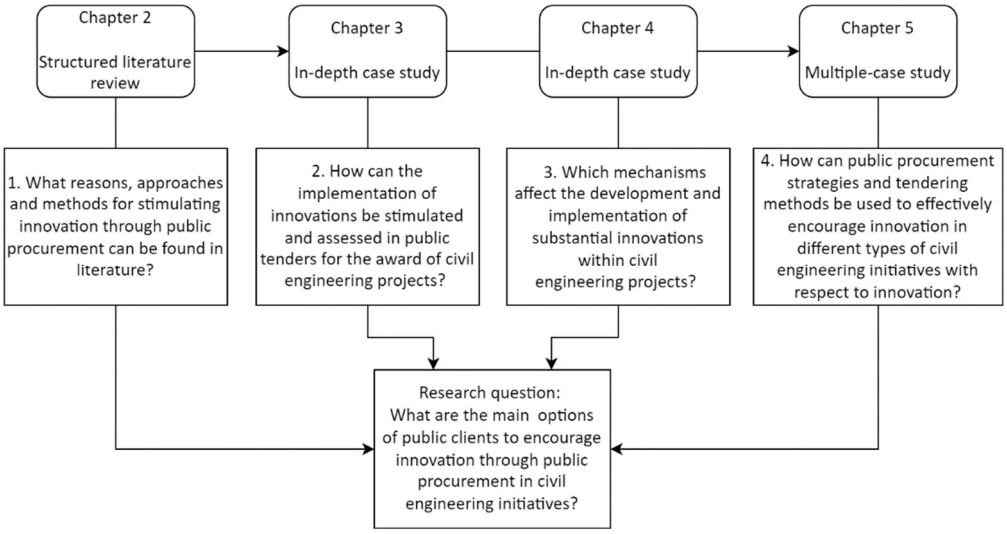

Figure 1: Research overview

In summary the thesis consists of four studies:

1. A structured literature review on different concepts, rationales and approaches for encouraging innovation through public procurement.
2. A design-oriented study in which a method for triggering and assessing innovations in tenders for bridge projects is developed, implemented and evaluated.

3. A single in-depth case study in which a case was analysed where a public client managed to realize a radical green innovation in a civil engineering project.
4. A multiple case study in which a typology for selecting innovation encouraging procurement strategies is developed.

Together, these four studies show that there are many ways and different reasons to stimulate the development and implementation of innovations through public procurement in projects and programmes. There is a famous saying "all roads lead to Rome", meaning that there are different ways to achieve the same goal or conclusion. However, with respect to innovation encouraging procurement there are not only different ways to achieve the same goal, but there is also a variety of goals to which innovation encouraging procurement can contribute. In other words: "Innovation encouraging public procurement in civil engineering; *Different roads leading to different Romes"*.

1.8. Financial support and collaboration

This study was financially supported by the municipalities of Eindhoven and Amsterdam. Furthermore, it was performed in close collaboration with these municipalities and the Dutch expertise centre on Public Procurement (PIANOo). Both municipalities have strong ambitions on the use of innovation encouraging public procurement and are therefore strongly motivated to learn from other public organizations who were pioneering on this front. To this end, a community of practise (COP) was created within the context of this research to improve learning and the exchange of knowledge between public clients on the use of different innovation encouraging procurement strategies. Although these COP activities are formally not a part of thesis, a short reflection on these activities is provided in the Epilogue.

References

Ali, S. H. (2014). Social and environmental impact of the rare earth industries. *Resources, 3*(1), 123-134.

Arnoldussen, J., Groot, P., Halman, J., & Van Zwet, R. (2017). *Innovatie in de bouw: Opgaven en kansen. Adviesrapport aan de paritaire organisaties in de bouw*. Retrieved from

Research University of Twente: https://research.utwente.nl/en/publications/innovatie-in-de-bouw-opgaven-en-kansen

Blayse, A. M., & Manley, K. (2004). Key influences on construction innovation. *Construction Innovation,* 4(3), 143-154.

Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G.H., Hilleary, M. A., Eriksen, M., Possingham, H.P., De Frond, H., Gerber, L.R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., & Rochman, C.M. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science,* 369(6510), 1515-1518.

Caerteling, J. S., Halman, J. I. M., & Dorée, A. G. (2008). Technology Commercialization in Road Infrastructure: How Government Affects the Variation and Appropriability of Technology. *Journal of Product Innovation Management,* 25(2), 143-161.

Covert, T., Greenstone, M., & Knittel, C. R. (2016). Will we ever stop using fossil fuels? *Journal of Economic Perspectives,* 30(1), 117-138.

Dalpé, R. (1994). Effects of government procurement on industrial innovation. *Technology in society,* 16(1), 65-83.

Directive 2014/24/EU. (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. *Official Journal of the European Union, 57*.

Dorée, A. G., & Holmen, E. (2004). Achieving the unlikely: innovating in the loosely coupled construction system. *Construction management and economics,* 22(8), 827-838.

Dreschler, M. (2009). *Fair competition: how to apply the 'economically most advantageous tender'(EMAT) award mechanism in the Dutch construction industry.* PhD thesis, TU Delft, Delft.

EARTO. (2014). *The TRL Scale as a Research & Innovation Policy Tool, EARTO Recommendations*. Retrieved from https://www.earto.eu/wp-content/uploads

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2012). Public Procurement for Innovation as mission-oriented innovation policy. *Research policy,* 41(10), 1757-1769.

Egan, J. (1998). Rethinking Construction, Construction Task Force Report for Department of the Environment, Transport and the Regions. In: HMSO, London.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of management journal,* 50(1), 25-32.

Eriksson, P. E., Volker, L., Kadefors, A., Lingegård, S., Larsson, J., & Rosander, L. (2019). Collaborative procurement strategies for infrastructure projects: a multiple-

case study. *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law,* 172(5), 197-205. doi:10.1680/jmapl.19.00016

Finer, M., Novoa, S., Weisse, M. J., Petersen, R., Mascaro, J., Souto, T., Stearns, F., & Martinez, R. G. (2018). Combating deforestation: From satellite to intervention. *Science, 360*(6395), 1303-1305.

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.

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.

George, G., Schillebeeckx, S. J., & Liak, T. L. (2018). The management of natural resources: An overview and research agenda. *Managing Natural Resources*.

Georghiou, L., Edler, J., Uyarra, E., & Yeow, J. (2014). Policy instruments for public procurement of innovation: Choice, design and assessment. *Technological Forecasting and Social Change, 86*, pp. 1-12.

Hoezen, M., Voordijk, H., & Dewulf, G. (2014). Procuring complex projects using the competitive dialogue. *International journal of project organisation and management,* 6(4), 319-335.

Hoornweg, D., Bhada-Tata, P., & Kennedy, C. (2013). Environment: Waste production must peak this century. *Nature News, 502*(7473), 615.

Huang, L., Krigsvoll, G., Johansen, F., Liu, Y., & Zhang, X. (2018). Carbon emission of global construction sector. *Renewable and Sustainable Energy Reviews,* 81, pp. 1906-1916. https://doi.org/10.1016/j.rser.2017.06.001

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Workin Group 1 to the Sixth Assesment Report of the Intergovernmental Panel on Climate Change*. Retrieved from: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FrontMatter.pdf

Khalfan, M. M., McDermott, P., Li, X., Arif, M., & Kashyap, M. (2008). The integration of suppliers and manufacturers within construction supply chains through innovative procurement strategies. *International Journal of Value Chain Management,* 2(3), 358-370.

Lenderink, B., Halman, J. I. M., & Voordijk, H. (2019). Innovation and public procurement: from fragmentation to synthesis on concepts, rationales and approaches. *Innovation: The European Journal of Social Science Research*, pp. 1-25. https://doi.org/10.1080/13511610.2019.1700101

Lenferink, S., Tillema, T., & Arts, J. (2013). Towards sustainable infrastructure development through integrated contracts: Experiences with inclusiveness in Dutch infrastructure projects. *International journal of project management,* 31(4), 615-627.

Lindblad, H., & Guerrero, J. R. (2020). Client's role in promoting BIM implementation and innovation in construction. *Construction management and economics,* 38(5), 468-482.

Loosemore, M. (2015). Construction innovation: Fifth generation perspective. *Journal of management in engineering, 31*(6), 04015012. Doi:10.1061/(ASCE)ME.1943-5479.0000368.

Loosemore, M., & Richard, J. (2015). Valuing innovation in construction and infrastructure: Getting clients past a lowest price mentality. *Engineering, Construction and Architectural Management,* 22(1), 38-53.

O'Raghallaigh, P., Sammon, D., & Murphy, C. (2010). *Theory-building using Typologies - A Worked Example of Building a Typology of Knowledge Activities for Innovation.* Series Frontiers in Artificial Intelligence and Applications, E-book: Volume 212: Bridging the Socio-technical Gap in Decision Support Systems. https://doi.org/10.3233/978-1-60750-577-8-371.

OECD. (2011). *Demand-side Innovation Policies*: OECD Publishing.

Rose, T. M., & Manley, K. (2012). Adoption of innovative products on Australian road infrastructure projects. *Construction management and economics,* 30(4), 277-298.

Rutten, M. E. J., Dorée, A. G., & Halman, J. I. M. (2009). Innovation and interorganizational cooperation: a synthesis of literature. *Construction Innovation,* 9(3), 285-297.

Semple, A. (2015). *A practical guide to public procurement* (M. Cook Ed.): Oxford University press.

Slaughter, E. S. (1998). Models of construction innovation. *Journal of Construction Engineering and Management,* 124(3), 226-231.

Telles, P., & Butler, L. R. A. (2014). Public Procurement Award Procedures in Directive 2014/24/EU. In F. Lichere, R. Caranta, & S. Treumer (Eds.), *Modernising Public Procurement: The New Directive*. Copenhagen: Djof Publishing.

United Nations. (2020). *The Sustainable Development Goals Report 2020*. New Yourk: United Nations Publications.

United Nations Environment Programme. (2017). *Global review of sustainable public procurement*. Retrieved from: https://www.unep.org/resources/report/2017-global-review-sustainable-public-procurement.

United Nations General Assembly. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. New York.

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.

van Aken, J., Chandrasekaran, A., & Halman, J. I. M. (2016). Conducting and publishing design science research: Inaugural essay of the design science department of the Journal of Operations Management. *Journal of Operations Management,* 47, 1-8.

van Belzen, T. (2021, 22-12-2021). Experts: 'IJdel Rwijkswaterstaat drijgt grip op renovatiegolf te verliezen'. *Cobouw*. Retrieved from www.cobouw.nl

van de Ven, A. (2007). *Engaged Scholarship: a guide for organizational and social research*. New York: Oxford University Press.

van den Berg, M. C. (2019). *Managing Circular Building Projects.* PhD Thesis University of Twente, Enschede.

van Weele, A. (2009). *Purchasing and Supply Chain Management* (5th Edition ed.). Hampshire: Cengage Learning Emea.

Wang, Z., Zhang, B., & Guan, D. (2016). Take responsibility for electronic-waste disposal. *Nature,* 536(7614), 23-25. doi:10.1038/536023a

Wientjes, B., Buitendijk, G., Meyboom, J., Verhagen, M., Nelissen, E., Reiner, C., & Van Wingerden, R. (2016). De bouwagenda: Bouwen aan de kwaliteit van leven. In: Delft: D*e Bouwagenda*.

Wieringa, R. J. (2014). *Design science methodology for information systems and software engineering*: Springer.World Economic Forum. (2016). *Shaping the Future of Construction: a Breakthrough in Mindset and Technology*. Retrieved from https://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_report_020516.pdf

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.

Yin, R. K. (2013). *Case Study Research: Design and Methods* (fifth edition ed.): Sage Publications Inc.

Yuan, H., & Shen, L. (2011). Trend of the research on construction and demolition waste management. *Waste Management,* 31(4), 670-679. https://doi.org/10.1016/j.wasman.2010.10.030

Zhou, S., Smith, A. D., & Knudsen, E. E. (2015). Ending overfishing while catching more fish. *Fish and Fisheries*, 16(4), 716-722.

Chapter 2

Innovation and public procurement: from fragmentation to synthesis on concepts, rationales and approaches

Bart Lenderink, Johannes I.M. Halman and Hans Voordijk[1]

This chapter is linked to the following sub-research question:

RQ 1: "What reasons, approaches and methods for stimulating innovation through public procurement can be found in literature?"

The answers to the sub-research questions are provided in section 6.1. of this thesis.

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2 Innovation and public procurement: from fragmentation to synthesis on concepts, rationales and approaches

Abstract

Public sector procurement is increasingly seen as an important instrument for inducing innovation in the private sector. Yet, a broad range of different concepts, each with their own associated rationales, and approaches, are used in literature and practice to describe the stimulation of innovation through public procurement. Due to a lack of an overview on the use of concepts, rationales and approaches to stimulate innovation through public procurement in literature and practice, it remains difficult for public organisations to decide why, how, and to what extent they will stimulate innovation in the private sector through public procurement. The contributions of this article to mitigate this problem are threefold. First, it provides a review of the different streams of literature, dichotomies and typologies on public procurement with respect to inducing innovation. Second, it discusses various approaches to stimulate innovation through public procurement individually and compares them in a structured overview. Finally, it provides guidance on the suitability of the use of these approaches in different situations.

2.1. Introduction

The role of the government in stimulating the development of innovations in the private sector was essential for the development of society as we know it today (Geroski 1990; Mazzucato 2011). Three concrete examples are: (1) the role of the Defence Advanced Research Projects Agency (DARPA) in funding the formation of computer science departments, contributing to semiconductor research and the development of the internet, (2) the discovery of molecular antibodies in public medical research labs in the UK, which provided the foundation of the biotech industry, and (3) the National Science Foundation research grant, which funded the development of the algorithm that led to the success of Google (Mazzucato 2011).

Given the impact of governments on private sector innovation, and the recognition of the need for demand-side innovation policy instruments in addition to supply-side

instruments, we have seen a considerable increase of interest in demand-side innovation policies and the stimulation of innovation through public procurement in specific (Lember, Kalvet, and Kattel 2011). On a European level, the interest started with a number of reports and policy documents stressing the need to use demand-side innovation as well as supply side instruments, in order to achieve socioeconomic and R&D targets (European Commission 2003; Kok 2004; Edler et al. 2005; Aho et al. 2006; Edler and Georghiou 2007). Nowadays, public procurement and the use of regulations and standards are a central part of innovation policy in Europe (European Commission 2010a, 2010b; OECD 2011; Directive 2014/24/EU 2014). Although most academic literature and policy documents on this topic stem from Europe, other countries, such as Australia (Berman and Squire 2011), Brazil (Ribeiro and Furtado 2015), China (Li 2013), India (Mani 2003), Japan (Myoken 2010), Korea (Lee 2011) and the United States (Vonortas 2015), have also shown interest in demand-based innovation policies and public procurement in relation to stimulating innovation. Despite the recent rise in interest, the notion of public procurement as an innovation policy instrument is not new. Various studies in the 1970s promoted the potential of public demand to stimulate innovation (Mowery and Rosenberg 1979; Rothwell and Zegveld 1981; Geroski 1990). Geroski (1990) concluded that public procurement could be a far more efficient instrument to stimulate innovation compared to R&D subsidies.

Various concepts are used in literature to describe the use of public procurement to stimulate innovation in the private sector. These concepts distinguish themselves from innovative procurement, such as e-procurement (Moon 2005), due to the fact that they focus on stimulating innovation in the private sector and not in the procurement process itself (Kautsch, Lichoń, and Whyles 2015). Yet, there are some profound differences between these concepts. These concepts differ with respect to:

1. The reason for stimulating innovation through public procurement,
2. What is considered as innovation, and
3. Which approaches and methods are included within the definition of the concepts.

Confusion can arise in cases where the same terms and abbreviations are used to refer to more than one concept. As a consequence, it may not always be clear to which concept the term refers. This in turn leads to ambiguity in the reason for stimulating innovation, what is considered as innovation, and which approaches and methods are used to do so. Further, the use of terms and what they refer to varies across different streams of literature, authors and individual papers.

Furthermore, a comprehensive discussion and structured overview of approaches that are used to stimulate innovation through public procurement is still missing in literature. Such an overview, in combination with insights on the suitability of various approaches in different situations, is valuable in public procurement practice as it provides information on the various ways to stimulate innovation and the conditions under which specific approaches might be useful. The aim of this article is to provide insight on the use of concepts, rationales, approaches and associated methods for stimulating innovation through public procurement in literature and practice. Furthermore, it aims to support procurement policy on the use of approaches for stimulating innovation through public procurement on the level of public organisations.

After discussing the research approach the paper is structured in three parts. The first part focusses on different types of public procurement with respect to inducing innovation in the private sector, by reviewing the use of terms, associated concepts, dichotomies and typologies in literature. The second part discusses a broad range of approaches with their associated rationales and methods for stimulating innovation through public procurement in depth, after which they are presented in a structured overview. The last part of the paper focusses on the suitability of the discussed approaches for use in different situations with respect to several factors. Management implications and suggestions for future research can be found in the conclusion.

2.2. Research approach

Over the last two decades many articles and policy documents have been written on the use of public procurement as an instrument to stimulate innovation. A preliminary review of the literature showed that: (a) these articles and policy documents use different concepts to describe this phenomenon, and (b) these concepts are associated with different rationales for stimulating innovation, as well as different approaches to achieve this. Further, a lack of a systemic overview was identified on the use of concepts, rationales and approaches to stimulate innovation through public procurement. The motivation for this literature review was to address this lack by providing an overview and in-depth discussion on the use of concepts, rationales and approaches for stimulating innovation through public procurement. In addition, the selection of a suitable approach to stimulate innovation through public procurement in different situations was added as an important topic in this review.

After the preliminary review, a peer-reviewed article search on public procurement in relation to stimulating innovation was carried out in the Scopus, Web of Science and Google Scholar electronic databases (English articles only). Several phrases and terms were used to find a comprehensive selection of articles on different approaches for stimulating innovation through public procurement: e.g. public procurement; public purchasing; innovation; innovation policy; procurement policy; demand-side innovation policy, and public procurement of/for/and innovation. This led to a selection of a considerable amount of papers (e.g. "public procurement and innovation" resulted over 160 articles in Scopus; over 100 articles in Web of Science; and over 100.000 results in Google Scholar). Therefore, the articles were first sorted on relevance and then selected based on the relevance of their title and abstract in relation to the topic and the number of times they were cited.

After this initial search, references in the selected peer-reviewed articles were used to find other relevant articles, books, policy documents and reports. This resulted in a final selection of 130 peer-reviewed articles, 5 doctoral theses, 18 policy reports, and 13 books which were reviewed in-depth. The peer-reviewed articles are scattered across many journals of which the most prominent for this literature review were: Journal of Public Procurement, Research Policy, European Planning Studies, Technology in Society, Technological Forecasting and Social Change, Technovation, R&D Management, and Innovation: The European Journal of Social Science Research.

The selected literature was analysed with a focus on the use of concepts, rationales and approaches for stimulating innovation through public procurement. The first step of the analysis was to read the selected articles while making notes and marking parts related to the purpose of the analyses. The second step was to make an overview of the scientific articles including: journal, authors, year of publication, title, abstract, and summarizing research methods, main conclusions and notes during the review process. In the third step, a preliminary version of the paper was written to structure the results found in the review and snowballing was used to find relevant books, policy documents and reports to add to the review. These were analysed by making notes and marking relevant information for the review. Finally, the literature review was improved by several rounds of going back and forth through the literature to corroborate findings from different sources.

2.3. Types of public procurement in relation to inducing innovation

Major streams, terms and associated concepts

As discussed above, the use of public procurement to stimulate innovation has been discussed under numerous headings, which are based on different concepts, rationales and associated methods. An analysis of the selected papers, books, theses and policy reports showed that the literature on this topic is fragmented on the use of concepts, rationales and associated methods for stimulating innovation through public procurement. Lember, Kattel, and Kalvet (2014) p.14 state that "one can identify two main approaches how public procurement is associated with innovation in current literature."

The first approach is referred to as Public Procurement for Innovation (PPI) or Public Technology Procurement (PTP), which can be understood as the procurement of something new, which does not yet exist, in order to address a specific need or societal challenge (Edquist and Hommen 2000; Lember, Kattel, and Kalvet 2014; Edquist, Vonortas, and Zabala-Iturriagagoitia 2015). Sometimes the term innovation procurement is used to refer to the same concept (Uyarra and Flanagan 2010). Somewhat confusing, the OECD (2017) provides its own definition of this term, which is "any kind of public procurement practice (pre-commercial or commercial) that is intended to stimulate innovation through research and development and the market uptake of innovative products and procurement" (OECD 2017). In addition, they use "Strategic use of Public Procurement for Innovation" to refer to the original concept.

The second approach identified by Lember, Kattel, and Kalvet (2014) is Public Procurement of Innovation (PPoI or PPI), which has a far broader perspective and is first defined by Max Rolfstam as "purchasing activities carried out by public agencies that lead to innovation" (Rolfstam 2012, 2013; Lember, Kattel, and Kalvet 2014). As opposed to the first approach, this broader perspective includes all purchasing-related activities throughout the entire commissioning or procurement cycle that lead to innovations of some kind. Based on this definition, Public Procurement of Innovation can be considered as an umbrella term covering all public procurement related activities which lead to the "process of innovation" (Dosi 1988).

Table 1a: Overview of terms and abbreviations used to refer to different concepts

Term	Source	Concept	Alternative or strongly related terms
Demand-side innovation policies	Edler and Georghiou (2007)	All public measures to induce innovations and/or speed up diffusion of innovations through increasing the demand for innovations, defining new functional requirement for products and services or better articulating demand	
Public procurement	Uyarra and Flanagan (2010),	The acquisition of goods and services by government or public sector organizations	Government procurement, public sector purchasing
Public procurement for innovation (PPI)	Edquist et al. (2015); Edquist and Zabala-Iturriagagoitia (2012)	Occurs when a public organization places an order for the fulfilment of certain functions within a reasonable period of time (through a new product, service or system)	Public technology procurement (PTP), Innovation Procurement
	OECD (2017)	Any kind of public procurement practice (pre-commercial or commercial) that is intended to stimulate innovation through research and development and the market uptake of innovative products and procurement	
Public procurement of innovation (PPI/PPoI)	Rolfstam (2012, 2013)	Purchasing activities carried out by public agencies that lead to innovation	
	Yeow and Edler (2012)	The commissioning and procuring of goods or services that are new to the purchasing organization and enable a novel service to citizens or enable a more efficient or effective delivery of that service.	
	Edler and Yeow (2016)	The purchase of a solution that is novel to the buying organisation in order to serve an organisational need.	

Table 1b: Overview of terms and abbreviations used to refer to different concepts

Term	Source	Concept	Alternative or strongly related terms
Public procurement of innovative solutions (PPI)	European Commission (2014)	Procurement where contracting authorities act as a launch customer for innovative goods or services which are not yet available on a largescale commercial basis, and may include conformance testing	
Pre-commercial procurement (PCP)	European Commission (2008), Edquist and Zabala-Iturriagagoitia (2015)	An approach to procuring R&D services, one which involves risk–benefit sharing at market conditions but excludes State aid	Small business innovation research programme (SBIR), Small business research initiative (SBRI)
Innovation friendly public procurement	OECD (2011); Uyarra and Flanagan (2010)	Conventional (regular) procurement practices that favour (or at least do not hinder) innovative solutions	
Innovative procurement	Kautsch, Lichoń, and Whyles (2015)	Buying something in an innovative way – i.e. in a way that is not usual for the situation in which the procurement is being undertaken	Innovative public procurement

A second definition of the term Public Procurement of Innovation is provided by Yeow and Edler (2012) who refer to "public procurement of innovation as the commissioning and procuring of goods and services which are new to the purchasing organisation and enable a novel service to citizens or enable a more efficient or effective delivery of that service". One can clearly distinguish different rationales associated with the two definitions of PPoI. In the first definition, the process of innovation itself is the focus, with PPoI seen as an innovation policy tool. The latter definition focuses on the outcome of the procurement activities, considering PPoI as a tool to deliver new or improved public services.

Edler and Yeow (2016) provide a third definition of the term Public Procurement of Innovation. In this article the term refers to "the purchase of a solution that is novel to the buying organisation in order to serve an organisational need". This concept is very similar to, and builds forth on, the concept of Public Procurement for Innovation as described above. However, Edler and Yeow (2016) take the perspective of the buying organisation with respect to what is considered as an innovation. As such,

they include the adoption of innovations which are new to the buying organisation in their definition.

Table 1 presents an overview of commonly used terms and concepts in the field of innovation and public procurement. This overview shows the ambiguity of the abbreviation PPI as it can refer to three different terms and even more concepts. These concepts vary in the rationale/reason for stimulating innovation, the approaches used and what is considered as innovation or an innovative solution.

2.4. Dichotomies

In order to clarify the exact topic under discussion, and to distinguish different types of public procurement in relation to innovation, several dichotomies and typologies have been used in the literature. A first distinction was made by Edquist and Hommen (2000). They distinguished regular public procurement of off-the-shelf products and services from Public Technology Procurement (PTP), which requires R&D from the supplier prior to delivering the products or services. Over time, the concept of Public Technology Procurement been replaced by Public Procurement for Innovation, reflecting a broadening of the notion (Edquist and Zabala-Iturriagagoitia 2012).

Edler and Georghiou (2007) differentiate between general procurement and strategic procurement with respect to innovation. This differentiation may appear similar to how Edquist and Hommen (2000) differentiate between regular procurement and Public Technology Procurement / Public Procurement for Innovation but is actually quite different. Both general procurement and regular procurement are used to obtain products and services needed on a daily basis (Yeow and Edler 2012). However, in general procurement, public procurement activities are organised in such a way that "innovation becomes an essential criterion in the call for tender and assessment of tender documents" (Edler et al. 2005; Edler and Georghiou 2007). Hence, it functions to stimulate innovation through procurement in general. Regular procurement, on the other hand, does not involve the stimulation of innovation. Further, according to Edler and Georghiou (2007) public procurement becomes strategic with respect to innovation, "when demand for certain technologies, products or services is encouraged in order to stimulate the market". Public Procurement for Innovation, on the other side, uses public procurement strategically to address a need which cannot be met by conventional solutions.

2.5. Typologies

A first typology on Public Procurement for Innovation was provided by Hommen et al. (2005) and is called the Hommen matrix. This typology was built on a preliminary typology of Edquist and Hommen (2000), which contrast direct (or intrinsic) procurement from catalytic (or extrinsic) procurement, and the procurement of adaptive innovations from the procurement of developmental innovations (Hommen et al. 2005; Rolfstam 2013). Procurement is seen as direct, or intrinsic, when the procuring organisation is also the end-user of the procured products and services. As such, the procuring organisation procures in order to satisfy its own (intrinsic) needs. If the procuring organisation primarily acts to satisfy the needs of others, either public or private, the procurement is considered catalytic or extrinsic. Hommen et al. (2005) added the cooperative type of public procurement to this dimension of the preliminary typology. Cooperative procurement occurs when the need for the procured goods and services are shared between procurement organisations and/or users.

In the second dimension of their preliminary typology, Edquist and Hommen (2000) distinguish between the procurement of products and systems that are completely new to the world (developmental), and the procurement of products and systems that are not entirely new but nevertheless require R&D or incremental innovation by the supplier prior to delivery (adaptive). Hommen et al. (2005) related these types of innovations to the phases of the technology lifecycle and the way the procurement of these innovations influences the development of the market. Developmental procurement targets innovations which are entirely new to the world, and as such, may contribute to the initiation of a new market. Adaptive procurement, on the other hand, may contribute to the diffusion of an innovation and the escalation of a market. Building forth on this reasoning, Hommen et al. (2005) also included the consolidation of markets, through standardising technical standards and performance criteria for procured products and services, as a role of public procurement of innovation in relation to market development (Hommen et al. 2005; Rolfstam 2013).

Table 2: Extended version of the Hommen matrix (adapted from Rolfstam 2013)

Type of social need	**Role in relation to the market**			
	Initiation Development	**Escalation** Adaptation	**Consolidation** Standardisation	**Destruction** Removal
Direct Intrinsic	Direct Initiation	Direct Escalation	Direct Consolidation	Direct Destruction
Catalytic Extrinsic	Catalytic Initiation	Catalytic Escalation	Catalytic Consolidation	Catalytic Destruction
Cooperative Congeneric	Cooperative Initiation	Cooperative Escalation	Cooperative Consolidation	Cooperative Destruction
Distributed Identified and satisfied externally	Distributed Initiation	Distributed Escalation	Distributed Consolidation	Distributed Destruction

In an extended version of the Hommen matrix Rolfstam (2013) added one element to each dimension (see Table 2). Rolfstam considers Public Procurement of Innovation (PPoI) to have a distributed need when a public organisation provides potential suppliers with an opportunity without stating a specific problem or committing itself to procure something. As such, it is up to a supplier in responding to this opportunity to identify a need of public or private users and develop a solution for it. For example, the public organisation can publish information as part of procurement activities, which can be used to develop a new product or service. Note that a distributive type of "Public Procurement for Innovation" cannot be possible by definition, as Public Procurement for innovation requires the commitment to procure something by placing an order (Edquist and Zabala-Iturriagagoitia 2012). Alongside initiation, escalation and consolidation of markets, Rolfstam (2013) states that Public Procurement of Innovation (PPoI) can also have a destructive effect on the market for certain products and services. That is, if new technologies mature, they could destroy or reduce the market for other technologies, products and services.

Edquist and Zabala-Iturriagagoitia (2012) developed the preliminary typology of Edquist and Hommen (2000) in a different direction, by including another dichotomy often used to distinguish several types of public procurement in relation to innovation (see Table 3). This dichotomy separates commercial procurement, i.e. the procurement of products and services on a commercial basis, from pre-commercial

procurement. Pre-Commercial Procurement (PCP) concerns the procurement of R&D services prior to commercialisation, where new solutions for a specific social need or challenge are developed in competition with risk-benefit sharing between the public organisation and potential suppliers (European Commission 2008; Edquist and Zabala-Iturriagagoitia 2015).

Table 3: Typology on different types of procurement in relation to stimulating innovation (adapted from Edquist and Zabala-Iturriagagoitia 2012)

Type of social need	**Type of procured products and services**		
	Pre-commercial procurement R&D services	**Developmental PPI** Radical innovation	**Adaptive PPI** Incremental innovation
Direct Intrinsic	Direct PCP	Direct Developmental PPI	Direct Adaptive PPI
Catalytic Extrinsic	Catalytic PCP	Catalytic Developmental PPI	Catalytic Adaptive PPI

Uyarra and Flanagan (2010) provide a distinctive typology on public procurement in relation to innovation which is based on Kraljic's model and Storper's categorisation of product types and focusses on the nature of the procured products and services. These products and services can be based either on specialised production processes or on standardised production processes. Furthermore, the products can be developed for a dedicated or a generic market, leading to four types of public procurement as shown in Table 4.

Table 4: A fourfold typology of public procurement (adapted from Uyarra and Flanagan 2010)

Type of market	**Type of production process**	
	Specialised	**Standardised**
Dedicated	Experimental procurement	Adapted procurement
Generic	Technological procurement	Efficient procurement

The selection of a particular type of public procurement in relation to innovation is important since each type: requires the procuring organisation to adopt a specific role in its interaction with suppliers; relates to different practices that potentially drive

innovation; stimulates distinctive kinds of innovation; is based on different motivations in awarding the procurement contract; and poses other innovation-related supply-side risks (Uyarra and Flanagan 2010).

Despite the relevance of the previously discussed typologies we do not consider any of them to be particularly suitable as a framework for discussing individual approaches and presenting a structured overview of these approaches. To be suitable for this task, the categorisation needs to be sufficiently broad to include all relevant approaches for stimulating innovation through public procurement, but also able to effectively group similar approaches. With these criteria in mind, the categorisation presented by the OECD (2011) was considered the best fit for our purposes.

This categorisation distinguishes between three types of public procurement: regular procurement that can be made more innovation-friendly; strategic procurement, where public organisations demand new technologies, products or services for the delivery of a public service or to address a specific need or societal challenge; and the procurement of R&D services, where targeted subsidies are used to trigger the development of new products and services for addressing specific needs and/or societal challenges. As shown in Table 5, these procurement categories have contrasting characteristics in terms of the main type of product or service procured, the main rationale for the procurement, and the time and resources needed by the public organisation to apply these approaches.

Table 5: Characteristics of three categories of public procurement approaches in relation to innovation (based on OECD 2011)

Characteristics	Categories of approaches		
	Regular procurement	**Strategic procurement**	**Procurement of R&D services**
Main type of products and services procured	Commercially available products and services.	Products and services that are not yet commercially available.	R&D services and potentially also newly developed products and services.
Main rationale for procurement	Procurement of products and services necessary for the delivery of public services on a daily basis.	Procurement of innovative solutions for the delivery of public services or addressing societal challenges.	Developing new solutions for specific needs or a societal challenges.
Time and resources needed by public agency	Medium	High.	High to very high.

2.6. Approaches for stimulating innovation through public procurement

In this section, seven approaches for stimulating innovation through public procurement are discussed and compared with respect to a number of aspects: their rationale, associated terms, definition/description, and the process and methods used. At the end of this section an overview of these approaches is presented in Table 7. Both the discussion and overview are structured according to the categorisation of the OECD (2011):

1. Regular and innovation-friendly procurement,
2. Strategic procurement of innovations, and
3. Procurement of R&D services.

Regular and innovation-friendly procurement

It is important to recognise that public procurement might affect innovation whether or not procurement policy focusses on stimulating innovation. For example, regular procurement can affect innovation through stating a demand for certain products or services, and specifying requirements and standards for procured products and services (Dalpé, DeBresson, and Xiaoping 1992; Dalpé 1994). Regular procurement covers procurements made on a daily basis in order to delivery necessary public

products and services (Yeow and Edler 2012), and covers items such as office supplies, ICT and physical infrastructure including roads, buildings and bridges. Unlike strategic and R&D procurement, regular procurement does not usually involve the procurement of an innovation or the development of new products and services. Moreover, stimulating innovation is generally not an explicit goal in regular procurement. Therefore, innovation can be considered as a potential by-product of regular procurement (Aschhoff and Sofka 2009).

The term innovation-friendly procurement is used to refer to regular procurement practices that favour (or at least do not hinder) innovative solutions (Uyarra and Flanagan 2010; OECD 2011; Edquist, Vonortas, and Zabala-Iturriagagoitia 2015). There are four rationales for making regular procurement more innovation-friendly. First, innovation-friendly procurement is likely to improve the value-for-money of procured products and services. Second, existing solutions are likely to be insufficient to meet future needs. For example due to the aging of the population, increasing effects of global warming and the gradual deterioration of existing physical public infrastructure. Third, innovation-friendly procurement is expected to enhance the competitiveness of suppliers and sub-suppliers. Four, regular innovation-friendly procurement can influence innovation on a far larger scale compared to strategic procurement and procurement of R&D services, due to the limited resources and time required for each tender.

In most cases stimulating innovation through procurement requires also requires some changes or innovation in the procurement process itself (Knutsson and Thomasson 2014). Five methods for making individual procurements more conducive to innovative solutions were identified during the analysis of literature.

The first method is to carry out a market consultation alongside a market analysis prior to the formal tendering. The use of a market consultation is covered by Directive 2014/24/EU article 40 and Directive 2014/25/25/EU article 58 of the European Parliament and Council. During a market consultation period, information is shared between the public agency, potential suppliers and other stakeholders concerning the needs of the public agency and other stakeholders on one hand, and possible solutions to these needs that can be supplied by the market on the other hand. The information obtained during the market consultation phase can be used to optimise the specification of requirements and the award criteria in the tendering procedure.

A second method to make procurement more innovation-friendly addresses the way requirements are specified in the public tendering documents. Traditionally, public agencies use technical specifications to define their needs, leaving little room for

suppliers to provide alternative solutions (Geroski 1990). For example, with respect to the use of materials or variations in the design. Instead, public agencies can also use functional specifications to define their needs, leaving the translation of these requirements into solutions up to the suppliers (Dalpé 1994; Wilkinson et al. 2005; Edquist, Vonortas, and Zabala-Iturriagagoitia 2015).

A third method, the explicit acceptance of alternative solutions in the tendering procedure, can provide further possibilities for suppliers to propose innovative solutions. This may be combined with traditional technical specifications indicating the needs and proposed solution by the procurement agency (European Commission 2007).

A fourth method for stimulating innovation relates to the mechanism for awarding public contracts. In regular procurement contracts are often awarded to the tenderer who offers to deliver the required products and services, in line with the specifications stated in the tender documents, against the lowest price. However, there are two other award mechanisms which can be used for the award of contracts that are more likely to stimulate innovation.

The most common award mechanism to stimulate innovation is performance-based tendering, which uses quality criteria and price, or quality criteria and a fixed price for the award of contracts. Performance-based tendering is often referred to as "Most Economical Advantageous Tendering" (MEAT) or "Economically Most Advantageous Tendering" (EMAT) (Wilkinson et al. 2005; Dreschler 2009). Performance-based tendering, especially if combined with functional specification of the requirements, may be very effective in inducing innovation since the former can provide the incentive and the latter the possibilities to potential suppliers to provide innovative solutions.

The second award mechanism which may stimulate innovation is life-cycle costing. Life-cycle costing includes a part or all costs, of a number or all phases, of the life cycle of the products and services procured (Dragos and Neamtu 2014). Examples are acquisition costs, user and maintenance costs and costs for demolition or recycling. Assessment methods for life cycle costing should be based on objectively verifiable and non-discriminatory criteria.

The fifth method to stimulate innovation is to include high quality standards in tenders for products and services, which may provide incentives to suppliers to innovate (Geroski 1990; Dalpé 1994). In addition to these methods, there are many factors which can have an influence on innovation through public procurement, such

as market engagement, the bundling or division of demand, and management of intellectual property rights, risks, resources and competences (Rolfstam 2009; Uyarra et al. 2014; Dale-Clough 2015).

Strategic procurement of innovations

Strategic procurement of innovations occurs when public organisations procure specific technologies, products and/or services, which are not yet available on a commercial scale, for the delivery of a public service or to address a specific need or societal challenge (Edquist and Zabala-Iturriagagoitia 2012). Four approaches are associated with strategic procurement: Public Procurement of Innovative Solutions (PPI or PPoI), Public Procurement for Innovation (PPI), Forward Commitment Procurement (FCP) and the use of procedures which provide possibilities to negotiate with potential suppliers (Competitive Dialogue and Competitive Procedure with Negotiation).

Public procurement of innovative solutions

Public Procurement of Innovative Solutions (PPI) is a term used by the European commission to refer to "procurements where contracting authorities act as a launch customer of innovative goods and services, which are not yet available on a large-scale commercial basis, and may include conformance testing" (European Commission 2014a, 2014b). The process of, or methods used in, the Public Procurement of Innovative Solutions are not explicitly defined, although it requires at least a commercial tender for innovative goods and/or services in some form. This could be a regular tender, but also involve a pilot study or a design contest (Edler et al. 2005). This approach has been introduced as a policy instrument to promote sustainable economic growth by stimulating the uptake of innovative solutions through public procurement. In addition, the use of Public Procurement of Innovative Solutions is promoted by the European Commission as an approach which can contribute to addressing societal challenges and improving the quality and efficiency of public services (European Commission 2014b). The Public Procurement of Innovative Solutions is closely related to Pre-Commercial Procurement in that it can used to perform a commercial tender after one or more solutions have been developed in a Pre-Commercial Procurement. The term Innovation Procurement is often used in practice and policy reports, when referring to Public Procurement of Innovative Solutions as well as Pre-Commercial Procurement when discussed together (European Commission 2014b). However, in the scientific literature, Innovation Procurement refers to "the procurement of innovations that do not yet exist" (Uyarra and Flanagan 2010; Edquist and Zabala-Iturriagagoitia 2012; Yeow and

Edler 2012). This definition excludes pre-commercial procurement of R&D services without a commercial tender for an innovation afterwards.

Public procurement for innovation

Public Procurement for Innovation occurs when "a public organization places an order for the fulfilment of certain function within a reasonable period of time through a new or improved product" (Edquist and Zabala-Iturriagagoitia 2012; Edquist, Vonortas, and Zabala-Iturriagagoitia 2015). The rationale behind this concept/approach is to "satisfy human needs, solve societal problems or support agency missions or needs" (Edquist and Zabala-Iturriagagoitia 2012; Edquist, Vonortas, and Zabala-Iturriagagoitia 2015). Unlike the Public Procurement of Innovative Solutions approach several stages are defined in this approach:

1. Identify a societal challenge or need of the agency,
2. Translate this challenge or need into functional specifications,
3. Call for tender,
4. Assess tender offers and award contracts, and
5. Manage the delivery process of products and services (Edquist and Zabala-Iturriagagoitia 2012; Edquist, Vonortas, and Zabala-Iturriagagoitia 2015).

Forward commitment procurement

The third approach in strategic procurement, Forward Commitment Procurement (FCP), addresses the perceived risks for potential suppliers due to the uncertainty over future public demand for an innovative product or service (DBIS 2011; Uyarra et al. 2014). Mitigating this risks is especially important in the scaling up phase of innovations, before commercial sales of products and/or services start, because the required investments by private parties are high and the possibilities for governmental support are low (van Meerveld, Nauta, and Whyles 2015; Whyles, Van Meerveld, and Nauta 2015). The FCP approach consists of three phases:

1. The identification phase,
2. The market engagement phase, and
3. The procurement phase.

During the identification phase, possible future problems and unmet needs, or opportunities for which new solutions are needed are identified. Subsequently, a project proposal addressing this problem, unmet need or opportunity is written and approved by the management of the public organisation to ensure commitment to the project. By guaranteeing commitment to the project, the uncertainty over future demand decreases, giving potential suppliers a greater incentive to invest in the

development of new products and services (DBIS 2011; van Meerveld, Nauta, and Whyles 2015).

After project approval, the market engagement phase starts in which potential suppliers are notified of the requirements of the forthcoming procurement. Further, the feasibility of the project's requirements and the availability of solutions are tested through taking a market sounding. After this, a market consultation is usually performed to improve interaction with potential suppliers in order to refine the project's requirements and optimise the procurement approach (DBIS 2011; Whyles, Van Meerveld, and Nauta 2015). In the final procurement phase, the procurement strategy is developed and the procurement process carried out. The information obtained in the market engagement phase can be used to establish a pro-innovation procurement strategy, for example through feedback on possible qualitative award criteria and outcome-based project requirements. More comprehensive discussions on Forward Commitment Procurement and example case studies are provided by DBIS (2011) and Whyles, Van Meerveld, and Nauta (2015).

Use of procurement procedures which provide opportunities for negotiation with potential suppliers

The final strategic procurement approach is the use of procurement procedures which provide additional opportunities to negotiate with potential suppliers. Two procurement procedures providing additional opportunities for interaction and negotiation were identified: (1) the Competitive Dialogue and (2) the Competitive Procedure with Negotiation. The Competitive Dialogue (CD) is a procurement procedure that provides additional opportunities for negotiations during the dialogue phase of procurement (Wilkinson et al. 2005; Directive 2014/24/EU 2014). The competitive dialogue approach aims to align the complex needs of contracting authorities with the potential solutions offered by suppliers (Hoezen et al. 2010). The procedure is especially useful in large complex projects, where it is often difficult for contracting authorities to define the means of satisfying their needs or to assess what potential suppliers are offering in terms of technical, financial or legal solutions (Wilkinson et al. 2005; Hoezen, Voordijk, and Dewulf 2012; Directive 2014/24/EU 2014). This is also often the situation when procuring an innovative solution for a specific need or societal challenge, which makes this procedure relevant to strategic procurement of innovations.

A Competitive Dialogue consists of three sequential phases:

1. The selection phase,
2. The dialogue phase, and

3. The contract-awarding phase.

During the selection phase, the needs and requirements of the contracting authority are published in a contract notice and tender documents, along with the criteria to be used in selecting the most economically advantageous tender (UK OGC and HM Treasury 2008; Directive 2014/24/EU 2014). Prior to selecting candidates to participate in a Competitive Dialogue, market research and/or a market sounding may take place.

In the dialogue stage, a number of discussion rounds are conducted with all the candidates individually to determine which solutions are likely to meet the needs and requirements of the contracting authority (Hoezen et al. 2010). Each discussion should be based on the solutions offered by that specific supplier and may address all aspects of the contract. However, it is not permitted to make use of ideas and solutions offered by other suppliers in the discussions without their agreement (European Commission 2005). Moreover, all suppliers should be treated equally and the contracting authority may not provide information that may give one supplier an advantage over another. After one or more suitable solutions have been identified, the dialogue phase is concluded and the suppliers of the potential solutions are requested to submit their final tenders based on the solutions discussed in the dialogue phase (UK OGC and HM Treasury 2008).

In the final phase, the submitted offers are assessed against the predefined award criteria and the contract is awarded to tenderer with the best valid offer. During this phase, communication between the contracting authority and the tenderers is restricted to avoid distorting the competition or introducing a discriminatory effect. More comprehensive discussions on the Competitive Dialogue can be found in European Commission (2005), UK OGC and HM Treasury (2008) and Hoezen, Voordijk, and Dewulf (2012).

With the new European procurement directive, the Competitive Procedure with Negotiation becomes available as a new procedure. This procedure is closely related to the Competitive Dialogue as both procedures provide possibilities for negotiation, have a similar purpose and the same conditions for use (Directive 2014/24/EU 2014; Telles and Butler 2014; Semple 2015). The main difference between the Competitive Dialogue and the Competitive Procedure with Negotiation approach is that the latter starts with an initial tender as a basis for subsequent negotiation, whereas the former does not. As a result of this, the procurement organisation must specify its needs and requirements in far more detail at the start of the Competitive Procedure with Negotiation compared to the Competitive Dialogue procedure (Telles and Butler

2014; Semple 2015). Another distinction is that in the Competitive Procedure with Negotiation the contract award criterion can also be based on lowest price or life-cycle costing.

Procurement of R&D services

The aim of procuring R&D services is to develop new solutions for specific needs or societal challenges and to make them available for future procurement or direct procurement after the development.

The Pre-Commercial Procurement (PCP) approach is used to develop new products or solutions for a specific need or challenge, up to the point of initial field testing of the developed products. The pre-commercial procurement approach should be considered as a supply side innovation policy instrument as it essentially subsidises the development of new solutions under competition and risk/benefit sharing (Edquist and Zabala-Iturriagagoitia 2015). As such the WTO General Procurement Agreement (GPA) is not applicable on the pre-commercial procurement approach. However, as the commercial procurement of developed solutions is not part of the PCP approach itself, a separate commercial tender is required in order to procure one or more of the developed solutions on a commercial scale. As such, other potential suppliers who did not participate in the PCP approach are allowed to compete and should be treated equally in subsequent commercial tenders.

In addition to the PCP approach, there are other approaches that are very similar to PCP, such as the Small Business Innovation Research (SBIR) programme and the Small Business Research Initiative (SBRI) (Audretsch 2003; Cooper 2003; Innovate UK 2015). As these approaches have so much in common with the PCP approach, they are not discussed separately in this article.

The Innovation Partnership procedure is used to procure R&D services for the development of solutions for a specific need or challenge, and subsequent procurement of one or more of these solutions on a commercial scale (Georghiou et al. 2014). As such, the WTO GPA does apply to the Innovation Partnership procedure, which is also regulated under article 31 of the European procurement directive (Directive 2014/24/EU 2014).

The various phases of Innovation Partnership and PCP approach are presented in Table 6. Both approaches start with a tender for the development of products and solutions for a specific need or societal challenge. In the subsequent phases, possible solutions are explored, different prototypes are developed and initial field tests performed. At the end of each phase, one or more suppliers are selected to proceed

to the next phase based on a performance assessment of the product ideas, designed solutions and prototypes as appropriate (European Commission 2008). At this point the PCP procedure ends, whereas the innovation partnership does not and follows by a commercial procurement of one or more solutions on a commercial scale.

Table 6: Pre-commercial procurement in combination with a commercial tender in relation to the Innovation Partnership procedure (based on Edquist & Zabala-Iturriagagoitia 2015, European Commission 2008)

Procurement procedure		**Phase**	**Activities**	**Deliverables**
Innovation partnership	Pre-commercial procurement (PCP)	0	Pre-commercial tender	Solution idea
		1	Solution exploration	Solution design
		2	Prototype development	Prototype(s)
		3	Development and testing of first products and services	Test products and test results
	Commercial tender (PPI)	4	Development to commercial quantities of products and services	Commercial products and/or services

Structured overview of various approaches

In the first part several concepts, dichotomies and typologies were discussed with respect to the inducing innovation through public procurement. Subsequently, various approaches and methods for stimulating innovation through public procurement were discussed. A structured overview of these approaches based on the categorisation of the OECD (2011) can be found in Table 7. In this table a definition/description is presented for each of these approaches, along with their rationale for stimulating innovation and associated steps/methods.

Table 7a: Structured overview of approaches to stimulate innovation through public procurement

Categories	Approaches	Definition/description	Rationale for using approach	Methods and steps
Regular procurement	**Innovation-friendly procurement**	Innovation-friendly procurement refers to conventional (regular) procurement practices that favour (or at least do not hinder) innovative solutions	- Increase the value-for-money of procured products and services - Ensure quality of future public services - Increase competiveness of suppliers	- Market consultation - Allow variants - Functional specification - Performance-based tendering - Request high quality standards
Strategic procurement of innovations	**Public Procurement of Innovative Solutions (PPI)**	Public Procurement of Innovative Solutions involves contracting authorities acting as a launch customer for innovative goods or services that are not yet available on a large-scale commercial basis, and may include conformance testing.	- Promote sustainable economic growth - Address societal challenges - Increase the quality and efficiency of public services	- Commercial tender aiming at procurement of innovative goods or services which are not yet available on a large-scale commercial basis - Design contest - Pilot study
	Public Procurement for Innovation (PPI)	Public Procurement for Innovation occurs when a public organisation places an order to fulfil a certain function within a reasonable period of time through a new or improved product	- To satisfy human needs, to solve societal problems or to support agency missions or needs	1) Identification of social challenges or agency needs 2) Translation of this need or challenge into functional specifications 3) Tendering process 4) Assessment of tenders and awarding of contract 5) Delivery process

Table 7b: Structured overview of approaches to stimulate innovation through public procurement

Categories	Approaches	Definition/description	Rationale for using approach	Methods and steps
Strategic procurement of innovations	**Forward Commitment Procurement (FCP)**	Forward commitment procurement reduces uncertainty of future demand for innovative products and services through providing information on future needs and stating a forward commitment to procuring certain products and services in the future	- To address problems, unmet needs or opportunities which require innovation - Stimulate private investment in R&D and innovation by reducing uncertainty of future demand	1) Identification of unmet needs or opportunities and ensure commitment for the project 2) Market engagement through market soundings and market consultation 3) Actual procurement
	Using procurement procedures which provide possibilities for negotiations with suppliers	Some procurement procedures provide possibilities for negotiations with potential suppliers before submitting final tenders, such as the Competitive Dialogue and Competitive Procedure with negotiation	- Aligning the complex needs of contracting authorities with possible solutions offered by suppliers - Determining potential solutions that could satisfy the needs of the procuring organisation - Improve solutions offered by suppliers prior to the final tender	**-** Competitive Dialogue: 1) Selection stage 2) Dialogue stage(s) 3) Award stage **-** Competitive procedure with negotiation: 1) Initial Tender stage 2) Dialogue stage(s) 3) Award stage

Table 7c: Structured overview of approaches to stimulate innovation through public procurement

Categories	Approaches	Definition/description	Rationale for using approach	Methods and steps
	Pre-Commercial Procurement (PCP) Related terms: SBIR and SBRI	Pre-Commercial Procurement involves the procurement of research and development services under market conditions while sharing the risks and benefits, and includes phased competitive development up to the point of testing initial prototypes	- Driving innovations to ensure sustainable high quality public services - Addressing societal challenges for which either commercially stable solution do not yet exist, or existing solutions exhibit shortcomings requiring further R&D	1) Competitive tender for R&D services 2) Solution design 3) Prototype development 4) Original development and testing of limited volume of initial products and/or services
Procurement of R&D services	**Innovation partnership** Related term: innovation procurement	In an innovation partnership, pre-commercial procurement is combined with the commercial procurement of developed products/services from the involved tenderers	- Driving innovations to ensure sustainable high quality public services - Addressing societal challenges for which either commercially stable solution do not yet exist, or existing solutions exhibit shortcomings requiring further R&D - Procurement of R&D services as well as of the developed products and services on a commercial scale	1) Competitive tender for R&D services 2) Solution design 3) Prototype development 4) Original development and testing of limited volume of initial products and/or services 5) Procurement of a commercial volume of products and/or services

When comparing the approaches on the basis of their rationale for stimulating innovation through procurement they can be categorised in two groups of rationales (Edler et al. 2015). In the first group, the rationales stem from an external policy perspective with respect to the procurement organisation. For example, to foster the competitiveness of suppliers in specific sectors or to stimulate sustainable economic growth. The second group adopts an internal organisational perspective where rationales focus on how public procurement of innovation contributes to achieving organisational goals of the procurement organisation, for example by increasing the value of procured products and services, ensuring the quality of products and

services procured in the future, and addressing specific needs and/or societal challenges.

2.7. Assessing the suitability of public procurement of innovation approaches in different situations

So far, this article discussed different concepts, dichotomies and typologies on the use of public procurement to stimulate innovation for different purposes. Further, it discussed various approaches for stimulating innovation through public procurement and compared these with respect to their definitions, rationales for stimulating innovation and their associated methods. In addition, a structured overview of various approaches is presented.

However, such an overview provides little insight into the suitability of the approaches in specific situations encountered in procurement practice. Hence, from a public procurement perspective, the question remains: "what approaches can be suitable for inducing innovation in a particular situation?" This is not an easy question to answer since it depends on a large number of factors. In the remainder of this article an initial attempt is made to shed light on this issue by comparing the characteristics for each category of approaches in Table 7, with respect to a number of factors. These factors were partly derived from Uyarra and Flanagan (2010).

As can be observed from Table 8, the approaches within each category have similar characteristics with respect to several factors, such as the required time and resources, the type of user-producer interaction, the rationale for stimulating innovation and the main degree of innovation towards the approaches are oriented. Yet, it is important to note that the characteristics of individual approaches may vary to some extent. In order to get an initial idea of the suitability of specific approaches for a particular situation, the characteristics of these approaches should be compared with:

- The characteristics of the procurement organisation,
- The characteristics of what is to be procured in terms of needs and requirements, and
- The current maturity/technology readiness level of solutions which may be offered by suppliers.

Characteristics to consider with respect to the procurement organisation include: the available resources in terms of time, budget and staff, the maturity of the organisation with respect to public procurement, and its experience with public procurement of

innovation (Uyarra et al. 2014). If, for example, the availability of skilled procurement staff is limited, this will reduce the suitability of approaches in the strategic procurement and procurement of R&D services categories as they require considerable effort and expertise by the procurement organisation in the tendering process (Knutsson and Thomasson 2014). This can be mitigated to some extend by involving external experts.

In addition, the public procurement of innovation approach should also fit with the products and services to be procured, in terms of needs and requirements (Edquist, Vonortas, and Zabala-Iturriagagoitia 2015). If one wants to procure an improved solution for products and services which are procured on a daily basis, it might be appropriate to opt for an innovation-friendly approach within regular procurement to obtain additional value with respect to standard solutions offered by suppliers. On the other hand, if the aim is to address a specific need or societal challenge which cannot be sufficiently satisfied by current solutions, it might be more appropriate to opt for either a strategic procurement approach, or a procurement of R&D services approach to develop new solutions to that specific need or challenge.

Finally, carrying out market research and consulting potential suppliers are valuable steps in determining whether the needs and requirements of the public agency can be delivered by suppliers and provides an indication of the amount of research and development which is necessary before a solution can be delivered (Knutsson and Thomasson 2014). If suppliers already have prototypes that are likely to satisfy the needs of the procuring agency, a regular but innovation-friendly procurement approach or strategic approaches are often more suitable compared to approaches for the procurement of R&D services. If, on the other hand, potential solutions are still conceptual, non-existent, or have to be adapted to such a degree that considerable R&D effort is needed, it is better to opt for the procurement of R&D services to stimulate the development of new solutions.

Table 8: Factors guiding the selection of an approach for stimulating innovation through public procurement (partly based on Uyarra and Flanagan 2010)

Factor	**Categories of approaches**		
	Regular procurement (innovation-friendly)	**Strategic procurement**	**Procurement of R&D services**
Required resources and time from the public organisation	Medium	High	High to very high
User-producer interaction	Arm's length or recurrent interaction	Recurrent interaction or partnership	Supervisory interaction or partnership
Required resources and time from the supplier	Medium	High	High to very high
Rationale(s)	- Ensuring quality of public services in the future - Obtaining high quality solutions - Stimulating innovation in the private sector	- Procuring a solution for a specific need or societal challenge - Improving the quality of public services - Supporting SMEs	- Developing new solutions for a specific public need or societal challenge - Improving the quality of public services -Supporting SMEs
Motivation for procurement award	- Best value for money	- Best available solution - Best value for money	- Feasibility, quality and costs of proposed solutions
Oriented to	Incremental innovation	Incremental/ Radical innovation	Radical innovation
Relevant methods and approaches	Methods: - Market consultation - Allowing variants - Functional specification - Performance-based tendering - Requesting high quality standards	Approaches: - Public procurement of innovative solutions - Public procurement for innovation - Forward commitment procurement - Using procurement procedures which provide possibilities for negotiations with suppliers	Approaches: - Pre-commercial procurement - SBIR - Innovation partnership

Based on our analysis of the literature, we argue that for most situations in daily procurement practice the use of the strategic procurement and procurement of R&D services approaches cannot be justified given the time, resources and expertise

required. Therefore, the relevance of these methods/approaches can be questioned with respect to regular procurement practices (Uyarra and Flanagan 2010). However, in certain cases these approaches can be very useful. Such cases often have a specific rationale for stimulating innovation through strategic procurement or procurement of R&D services. For example, when a specific problem or need cannot be adequately addressed using commercially available solutions, when the procuring organisation is unable to define the means required to satisfy its needs or cannot assess what potential suppliers can offer (Edquist and Zabala-Iturriagagoitia 2012; Edquist, Vonortas, and Zabala-Iturriagagoitia 2015).

2.8. Scientific contribution, policy implications and future research

This review of the literature shows that a range of different concepts are used in academic articles and policy documents to describe the phenomenon of stimulating innovation through the use of public procurement. Second, it points out that these concepts are associated with different rationales and approaches for stimulating innovation through public procurement. As a result, confusion on the used rationales and approaches for stimulating innovation can arise in cases where the same abbreviations and terms are used to refer to different concepts. This study provides an overview on the use of terms and abbreviations which refer to different concepts in scientific literature and policy documents.

This review also reveals several typologies that have been developed, and a broad range of approaches to stimulate innovation through public procurement. These approaches can be found scattered across the literature. A systemic overview on the use of these typologies and approaches in literature was still missing.

This article provides three important contributions. First, it provides a structured review and overview of approaches to stimulate innovation through public procurement based on the categorisation of the OECD. Second, it provides initial insights in the suitability of each category of approaches for different situations based on their characteristics. Lastly, it identifies three important factors for assessing the suitability of the approaches in different situations in this study: (1) the characteristics of the procurement organisation, (2) what is to be procured in terms of needs and requirements, and (3) the current maturity/technology readiness level of solutions which may be offered by potential suppliers.

Policy implications

This study supports procurement policy on the use of procurement approaches for stimulating innovation on the level of public organisations by providing insights in the different rationales and approaches for stimulating innovation. Some of these approaches require more, and some require less, resources and time from the procurement organisation as well as potential suppliers. Public procurement of innovation can be used as an external policy instrument to foster the competitiveness of firms in specific sectors and stimulate economic growth. On the other hand, it can be used as an instrument to contribute to internal organisational goals of the procurement organisation or to address specific needs or societal challenges.

The use of innovation-friendly regular procurement can be used on a far larger scale compared to strategic procurement approaches and approaches for the procurement of R&D services, as it requires less resources and time to perform. Strategic procurement and procurement of R&D services, on the other hand, are more suitable to address specific needs and challenges. In addition, the selection of a suitable approach is largely dependent on the development stage of potential solutions of suppliers. Performing market research and consulting potential suppliers can be very helpful in assessing the development stage of potential solutions.

Suggestions for future research

This study has been a first attempt to provide an overview of the various approaches available to stimulate innovation through public procurement and to assess the suitability of these approaches in different situations. We suggest that more research should be performed on the suitability of individual approaches in different situations and how the use of these approaches influence tender offers provided by tenderers. Edler et al. (2015) state that "the evaluation of demand-side innovation policies is still in its infancy". To tackle this problem, more research is needed on the effectiveness of public procurement of innovation in stimulating innovation in private firms, and how these innovations contribute to the needs of public organisations and addressing societal challenges.

Finally, this study identified continuous learning and knowledge exchange with respect to the use of public procurement of innovation within public organisations, and how this can be supported, as a blind spot in literature. This can be a valuable line of inquiry as the lack of knowledge, skills and resources in public organisations has been identified as an important barrier for the use of public procurement of innovation (OECD 2011; Georghiou et al. 2014; Uyarra et al. 2014).

References

Aho, E., J. Cornu, L. Georghiou, and A. Subira. (2006) *Creating an Innovative Europe.* Report of the Independent Expert Group on R&D and Innovation appointed following the Hampton Court Summit.

Aschhoff, B., and W. Sofka (2009) Innovation on Demand: Can Public Procurement Drive Market Success of Innovations? *Research Policy* 38 (8): 1235–1247.

Audretsch, D.B. (2003) Standing on the Shoulders of Midgets: The US Small Business Innovation Research Program (SBIR). *Small Business Economics* 20 (2): 129–135.

Berman, T. and M. Squire. (2011) Demand-side Innovation Policies in Austrialia. In *Demand-side Innovation Policies*, 95–113. OECD Publishing.

Cooper, R.S. (2003) Purpose and Performance of the Small Business Innovation Research (SBIR) Program. *Small Business Economics* 20 (2): 137–151.

Dale-Clough, L. (2015) Public Procurement of Innovation and Local Authority Procurement: Procurement Modes and Framework Conditions in Three European Cities. *Innovation: The European Journal of Social Science Research* 28 (3): 220–242.

Dalpé, R. (1994) Effects of Government Procurement on Industrial Innovation. *Technology in Society* 16 (1): 65–83.

Dalpé, R., C. DeBresson, and H. Xiaoping (1992) The Public Sector as First User of Innovations. *Research Policy* 21 (3): 251–263.

DBIS. 2011. *Forward Commitment Procurement: Practical Pathways to Buying Innovative Solutions*. London: Department for Business Innovation & Skills.

Directive 2014/24/EU. 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. *Official Journal of the European Union* 57: 65–143.

Directive 2014/25/EU. 2014. "Directive 2014/25/EU of the European Parliament and of the Council." *Official Journal of the European Union* 243–331.

Dosi, G. (1988) The Nature of the Innovation Process. In *Technical Change and Economic Theory*, edited by G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete, 221–238. Londen: Pinter.

Dragos, D., and B. Neamtu (2014). Sustainable Public Procurement in the EU: Experiences and Prospects. In *Modernising Public Procurement: The New Directive*, edited by Francois Lichere, Roberto Caranta, and Steen Treumer, 301–335. Copenhagen: DJOF publishing.

Dreschler, M.. (2009) *Fair Competition: How to Apply the 'Economically Most Advantageous Tender'(EMAT) Award Mechanism in the Dutch Construction Industry*. PhD thesis, TU Delft, Delft.

Edler, J., Charles E., N.S. Vonortas, and J.M. Zabala-Iturriagagoitia (2015) Conclusions: Lessons, Limitations and Way Forward." In *Public Procurement for Innovation*, edited by Charles Edquist, Nicholas S Vonortas, Jon Mikel Zabala-Iturriagagoitia, and Jakob Edler, 299–305. Cheltenham: Edward Elgar Publishing.

Edler, J., and L. Georghiou (2007) Public Procurement and Innovation—Resurrecting the Demand Side. *Research Policy* 36 (7): 949–963.

Edler, J., S. Ruhland, S. Hafner, J. Rigby, L. Georghiou, L. Hommen, M. Rolfstam, C. Edquist, L. Tsipouri, and M. Papadakou (2005) *Innovation and Public Procurement–Review of Issues at Stake*. ISI Fraunhofer Institute Systems and Innovation Research, Karlsruhe.

Edler, J., and J. Yeow (2016). Connecting Demand and Supply: The Role of Intermediation in Public Procurement of Innovation. *Research Policy* 45 (2): 414–426.

Edquist, C., and L. Hommen (2000) Public Technology Procurement and Innovation Theory. In *Public Technology Procurement and Innovation*, edited by Charles Edquist, Leif Hommen, and Lena Tsipouri, 5–70. Boston: Kluwer Academic Publishers.

Edquist, C., N.S. Vonortas, and J.M. Zabala-Iturriagagoitia (2015) "Introduction." In *Public Procurement for Innovation*, edited by Charles Edquist, Nicholas S Vonortas, Jon Mikel Zabala-Iturriagagoitia, and J. Edler, 1–4. Boston: Edward Elgar Publishing.

Edquist, C., and J.M. Zabala-Iturriagagoitia (2012) Public Procurement for Innovation as Mission-Oriented Innovation Policy. *Research Policy* 41 (10): 1757–1769.

Edquist, C. and J.M. Zabala-Iturriagagoitia (2015) Pre-commercial Procurement: A Demand or Supply Policy Instrument in Relation to Innovation? *R&D Management* 45 (2): 147–160.

European Commission (2003) *Investing in research: an action plan for Europe*. Brussels.

European Commission (2005) *Explanatory Note - Competitive Dialogue - Classic Directive*.

European Commission (2007) G*uide on Dealing with Innovative Solutions in Public Procurement*. Luxemburg.

European Commission (2008) *Pre-commercial Procurement: Driving Innovation to Ensure High Quality Public Services in Europe*. Luxemburg: Office for Official Publications of the European Communities.

European Commission (2010a) *Europe 2020 Flagship Initiative: Innovation Union*. Brussels.

European Commission (2010b). *Europe 2020: A Strategy for Smart, Sustainable and Inclusive Growth: Communication from the Commission*. Brussels.

European Commission (2014a) *Horizon 2020 - Work Programme 2014–2015 General Annexes*. Brussels.

European Commission (2014b) *Public Procurement as a Driver of Innovation in SMEs and Public Services*. Belgium: European Union.

Georghiou, L., J. Edler, E. Uyarra, and J. Yeow (2014) Policy Instruments for Public Procurement of Innovation: Choice, Design and Assessment. *Technological Forecasting and Social Change* 86: 1–12.

Geroski, P.A. (1990) Procurement Policy as a Tool of Industrial Policy. *International Review of Applied Economics* 4 (2): 182–198.

Hoezen, M., J. van Rutten, H. Voordijk, and G. Dewulf (2010) Towards Better Customized Service-led Contracts Through the Competitive Dialogue Procedure. *Construction Management and Economics* 28 (11): 1177–1186.

Hoezen, M., H. Voordijk, and G. Dewulf (2012) Contracting Dynamics in the Competitive Dialogue Procedure. *Built Environment Project and Asset Management* 2 (1): 6–24. doi:10.1108/20441241211235017.

Hommen, L., M. Rolfstam, J. Edler, L. Tsipouri, and J. Rigby (2005) *Innovation and Public Procurement: Review of Issues*. Karlsruhe: University of Lund, Fraunhofer ISI, University of Athens and Prest.

Innovate UK (2015) *SBRI Brochure*. Technology Strategy board UK.

Kautsch, M., M. Lichoń, and G. Whyles (2015) Tools of Innovative Public Procurement in Health Care in Poland. *Innovation: The European Journal of Social Science Research* 28 (3): 312–323. doi:10.1080/13511610.2015.1043243.

Knutsson, H., and A. Thomasson (2014) Innovation in the Public Procurement Process: A Study of the Creation of Innovation-Friendly Public Procurement. *Public Management Review* 16 (2): 242–255.

Kok, Wim (2004) *Facing the Challenge: The Lisbon Strategy for Growth and Employment*. Report from the High Level Group Chaired by Wim Kok. Luxembourg: Office for Official Publications of the European Communities.

Lee, Woosung (2011) Demand-side Innovation Policies in Korea. In *Demand-side Innovation Policies*, 151–162. OECD.

Lember, V., T. Kalvet, and R. Kattel (2011) Urban Competitiveness and Public Procurement for Innovation. *Urban Studies* 48 (7): 1373–1395.

Lember, V., R. Kattel, and T. Kalvet (2014) *Public Procurement, Innovation and Policy: International Perspectives*. Berlin Heidelberg: Springer-Verlag. doi:10.1007/978-3-642-40258-6.

Li, Y. (2013) *Public Procurement as a Demand-Side Innovation Policy in China*. Manchester: Manchester Business School.

Mani, Sunil (2003) *Deregulation, Entry of MNCs, Public Technology Procurement and Innovation Capability in India's Telecommunications Equipment Industry*. Tokyo: United Nations University.

Mazzucato, M. (2011) *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. Vol. 1. Londen: Demos.

Moon, M.J. (2005) E-procurement Management in State Governments: Diffusion of E-procurement Practices and its Determinants. *Journal of Public Procurement* 5 (1): 54–72.

Mowery, D., and N. Rosenberg (1979) The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies. *Research Policy* 8 (2): 102–153.

Myoken, Y. (2010) Demand-orientated Policy on Leading-Edge Industry and Technology: Public Procurement for Innovation. *International Journal of Technology Management* 49 (1): 196–219.

OECD (2011) *Demand-side Innovation Policies*. OECD Publishing.

OECD (2017) Public Procurement for Innovation.

Ribeiro, C.G, and A.T. Furtado (2015) Public Procurement for Innovation in Developing Countries: The Case of Petrobras. In *Public Procurement for Innovation*, edited by Charles Edquist, Nicholas S. Vonortas, Jon Mikel Zabala-Iturriagagoitia, and Jakob Edler, 263–298. Cheltenham: Edward Elgar Publishing.

Rolfstam, M. (2009) Public Procurement as an Innovation Policy Tool: The Role of Institutions. *Science and Public Policy* 36 (5): 349–360. doi:10.3152/030234209X442025.

Rolfstam, M. (2012) An Institutional Approach to Research on Public Procurement of Innovation. *Innovation: The European Journal of Social Science Research* 25 (3): 303–321.

Rolfstam, M. (2013) *Public Procurement and Innovation*. Cheltenham: Edward Elgar Publishing.

Rothwell, R., and W. Zegveld (1981) *Industrial Innovation and Public Policy: Preparing for the1980s and the 1990s*. London: Frances Pinter.

Semple, A. (2015) *A Practical Guide to Public Procurement*. Oxford: Oxford University press.

Telles, P., and L.R.A. Butler (2014) Public Procurement Award Procedures in Directive 2014/24/EU. In *Modernising Public Procurement: The New Directive*, edited by Francois Lichere, Roberto Caranta, and Steen Treumer, 131–183. Copenhagen: Djof Publishing.

UK OGC, and HM Treasury (2008) *OGC/HMT Guidance on Competitive Dialogue*. Norwich: UK Office of Government Commerce, UK HM Treasury.

Uyarra, E., J. Edler, J. Garcia-Estevez, L. Georghiou, and J. Yeow (2014) Barriers to Innovation Through Public Procurement: A Supplier Perspective. *Technovation* 34 (10): 631–645.

Uyarra, E., J. Edler, S. Gee, L. Georghiou, and J. Yeow (2014) "UK." In *Public Procurement, Innovation and Policy*, edited by Veiko Lember, Rainer Kattel, Tarmo Kalvet, and New York Heidelberg, 233–257. Berlin, Heidelberg: Springer. doi:10.1007/978-3-642- 40258-6.

Uyarra, E. and K. Flanagan (2010) Understanding the Innovation Impacts of Public Procurement. *European Planning Studies* 18 (1): 123–143.

Van Meerveld, H., J. Nauta, and G. Whyles (2015) Forward Commitment Procurement and its Effect on Perceived Risks in PPI Projects. In *Public Procurement for Innovation*, edited by Charles Edquist, Nicholas S. Vonortas, Jon Mikel Zabala-iturriagagoitia, and Jakob Edler, 110–146. Cheltenham: Edward Elgar publishing.

Vonortas, N.S. (2015) Innovation and Public Procurement in the United States. In *Public Procurement for Innovation*, edited by Charles Edquist, Nicholas S Vonortas, Jon Mikel Zabala-Iturriagagoitia, and Jakob Edler, 147–178. Cheltenham: Edward Elgar Publishing.

Whyles, G., H. Van Meerveld, and J. Nauta (2015) Forward Commitment Procurement: A Practical Methodology That Helps to Manage Risk in Procuring Innovative Goods and Services. *Innovation: The European Journal of Social Science Research* 28: 1–19. doi:10.1080/13511610.2015.1024638.

Wilkinson, R., L. Georghiou, J. Cave, C. Bosch, Y. Caloghirou, S. Corvers, R. Dalpé, J. Edler, K. Hornbanger, and M. Mabile (2005) *Public Procurement for Research and Innovation. Developing Procurement Practices Favourable to R&D and Innovation*. Expert Group Report EUR 21793.

Yeow, J., and J. Edler (2012) Innovation Procurement as Projects. *Journal of Public Procurement* 12 (4): 472–504.

Chapter 3

A method to encourage and assess innovations in public tenders for infrastructure and construction projects

Bart Lenderink, Johannes I.M. Halman, Hans Boes and Hans Voordijk[2]

This chapter is linked to the following sub-research question:

RQ 2: How can the implementation of innovations be encouraged and assessed in public tenders for the award of civil engineering projects?

The answers to the sub-research questions are provided in section 6.1. of this thesis.

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3 A method to encourage and assess innovations in public tenders for infrastructure and construction projects

Abstract

Purpose

Stimulating innovation in projects can contribute to achieving policy goals, addressing societal challenges and meeting objectives within programs and projects. Despite their potential, innovations are rarely included in tender assignments and evaluated in the award of civil engineering projects. One explanation for this is the perceived difficulty in triggering and objectively assessing innovations in the awarding of projects. The aim of this paper is to develop, implement and evaluated a method to encourage and assess innovations in the awarding of bridge construction projects to address this problem.

Design/methodology/approach

A design science research (DSR) approach is used to develop, implement and evaluate a method to trigger and assess innovations in tenders for bridge projects. DSR approaches are used to develop "well-tested, well-understood and well documented innovative generic designs, dealing with authentic field problems or opportunities" (van Aken et al., 2016).

Findings

The findings show that the application of the developed method in a bridge project led to the inclusion of a broad range of innovations in the tender offers. Despite the broad support for the defined criteria, there were some differences in the way the criteria were interpreted by the public procurement team and by the tenderers. Despite these differences, no legal claims were filed in court.

Practical implications

Further development and wider adoption of the method is likely to have a positive impact on the application of innovations in bridge projects. With some adjustments, the method would also be appropriate for other civil engineering and construction projects.

Originality/value

This paper contributes to the discussion on how the terms innovation and innovativeness can be operationalized and used in the literature and practice. The

developed method provides definitions for assessing the degree as well as the level of innovations in tenders for bridge projects. Further, it provides a way to rank innovations and determine the additional value of the offered innovations in terms of a notional reduction in tender price. Finally, it provides insights into how to encourage innovations through public procurement in civil engineering projects.

3.1. Introduction

Public procurement is increasingly seen as an important instrument for contributing to policy goals and in the creation of additional public value (Grandia and Meehan, 2017; Arrowsmith, 2010). Stimulating innovation in civil engineering projects can be an example of the use of public procurement as a strategic tool in innovation policy, targeting national/regional competitiveness and economic growth (OECD, 2010; Edler and Georghiou, 2007). Furthermore, the stimulation of innovation in projects through public procurement can contribute to a wide range of goals and policy objectives on various levels. On the program or organizational level, innovation can be triggered to address societal challenges, such as the increasing effects of climate change (Edquist and Zabala-Iturriagagoitia, 2012) and contribute to organizational objectives, such as the upkeep of public infrastructure and to policy goals, including sustainability and the creation of a circular economy (Witjes and Lozano, 2016; Lember et al., 2014). On a project level, innovation can be triggered to achieve specific objectives within the project and/or to obtain additional value for the money spent with respect to the tender assignment (Yeow and Edler, 2012; Leendertse et al., 2012). An example of such an objective is to design and construct a bridge using bio-based composite materials. Examples of additional value in projects are the reduction of construction-related nuisance and a decrease in the need for maintenance and the lifecycle costs of the procured civil works.

Despite strong policy support and the potential of innovations to contribute to a broad range of goals and policy objectives, innovation is rarely included and stimulated in tender documents for civil engineering and construction projects (Loosemore, 2015; Farmer, 2016; Maghsoudi et al., 2016). This lack of focus on innovation in procurement is reflected in the findings of Lember et al. (2014) who identified a clear implementation gap in innovation-oriented procurement policies in most of the countries they investigated. In addition, they found that, in practice, it was public needs and demands for innovative products and services that often served as the driver for stimulating innovation through public procurement (OECD, 2017; Lember et al., 2014).

So, why is innovation rarely included and stimulated in civil engineering and construction projects and what is needed to stimulate innovation in this kind of projects? To answer these questions a literature review on innovation in construction was first performed. Subsequently, a generic method to assess innovations in the award of bridge construction projects was developed, applied and evaluated within a bridge project in The Netherlands.

This paper is structured as follows. In the next section a review about innovation in construction is presented. This section is followed by the research method section in which the successive research steps are explained. After the research method section, the development of the assessment method in this paper is divided in three parts. First, the development of a generic method to assess innovation in tenders based on the literature review of Garcia and Calantone (2002). Second, the implementation of the assessment method in the project Bridge of Boekelo. Third, the results of the evaluation of the method and the interpretation of these results.

The paper concludes with a discussion on the research contributions, the research findings and their implications, limitations and suggestions for future research, which is followed by the main conclusion.

3.2. Innovation in construction

The construction industry is often considered as an industry with a lack of innovation (Dorée and Holmen, 2004; Murphy et al., 2015; Loosemore and Richard, 2015; Xue et al., 2014). Yet, there are several studies indicating that this view on innovation in construction is negatively biased because of the way innovation is traditionally measured through R&D expenditure (Gambatese and Hallowell, 2011; Loosemore, 2015) and the exclusion of many innovations developed at the project level in such measurements (Aouad et al., 2010). In addition, the study of Brockmann et al. (2016) indicates that a lot of innovation does occur in megaprojects, which provide plenty opportunities for innovation because of their complexity. As such, they plead for a distinction between different types of projects while reporting on innovation in construction as the innovation potential is strongly affected by the type and size of the project. The relative lack of innovation can also be partly explained by some of the characteristics of the construction industry (Davis et al., 2016):

The project-based mode of production, producing and integrating products and services in “one-offs or small batches” of final products (Rutten et al., 2009; Gann and Salter, 2000). This limited production volume makes it more difficult to earn

back the investments in innovation and seems to favor process – over product – and incremental over more radical innovations from a firms perspective.

- The inter-organizational mode of production in a "loosely coupled system" (Dubois and Gadde, 2002; Dorée and Holmen, 2004), producing and integrating products andservices in varying compositions of organizations across projects. As such interorganizational collaboration is considered to be important for innovation. Wheresuppliers are often seen as an important source of innovations (source) and the mainarchitect/engineer and contractor provide value through the integration ofinnovations in the design and realization of projects (Winch, 1998).
- The relative complexity, physical scale and expected life span of the final products (Slaughter, 1998), which provide additional requirements for innovations.
- The strong influence of the client on the design and requirements of the final product and provided services (Blayse and Manley, 2004).

Last but not least, construction companies are not always fully aware of the potential benefits of innovation for increasing their technical capabilities and competitiveness as a whole (Pellicer et al., 2014; Winch, 1998). Yet, together with technical problems in projects and client requirements, the stimulation of innovation by senior management is found to be one of the main drivers for innovation in construction companies (Pellicer et al., 2014).

The importance of the role of the client in stimulating innovation has been part of many policy initiatives to improve the performance in the industry over the past decades (Egan, 1998; Latham, 1994; Farmer, 2016; Barbosa et al., 2017; Wolstenholme et al., 2009). Despite these efforts there is still considerable room for improvement, as many clients still award most of their projects based on the lowest price (Loosemore and Richard, 2015), and limit the solution space too much through the use of detailed designs and requirements (Eriksson et al., 2019). Further, they often lack the required knowledge and/or resources to stimulate and assess innovations through public procurement to meet their needs and requirements.

Together with the project- and contextual characteristics, the selection of a procurement strategy has a strong influence on the innovation potential in projects (Tawiah and Russell, 2008; Eriksson et al., 2019). Eriksson et al. (2019) identified four aspects in the procurement strategy to be of particular importance with respect to

collaboration, innovation and project performance: (a) the project delivery model, (b) incentives, (c) partner selection and (d) the collaboration model.

Addressing the first of these aspects, Tawiah and Russell (2008) developed an assessment framework to aid civil servants in the selection of a procurement mode/project delivery model to increase the innovation potential in projects. Procurement modes/project delivery models can range from regular design-bid-build, to integrated contracts and public private partnerships. The developed framework is unique in that it provides civil servants a means to assess the innovation potential at the front end of a project, based on 22 project context factors, which can either inhibit or stimulate innovation.

Although the selection of an appropriate project delivery strategy is important with respect to the innovation potential in a project, this research focuses on a different challenge with respect to stimulating innovation in projects from a client perspective: The perceived difficulty in objectively assessing innovation in tenders. This challenge relates to partner selection as well as incentives for stimulating innovation in a procurement strategy.

In fact, a municipality in The Netherlands acting as a client requested two of the authors to develop a method to stimulate and assess innovation for a specific bridge project, whereas this was considered to be a major challenge in the project and the municipality lacked the knowledge to develop this within their own organization. To address this challenge, a design science research (DSR) approach was used to develop and evaluate a generic method for assessing innovations in the tendering phase of bridge projects.

3.3. Research method

The aim of DSR is to develop "well-tested, well-understood and well documented innovative generic designs, dealing with authentic field problems or opportunities"(van Aken et al., 2016). DSR investigations are driven by a field problem or an opportunity. In our study, the field problem is the perceived difficulty in objectively assessing innovations in a tendering process for bridge projects. The justification for generic designs as an outcome of DSR is underpinned by their pragmatic validity and/or the production of desired outcomes because of the implementation of the design (van Aken et al., 2016).

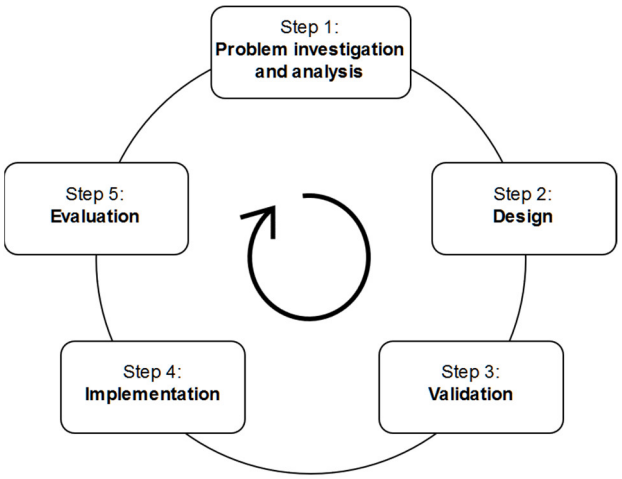

Figure 1: Cyclical design approach for the development of the method, based on (Wieringa, 2014)

A cyclical design approach, as presented in Figure 1, was used in developing a method for triggering and assessing innovations (Van Strien, 1997; Wieringa, 2014; Van Aken and Romme, 2009). The first step in the approach was problem investigation and analysis. During this step, a study was performed on why it is particularly difficult to objectively assess innovations in tender offers. Further, the context of the bridge project was investigated, including its scope, aims and objectives.

In the second step, the design requirements and the initial version of the method for assessing innovations in a tender were developed. For this, the innovation typology of Garcia and Calantone (2002) was tailored to create a method for ranking innovations based on their innovation level as well as the level of the innovation. Subsequently, the developed method was further tailored to fit within the bridge project and the associated procurement strategy.

In the third step, the design was validated through discussions with the public procurement team. This step aimed to assess: (1) if the developed method fitted with the project and procurement strategy and (2) if the developed method provides sufficient incentives for tenderers to offer innovations, which contribute to the design and realization of the bridge. In steps four and five, the developed method was implemented and evaluated within the bridge project. Specifically, the evaluation assessed:

- The extent to which the method triggered the inclusion of innovations in the tender offers;

- The extent to which the innovations contributed to the design and construction of the bridge; and
- The extent to which the method for assessing the innovations led to differences in interpretation and discussions.

The development and implementation of the method was performed by two researchers who were also part of the assessment committee for the project tender. The data collection and the validation of the developed method was carried out by two other researchers. The analyzed data for the validation of the method consisted of project and tender documents included assessment documents of the tender offers and information notices and recordings of semi-structured interviews with various people involved from the public organizations involved as well as with the tender managers of the five tenderers in the project.

3.4. Development of the method for assessing innovations in bridge projects

To provide an operational definition, Garcia and Calantone (2002) delineated the domain of the constructs "innovation" and "innovativeness." In their literature review, they conclude that the 1991 Organisation for Economic Co-operation and Development (OECD) study on technological innovations best captures the overall essence of innovation: "Innovation is an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to deployment, production, and marketing tasks striving for the commercial success of the intervention." As Garcia and Calantone explain, this definition addresses two important aspects. First, the "innovation" process comprises the technological development of an invention combined with the market introduction of that invention to end-users through adoption and diffusion. Second, that the innovation process can be considered iterative and inevitably includes, after the initial introduction of an innovation, a reintroduction of an improved innovation. This iterative process implies there are varying degrees of innovativeness and thus necessitates a typology that can describe different types of innovation.

Garcia and Calantone (2002) propose making distinctions in the degree of newness, ranging from incremental, through really new to radical innovation and in the level of innovation i.e. macro- versus micro-perspectives. These distinctions result in a classification schema consisting of six possible combinations.

We adapted the typology on innovativeness proposed by Garcia and Calantone (2002) to the specific context of bridge projects. For this, definitions for different types

of innovations, degrees of innovation and innovation scale levels were tailored to fit within the context of bridge projects.

Types of innovations

Innovation within the bridge project is defined as the development and potentially successful implementation of new ideas, products or processes in the design and realization of bridges. A distinction was made between product and process innovations:

- A product innovation is an innovative solution, which leads to a substantial improvement in the functionality of a bridge, the extension of the functionality of a bridge and/or the improvement of the technical performance of a bridge.
- A process innovation is an innovative solution to increase the efficiency of the construction process.

Examples of process innovations in bridge projects are solutions leading to:

- A substantial reduction in the necessary maintenance during the lifetime of a bridge;
- A substantial reduction in the total lifecycle costs of a bridge;
- A substantial improvement with respect to sustainability (such as a substantial reduction in CO2 emissions or circular design solutions for the materials that are used); and
- The successful application of new technologies such as 3D-printing, robotics, smart materials, self-healing materials, drones and intelligent systems for corrective and predictive maintenance.

The degree of innovation

Innovations can be classified according to the degree of innovation or the innovation level. The literature makes a distinction between radical innovations, these are completely new to the world market and realized using totally new technology; substantial innovations, which are completely new to a specific sector and realized with new technology; and incremental innovations, which are substantial improvements using an existing technology (Song and Montoya-Weiss, 1998; O'Connor, 1998; Garcia and Calantone, 2002). This differentiation of innovations, based on the degree of innovation, is in line with the models of construction innovation as suggested by Slaughter (1998). She indicates that innovation models can be found on a spectrum from incremental to radical innovations.

When applied to the bridge project the following definitions for the different degrees of innovation were used:

- Radical innovations are new or only very limitedly applied worldwide solutions, which use new technology;
- Substantial innovations are new or only limitedly applied solutions in the Dutch market that use new technology;
- Incremental innovations are substantial improvements to existing solutions for bridges or for the bridge construction process;
- Creative solutions are original solutions achieved through combining existing solutions for bridges and/or for their construction process; and
- Other solutions, which are not regarded as innovations.

In consultation with the public procurement team, it was decided to include creative solutions in the assessment of innovations. This was to provide an incentive for offering original and creative combinations of existing solutions that could provide additional value to the bridge or its realization process.

Innovation scale level

In line with Garcia and Calantone (2002) and Slaughter (1998), we further distinguished three innovation scale levels for product innovations:

- An innovative solution for the bridge as a whole (system innovation);
- An innovative solution for a major part of the bridge (module innovation); and
- An innovative solution for a small part of the bridge (component innovation).

A similar distinction was made for process innovations:

- An innovative solution for multiple work packages (system innovation);
- An innovative solution for one work package (module innovation); and
- An innovative solution for a process requirement within a work package (component innovation).

Ranking the innovativeness of an innovative solution

When assessing the innovativeness of a specific solution for a new bridge one needs to rank the degree of innovation as well as the scale level on which the innovation is applied. A total innovativeness score can be provided by applying weights to both innovation dimensions. For example, the innovation degrees radical innovation,

substantial innovation, incremental innovation and creative solution can be given relative weights of 9, 6, 3 and 3, respectively, and a similar weighting formula can be used for the innovation scale levels component, module and system innovation (Table I). Using these values, an incremental innovation on the module level is given an innovativeness score of 3 6 = 18 points, a radical innovation on the component level an innovativeness score of 9 3 = 27 points and a system-level radical innovation an innovativeness score of 9 9 = 81 points. If an offered solution is not considered to be an innovation a score of 0 points can be given.

Table 1: A possible classification score of innovations

Weights	Degree of Innovation	Innovation scale level
3 points	Incremental innovation or creative solution	Component level
6 points	Substantial innovation	Module level
9 points	Radical innovation	System level

3.5. Implementation of the assessment method in a bridge project

To validate the method, it was applied in the Bridge of Boekelo project. This project consisted of the design and construction of a new bridge to replaces an old bridge on the south side of the city of Hengelo in The Netherlands. First, the context of this bridge project and the approach for encouraging innovation in this project are explained. Second, the innovation assessment method as implemented and the results of the evaluation are discussed.

Context of the bridge project

The project was part of a large area redevelopment on the south side of the city center. This area redevelopment project was carried out under a public–private partnership between the municipality of Hengelo and a real estate developer. However, for this project the municipality acted as a public client on its own. In addition to the municipality, there were several other organizations involved in the client side of the tendering process as follows. The Dutch road and waterway agency Rijkswaterstaat, which is responsible for the management and maintenance of the canal and its infrastructure including the bridges across the canal. The Province of Overijssel, who provided a subsidy to finance a large share of the project. The engineering company SWECO, which managed the tendering process including the development of the tender assignment and the associated requirements and tender documents. In addition, the city architect was involved in designing the spatial guidelines for the

bridge. Finally, two researchers, also authors of this paper, were involved to develop the method to be used to trigger and assess the use of innovations in the tender offers.

The main aim of the project was to improve the accessibility, traffic flow and traffic safety of Hengelo within the time and budget restrictions of the project. The main objective in the project was to replace an old bridge with a bridge that would allow more and heavier traffic. This new bridge, with a minimum span of 44 m, should be designed and realized in accordance with the developed requirements and developed design guidelines for the bridge. The second objective in the project was to deliver the southern part of the avenue to the city center in line with design specifications. Within the project, there was a strong focus on realizing an architecturally appealing bridge of high aesthetic quality since the bridge forms the new entrance into the city from the south. Furthermore, there was a strong focus on stimulating the use of product and process innovations to obtain additional value in the design and construction of the bridge.

Triggering innovations in the bridge of Boekelo project

An integrated design and construct contract was adopted to integrate the design and construction phases of the project in a single tender assignment. The contracting authority opted for a broad solution space within the boundaries set in the spatial design guidelines for the bridge, which were predefined by the municipality. This allowed tenderers to offer a broad range of solutions and innovations with respect to the design and construction of a plate, arch or cable-stayed bridge. Moreover, tenderers were specifically requested to include up to three product and/or process innovations in their tender offer for the design and realization of the bridge. The solution space for the design and construction of the new avenue was fairly limited and the design of the avenue was not the focus of the project.

Innovation played a strong role in the selection as well as the award phases of the restricted tender procedure used in the project. In the selection phase, the number of candidates was reduced based on:

- Their ability to integrally perform five pre-defined core competences; and
- The extent to which candidates could convincingly prove that innovation is part of their corporate strategy and underpins their relevant achievements in the development and/or application of innovations in projects comparable to this project.

Innovation was one of the award criteria in determining the quality of the tender offers in the award phase. Other criteria in determining the quality of the tender

offers were the architectural and aesthetic quality of the bridge design and the time needed to realize the project. In addition, the tender price was used as an award criterion in combination with a maximum allowable tender price of €8.2m.

An overview of the staged tender procedure with the selection and award criteria can be found in Figure 2. The contract was awarded to the tender with the lowest fictional tender price that met all the requirements of the contract. The fictional tender price ($P_{Fictional}$) is determined by subtracting the sum of additional values provided by each of the qualitative award criteria ($\sum V_{Additional}$) from the offered tender price, ($P_{Offered}$), equations 1 and 2. According to Dreschler (2009) p. 122 and 140, this is one of the most suitable options to determine the most economical advantageous tender in the award of construction projects:

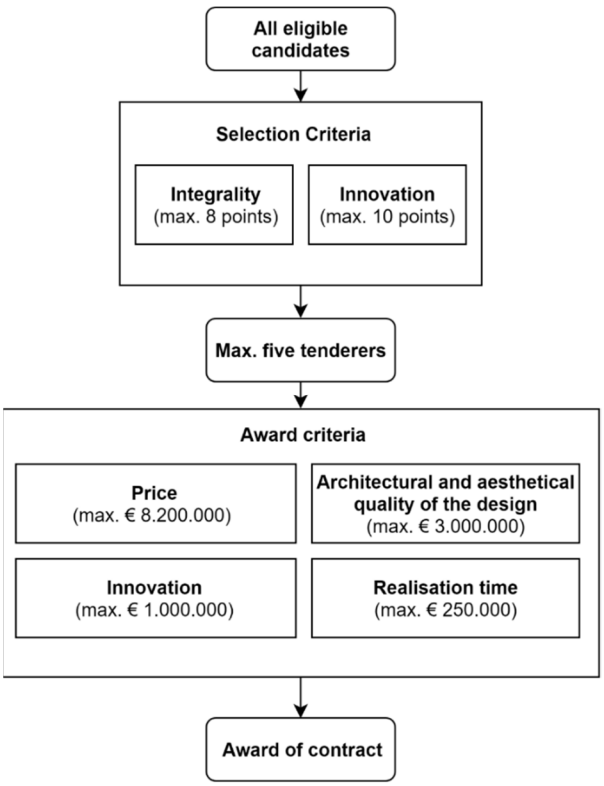

Figure 2: Overview of the tender procedure including selection and award criteria

$$P_{Fictional} = P_{Offered} - \sum V_{Additional} \qquad \text{Equation 1.}$$

$$P_{Fictional} = P_{Offered} - (V_{Architectual\ and\ aesthetic\ quality\ of\ the\ bridge\ design} + V_{Innovation} + V_{Realisation\ time})$$ Equation 2.

The maximum fictional reduction allowed on the tender price was €4.25m against a maximum allowed tender price of €8.2m in the tender offer. The innovation award criterion accounted for €1.0m of this €4.25m to provide a strong incentive for tenderers to include innovations in their tender offer. Nevertheless, innovation was not the most important criterion for determining the quality of the tender offers. Rather, the architectural and aesthetic quality award criterion, with a maximum reduction of €3.0m, was the most important criterion in assessing the quality of the offers. Reducing the realization time had a maximum value of €0.25m.

Assessment method of innovations as implemented in the bridge project

All tenderers were requested to offer up to three innovations in their tender offer for which they could obtain a maximum €1.0m fictional reduction on their tender price. A six-step approach was used to assess the additional value of the proposed solutions offered as innovations in the tender offers:

1. Assess if the proposed solutions can be considered as a product or process innovation;
2. Assess the degree of innovativeness of the proposed solutions (0; 3; 6; 9 pt.);
3. Assess the scale level on which the solutions are implemented (3; 6; 9 pt.);
4. Multiply the degree of innovativeness by the scale level on which they are implemented to determine the score for each of offered solutions (e.g. 3*6 = 18 pt.);
5. Determine the total score for the provided innovations by summing the individual scores for each innovation (e.g. 18 + 27 + 18 = 63 pt.); and
6. Determine the added value using equation 3:

$$V_{innovation} = \frac{Total\ score\ (max.\ 90\ pt.)}{90} * \text{€}\ 1.0\ million$$ Equation 3.

The possible scores for the different degrees of innovation and innovation scale levels of offered innovations, as well as the total score for individual innovations and combined score for a set of offered innovations are presented in Table II. Note that the total combined score for the three innovations was limited to 90 points for which the maximum reduction on the tender price of €1.0m would be granted.

Table 2: Possible scores for including innovations in the tender offer

Dimensions of innovation	Offered innovations		
	Innovation 1	Innovation 2	Innovation3
Degree of innovation	<0;3;6;9>	<0;3;6;9>	<0;3;6;9>
Innovation scale level	<3;6;9>	<3;6;9>	<3;6;9>
Individual innovation	<0-81>	<0-81>	<0-81>
Total score (max. 90 pt.)	<0-90>		

3.6. Evaluation of the assessment method in the bridge project

The call for tenders for the Bridge of Boekelo project led to the enrolment of nine candidates in the selection phase, from which five candidates were invited to submit an offer for the tender in the award phase. All five tenderers who were invited did submit an offer for consideration in the award phase.

Innovation in the tender offers

The method used to trigger the implementation of innovations in the tender offers resulted in the inclusion of nine product and six process innovations in the tender offers. Hence, each tenderer included the maximum three innovations in their offer. Of the offered innovations, two process innovations and one product innovation were not considered as innovations based on the working definitions of innovation in the project. The reasons for this provided by the assessment committee were: a lack of underpinning of promises and guaranties, a lack of innovativeness in the provided solution and a provided solution that did not fit the working definitions for innovation with respect to the scope/focus of the project.

The average reduction granted on the tender price for the total additional quality offered was €2.45m compared to the maximum of €4.25m. The innovation award criterion accounted for €0.58m of this €2.45m. At the same time, there was a large spread in the additional value offered through the inclusion of innovations in the tender offers. The associated standard deviation for the innovation award criterion was €0.31m.

With respect to the degree and level of innovation of the provided solutions, more than half of the solutions were assessed as creative solutions or incremental innovations at the level of a component or module innovation (Table III). Two solutions were assessed as substantial innovations on the module level, one as a

substantial innovation on the system level and another as a radical innovation on the component level. Notably, none of the solutions was assessed as a radical innovation on the level of a system or module.

Contribution of innovations to the design and construction of the bridge Tenderers were specifically requested to include innovations in their tender offers that would contribute to the design and construction of the bridge. Most of the offered innovations contributed to the design and construction of the bridge to some extent. Those that did not were not considered as innovations within the project working definitions for innovation. Subsequently, these proposed solutions were given zero points in the assessment.

The extent and to what element of the design and construction of the bridge the offered innovations contributed to varied from innovation to innovation. Unfortunately, it is not possible to discuss in detail the offered solutions from the unsuccessful tenderers. Nevertheless, some insights into the trends in the contributions of the proposed solutions can be presented.

Overall, there were nine product innovations focusing on improving the functionality and technical performance of the bridge or adding additional functionalities and six process innovations focusing on the design and construction process. A large proportion of the product innovations included the use of new materials or the use of systems related to energy in the design of the bridge. Many of the offered process innovations focused on improving the design process or monitoring the need for maintenance of the bridge.

The tenderer to which the contract was awarded included the use of mixed reality as an innovative way to integrate the design and construction processes. More specifically, the bridge is designed in a 3D model and then placed on top of what can be seen in practice through the use of an Engineer and Build in Mixed Reality Solution. Second, the winning tenderer included high weight resistant solar panels in the road surface of the bridge to provide the energy for the lights on the bridge. The third innovation was the use of a low-temperature baked powder coating to extend the lifespan and reduce the maintenance of the handrails of the bridge.

Table 3: Assessment of innovativeness of all offered product and process innovations in the tender offers in terms of innovation scale level and degree of innovation

Legend: **Number of innovations** (product innovations; process innovations) (Score) **Degree of innovation**	**Innovation scale level**		
	System innovation (9pt.)	Module innovation (6 pt.)	Component innovation (3 pt.)
Radical Innovation (9pt.)	**0** (0; 0) (81 pt.)	**0** (0; 0) (54 pt.)	**1** (1; 0) (27 pt.)
Substantial Innovation (6 pt.)	**1** (0; 1) (54 pt.)	**2** (2; 0) (36 pt.)	**0** (0; 0) (18 pt.)
Incremental innovations/ creative solutions (3pt.)	**0** (0; 0) (27 pt.)	**4** (1; 3) (18 pt.)	**4** (4; 0) (9 pt.)
Solution not considered as an innovation	**3** (1; 2) (0 pt.)		

In addition, the contracted tenderer offered an innovative plate bridge design integrating the three innovations. This design led to a large reduction in the fictional tender price because of the additional architectural and aesthetic quality it provided. Nevertheless, this innovative design also required the tenderer to develop a new model to calculate the forces and the bearing capacity of the bridge. As the future owner being responsible for the design and maintenance of the bridge, the Dutch road and waterway agency also had to develop a new model to check the calculations. The development of this model caused some delay in the project. The award criterion "reduction in realization time" did not combine well with the implementation of innovations in the project as they increased the chances of delay either caused by the contractor/suppliers or the client. An important conclusion from this is that contractors and suppliers need sufficient time to deal with potential delays related to the implementation of innovations in projects.

Differences in interpretation related to the assessment method

Both the public procurement team and the tenderers indicated that the criteria for the different degrees and levels of innovation were clear and beneficial for assessing the innovations in the tender offers. Originally, the intention had been to score innovations on a continuous level from 0 to 9 but one of the tenderers requested limiting the possible scores to either 0, 3, 6 or 9 (as indicated earlier in the paper). This

request was approved and implemented as it made it easier to justify the scores awarded to the proposed innovations.

Despite the broad support for the defined criteria, there were some differences in the way the criteria were interpreted by the public procurement team and the tenderers. As a result of this, there were four occasions where the tenderers indicated that they felt their offered innovations should have been scored more highly. For example, one innovation was expected to be assessed as a system-level radical innovation by the tenderer, whereas the assessment committee assessed the innovation as a substantial innovation on the module level. Even though there were such differences in interpreting the criteria, this did not lead to legal claims and the evaluations of tender offers by the public procurement team were accepted. The fact that most of the potential reduction in the tender price could be obtained through the architectural and aesthetic quality criterion of the bridge, coupled with the significant difference between the overall scores of the winning and second-placed tenderer, may have contributed to this acceptance of the innovation scores.

3.7. Interpretation of the evaluation results

The implementation of the method in the Bridge of Boekelo project led to the inclusion of nine product and six process innovations in the tender offers. Most of these innovations were assessed as creative solutions or incremental innovations on the level of a component or module innovation. Further, the method did not trigger the inclusion of radical innovations on the level of module or system innovations. Further, 3 of the 15 offered solutions were not considered as innovations based on the working definitions.

Several factors may have limited the degree and level of the innovations offered. As expressed by some of the tenderers, the time to develop the tender offer was fairly limited for a project that was focusing on innovation. This limited the time available to assess the value and potential risks of including innovations in the tender offer. In addition, the third qualitative award criterion, focusing on reducing the realization time, increased the time pressures on the project to some extent. Given that radical innovations are more prone to bugs and/or breakdowns compared to conventional solutions and incremental innovations (Klein Katherine, 1996), one could expect time pressures to have a negative effect on the degree and level of the innovations offered.

Setting a higher maximum tender price might well have stimulated tenderers to provide more radical system-level innovations by enabling them to earn a larger

return on their investments in innovations in the project. Further, many tenderers stated that the transaction costs for this project were particularly high compared to other projects of this size. According to them, a considerable amount of time and effort was required to submit an offer in the award phase, and only one tenderer would obtain a contract. Two ways to reduce the involved transaction costs for the tenderers would be to:

- Limit the number of tenderers who are invited to submit offers; and
- Provide reasonable compensation for the work involved in submitting an offer (Hardeman, 2014).

The developed assessment method reduced the subjectivity in the assessment of innovations to a large extent. However, some subjectivity in assessing the degree and the level of innovation in the offered solutions cannot be avoided as it is based on expert judgment. We argue that this should not be considered problematic provided the assessment committee can sufficiently justify how and why they came to their rating. In this respect, evaluation meetings with the tenderers after the tender has been awarded are important in reducing the likelihood of claims being filed in court. The same is true for the assessment, through the use of expert judgment, of designs for civil engineering projects based on predefined spatial design guidelines.

Although most of the offered innovations contributed to the design and construction of the bridge, the extent of the contribution varied from innovation to innovation. This may be explained by the fact that although the contribution of the innovations was included in the working definitions for innovation in the project, it was not used as a separate criterion for assessing the offered innovations. As such, there were no specific incentives to include innovations that made particularly large contributions to the design and construction of the bridge compared to other eligible innovations. Including a four-point scale and definitions for this criterion, similar to those for the degree and level of the innovations, might have encouraged a stronger focus on the contribution of the innovations to these aspects of the project.

3.8. Discussion

Research contributions

This study makes three research contributions. First, it contributes to the debate on how to operationalize the terms innovation and innovativeness given that these terms are used in numerous ways in the literature and in practice. The innovativeness typology proposed by Garcia and Calantone (2002) has been adapted to the specific

context of innovation in bridge projects. The study provides clear definitions and examples of product and process innovations within the context of bridge projects. Further, it provides definitions to distinguish different degrees of innovativeness and levels on which product and process innovations can be applied within bridge projects.

Second, this study provides a method based on objective criteria to assess and rank innovations in tenders for bridge projects. This method applies the definitions for product and process innovations to assess if the offered solutions should be considered as an innovation within the tender. Further, it uses the definitions of different degrees of innovativeness and levels of the application to determine the additional value of the proposed innovations in terms of a fictional reduction in the tender price.

Third, the study contributes to and supports existing findings in the literature on how to stimulate and trigger innovation through public procurement in civil engineering and construction. This was achieved through explaining how tenderers were triggered to provide innovations as part of their tender offers in the case of a specific bridge project. In short, innovation was triggered in three different ways. First, by providing sufficient incentives to offer innovative solutions (Dreschler, 2009; Edquist and Zabala-Iturriagagoitia, 2012). Second, by providing sufficient solution space to offer innovative solutions (Dalpé, 1994; Uyarra et al., 2014). Third, by using innovation as a selection criterion in shortlisting tendering candidates to go forward and submit a tender offer. Fourth, by providing sufficient time in the project to deal with potential delays related to the implementation of innovations.

Main findings and their policy implications

The findings from this study suggests that it is possible to trigger and assess innovations in tenders for civil engineering projects in line with procurement regulations and their underlying values using the developed method. Inevitably, there will be some subjectivity in the assessment of innovations because of the use of expert judgment to interpret and assess innovations based on the developed working definitions for:

- Product/process innovation;
- Degree of innovation; and
- Level on which an innovation is implemented.

Alternative to using the applied method as a whole, elements of the developed method and applied procurement strategy in the bridge project can be used as

components to develop other innovation-oriented procurement strategies. For example, using innovation as a selection criterion and principles such as providing ample incentives and solution space for tenderers to provide innovative solutions could be used as part of other approaches.

The developed method has strong policy implications for procurement practice as it supports the use of public procurement to trigger and assess innovations in tenders for civil engineering projects. Moreover, the use of the proposed method can support public organizations in achieving the intended aims of their projects and in obtaining greater value for money in civil engineering projects.

Further development and wider application of the method is likely to have a positive impact on the adoption of innovations in civil engineering projects since it provides tenderers with the possibility and actively encourages them, to include innovations in their tender offers.

Limitations and future research

The proposed method has been developed, applied and evaluated within one single project in the domain of civil engineering. As such, further development and evaluation are needed to increase the validity of the results, improve the developed method and broaden its applicability. One suggestion for future research is to adapt the definitions to assess innovations in other types of civil engineering projects, such as a sluice construction or a new road project and evaluate the use of assessment method in these types of projects. Further, with some adaptations, the method may also be applicable in other domains, such as in the tendering process for utility buildings or housing projects.

The method is considered most appropriate for civil engineering projects that want to encourage the use of innovations and to offer tenderers an opportunity to test their innovative ideas in practice. In such situations, the underlying rationale is often to stimulate economic development and competitiveness in a region and/or sector. When this aim is coupled with obtaining additional value in terms of the goals of a project, policy and/or organizational level it becomes a win–win situation. However, we admit that this method is only one way to stimulate innovation in civil engineering projects, and that this method will not work for all objectives whereas different goals and objectives require different approaches.

There are at least two situations in which a different approach to stimulating innovation through procurement would be required in civil engineering projects. The first is when the development and/or procurement of one or more innovations is a

project on itself (Yeow and Edler, 2012). In this case, the purpose of the project is to develop and/or procure an innovation to address a specific problem. The second is when the development and/or procurement of innovations are required to achieve the aims of the project or to address a specific problem within a project that requires an innovative solution. Since these situations focus on achieving specific aims or addressing specific problems, it would not make sense to insist that tenderers include three innovations as part of their offer and then to assess these innovations with respect to their degree of innovation and the level on which they are applied. In fact, it would make far more sense to focus on the contribution of the proposed solutions to achieve the intended project aims, or to address specific problems, in selecting the successful tender offer.

3.9. Conclusion

The relative lack of innovation in civil engineering and construction industry can partly be explained by the way innovation is traditionally measured, the characteristics of the industry as well as the type of products they produce. Moreover, innovation is rarely stimulated and included in the award of infrastructure and construction projects. One important reason for this is the difficulty, as perceived by public clients, to stimulate and objectively assess innovations in tenders for infrastructure and construction projects, often caused by a lack of knowledge and experience.

As a first step to address this challenge, a generic method to encourage and assess innovations in public tenders for infrastructure and construction projects has been developed, implemented and evaluated in a bridge project using a DSR approach.

The findings from the evaluation of the developed method suggest that it is possible to encourage and assess innovation in tenders in line with procurement regulations and their underlying values using the developed assessment method. Yet, some subjectivity in the assessment of the innovations cannot be excluded because of the use of expert judgment.

The developed method is most suitable for encouraging and providing tenderers the opportunity to include and test innovations in the project as part of their tender offer. However, in cases where innovations are not ready for application and need more development, and/or in cases where innovation is necessary to address a specific challenge or problem in the project, the developed method is less suitable.

Finally, we want to stress that the use of innovation-oriented procurement strategies to contribute to the policy objectives and objectives and/or challenges within projects is still largely neglected in the literature. Given the major challenges facing us related to sustainability, the exhaustion of resources and the effects of climate change on our public infrastructure, we consider this an important topic with high policy implications that warrants further research.

References

Aouad, G., Ozorhon, B. and Abbott, C. (2010), "Facilitating innovation in construction: directions and implications for research and policy", *Construction Innovation*, Vol. 10(4), 374-394.

Arrowsmith, S. (2010), "Horizontal policies in public procurement: a taxonomy", *Journal of Public Procurement*, Vol. 10(2), 149-186.

Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M.J., Sridhar, M., Parsons, M., Bertram, N. and Brown, S. (2017), *Reinventing Construction: A Route to Higher Productivity*, McKinsey Global Institute.

Blayse, A.M. and Manley, K. (2004), "Key influences on construction innovation", *Construction Innovation*, Vol. 4(3), 143-154.

Brockmann, C., Brezinski, H. and Erbe, A. (2016), "Innovation in construction megaprojects", *Journal of Construction Engineering and Management*, Vol. 142 No. 11, pp. 4016059.

Dalpé, R. (1994), "Effects of government procurement on industrial innovation", *Technology in Society*, Vol. 16(1), 65-83.

Davis, P., Gajendran, T., Vaughan, J. and Owi, T. (2016), "Assessing construction innovation: theoretical and practical perspectives", *Construction Economics and Building*, Vol. 16(3), 104-115.

Dorée, A.G. and Holmen, E. (2004), "Achieving the unlikely: innovating in the loosely coupled construction system", *Construction Management and Economics*, Vol. 22(8), 827-838.

Dreschler, M. (2009), *Fair competition: how to apply the 'economically most advantageous tender'(EMAT) award mechanism in the Dutch construction industry*, PhD thesis, TU Delft, Delft.

Dubois, A. and Gadde, L.-E. (2002), "The construction industry as a loosely coupled system: implications for productivity and innovation", *Construction Management and Economics*, Vol. 20, (621-631).

Edler, J. and Georghiou, L. (2007), "Public procurement and innovation—resurrecting the demand side", *Research Policy*, Vol. 36(7), 949-963.

Edquist, C. and Zabala-Iturriagagoitia, J.M. (2012), "Public procurement for innovation as missionoriented innovation policy", *Research Policy*, Vol. 41(10), 1757-1769.

Egan, J. (1998), *Rethinking Construction*, Construction Task Force Report for Department of the Environment, Transport and the Regions, HMSO, London.

Eriksson, P.E., Volker, L., Kadefors, A. , Lingegard, S. , Larsson, J.. and Rosander, L., (2019), "Collaborative procurement strategies for infrastructure projects: a multiple-case study", *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law*, Vol. 172(5), 197-205.

Farmer, M. (2016), *Modernise or Die: The Farmer Review of the UK Construction Labour Market*, Construction Leadership Council, London.

Gambatese, J.A. and Hallowell, M. (2011), "Factors that influence the development and diffusion of technical innovations in the construction industry", *Construction Management and Economics*, Vol. 29(5), 507-517.

Gann, D.M. and Salter, A.J. (2000), "Innovation in project-based, service-enhanced firms: the construction of complex products and systems", *Research Policy*, Vol. 29(7/8), 955-972.

Garcia, R. and Calantone, R. (2002), "A critical look at technological innovation typology and innovativeness terminology: a literature review", *Journal of Product Innovation Management*, Vol. 19, 110-132.

Grandia, J. and Meehan, J. (2017), "Public procurement as a policy tool: using procurement to reach desired outcomes in society", *International Journal of Public Sector Management*, Vol. 30(4), 302-309.

Hardeman, S. (2014), *Transactiekosten aanbesteden: Effecten van aanbestedingswet en marktdynamiek* Economisch instituut voor de Bouw, Amsterdam.

Klein Katherine, J. (1996), "The challenge of innovation implementation", *Academy of Management Review*, Vol. 21(4), 1055.

Latham, M. (1994), *Constructing the Team: final Report of the Government/Industry Review of Procurement and Contractual Arrangements in the UK Construction Industry*, HMSO, London.

Leendertse, W., Arts, J. and De Ridder, H. (2012), "How can procurement contribute to network performance? streamlining network, project and procurement objectives", *Procedia - Social and Behavioral Sciences*, Vol. 48, 2950-2966.

Lember, V., Kattel, R. and Kalvet, T. (2014), *Public Procurement, Innovation and Policy: International Perspectives*, Springer Science and Business Media.

Loosemore, M. (2015), "Construction innovation: Fifth generation perspective", *Journal of Management in Engineering*, Vol. 31(6), 04015012. DOI: 10.1061/(ASCE)ME.1943-5479.0000368

Loosemore, M. and Richard, J. (2015), "Valuing innovation in construction and infrastructure: Getting clients past a lowest price mentality", *Engineering, Construction and Architectural Management*, Vol. 22(1), 38-53.

Maghsoudi, S., Duffield, C. and Wilson, D. (2016), "Innovation in infrastructure projects: an Australian perspective", *International Journal of Innovation Science*, Vol. 8(2), 113-132.

Murphy, M.E., Perera, S. and Heaney, G. (2015), "Innovation management model: a tool for sustained implementation of product innovation into construction projects", *Construction Management and Economics*, Vol. 33(3), 209-232.

O'Connor, G.C. (1998), "Market learning and radical innovation: a cross case comparison of eight radical innovation projects", *Journal of Product Innovation Management*, Vol. 15, 151-166.

OECD (2010), *The OECD Innovation Strategy: Getting a Head Start on Tomorrow*, OECD publishing, Paris. OECD (2017), Public Procurement for Innovation.

Pellicer, E., Yepes, V., Correa, C.L. and Alarcon, L.F. (2014), "Model for systematic innovation in construction companies", *Journal of Construction Engineering and Management*, Vol. 140(4):1-8. doi:10.1061/(ASCE)CO.1943-7862.0000700

Rutten, M.E., Dorée, A.G. and Halman, J.I.M. (2009), "Innovation and interorganizational cooperation: a synthesis of literature", *Construction Innovation*, Vol. 9(3), 285-297.

Slaughter, E.S. (1998), "Models of construction innovation", *Journal of Construction Engineering and Management*, Vol. 124(3), 226-231.

Song, X.M. and Montoya-Weiss, M.M. (1998), "Critical development activities for really new versus incremental products", *Journal of Product Innovation Management*, Vol. 15, 124-135.

Tawiah, P.A. and Russell, A.D. (2008), "Assessing infrastructure project innovation potential as a function of procurement mode", *Journal of Management in Engineering*, Vol. 24(3), 173-186.

Uyarra, E., Edler, J., Garcia-Estevez, J., Georghiou, L. and Yeow, J. (2014), "Barriers to innovation through public procurement: a supplier perspective", *Technovation*, Vol. 34(10), 631-645.

Van Aken, J., Chandrasekaran, A. and Halman, J. (2016), "Conducting and publishing design science research: Inaugural essay of the design science department of the journal of operations management", *Journal of Operations Management*, Vol. 47, 1-8.

Van Aken, J.E. and Romme, G. (2009), "Reinventing the future: adding design science to the repertoire of organization and management studies", *Organization Management Journal*, Vol. 6(1), 5-12.

Van Strien, P.J. (1997), "Towards a methodology of psychological practice: the regulative cycle", *Theory and Psychology*, Vol. 7(5), 683-700.

Wieringa, R.J. (2014), *Design Science Methodology for Information Systems and Software Engineering*, Springer.

Winch, G. (1998), "Zephyrs of creative destruction: understanding the management of innovation in construction", *Building Research and Information*, Vol. 26, 268-279.

Witjes, S. and Lozano, R. (2016), "Towards a more circular economy: Proposing a framework linking sustainable public procurement and sustainable business models", *Resources, Conservation and Recycling*, Vol. 112, 37-44.

Wolstenholme, A., Austin, S.A., Bairstow, M., Blumenthal, A., Lorimer, J., McGuckin, S., Rhys Jones, S., Ward, D., Whysall, D. and Le Grand, Z. (2009), *Never waste a good crisis: a review of progress since Rethinking Construction and thoughts for our future*.

Xue, X., Zhang, R., Yang, R. and Dai, J. (2014), "Innovation in construction: a critical review and future research", International Journal of Innovation Science, Vol. 6 No.

2, pp. 111-126. Yeow, J. and Edler, J. (2012), "Innovation procurement as projects", *Journal of Public Procurement*, Vol. 12(4), 472-504.

Chapter 4

Procurement and innovation risk management: How a public client managed to realize a radical green innovation in a civil engineering project

Bart Lenderink, Johannes I.M. Halman, Hans Boes, Hans Voordijk and André G. Dorée[3]

This chapter is linked to the following sub-research question:

RQ 3: What determining factors and mechanisms influence the successful development and implementation of radical innovations in civil engineering projects?

The answers to the sub-research questions are provided in section 6.1. of this thesis.

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4 Procurement and innovation risk management: How a public client managed to realize a radical green innovation in a civil engineering project

Abstract

Public clients' decisions on the procurement and contracting of civil engineering projects have far-reaching effects on the development and implementation of innovations. Two decades ago, a trend towards the use of integrated contracts started to improve constructability and stimulate innovations. However, for radical innovations, the unilateral allocation of innovation risks to the main contractor is undesirable since most of the associated innovation risks are difficult to assess and manage due to the inherent uncertainties. An in-depth case study was used to investigate the development and application of an alternative public-client-led approach to realizing a radical innovation in a civil engineering project. This study shows that: (1) government championship, through a proactive participation of the public client in the initiation, development and implementation of the innovation project and the willingness to bear innovation risks; (2) the application of innovation risk management strategies and the availability of a fall back option; (3) the establishing of favourable organizational and relational conditions, were determinative factors for the successful development and implementation of the intended radical innovation. Furthermore, seven propositions have been derived that together provide instruments through which public clients can actively promote the development and implementation of radical innovations in civil engineering projects.

4.1. Introduction

The quality of our physical environment is under increasing pressure due to grand challenges such as climate change and future energy and water supply, and to meet a new set of policy goals on themes such as sustainability and circularity. The sustainable development goals of the United Nations are an important example in this regard where innovations can provide a significant contribution towards obtaining these far-reaching goals (United Nations General Assembly, 2015). In addition, radical innovations may also be required where existing solutions appear ineffective. Government, as the largest client of the construction industry, is the single

most influential party in supporting the achievement of these sustainability targets (Miller et al., 2009).

Through its role as a client and regulator, governments can influence the outcomes of procurement activities by addressing the impediments to innovation and fostering its enablers (Eriksson et al., 2019; Rose and Manley, 2012). However, a recent report published by the Economic Institute of the Building environment (EIB) in the Netherlands (Arnoldussen et al., 2017) and earlier studies conducted by Blayse and Manley (2004), Ivory (2005), Manley (2006), and Na et al. (2006) noted several challenges for innovation in the construction industry. One of these challenges is the lacking of effective procurement methods that encourage and support the development and implementation of radical innovations in the construction industry. Currently, the two most commonly applied project delivery methods for construction projects by public clients are design-bid-build and integrated contracts. The EIB report seriously questions the extent to which these project delivery methods encourage radical innovation in construction projects.

The design-bid-build project delivery method is often used for smaller, more predictable and less complex projects. In this delivery method, detailed design and specifications are developed prior to the tendering process for the realization phase of a project (Hale et al., 2009; Lenferink et al., 2013). Most projects using this delivery method are awarded based on the price in the tender offers, and to a lesser extent on quality criteria (Loosemore and Richard, 2015). This delivery method, in combination with competitive tendering, stimulates arms-length working relationships (Eriksson, 2008; Eriksson and Westerberg, 2011), where each of the involved organizations focusses on their own part of the project and collaboration between organizations is limited (Kent et al., 2010). This delivery method is considered to be less conducive to the development and implementation of innovations in construction and civil engineering projects for three reasons. First, the split between those organizations involved in the design phase and those in the realization phase limits possibilities for optimization between the design and construction parts of the project (Eriksson et al., 2019). Second, the common focus on price in awarding the contract limits incentives to offer innovative solutions with additional value beyond reducing the realization price (Loosemore and Richard, 2015). Third, the inclusion of a detailed design in the tender documents, with a list of technical specifications and requirements, limits the space for alternative solutions (Rose and Manley, 2012).

An alternative to design-bid-build that is often applied is the use of integrated contracts as a project delivery method. Integrated contracts are often used for larger

and/or more complex projects where additional value from early involvement of the contractor is foreseen. Integrated contracts combine design activities and the realization of the project in a single tendering assignment (Hale et al., 2009), and may also include maintenance, operation and/or finance components (Lenferink et al., 2013). Generally, a combination of price and qualitative assessment criteria is used to assess the tender offers and guide the direction in which additional value can be offered. When a significant share of the design activities is performed by the main contractor, integrated contracts provide more options for optimization between the design and the realization of the project and stimulate the inclusion of incremental innovations (Eriksson et al., 2019; Rose and Manley, 2012). At the same time, they reduce the financial risks for the client because the contractor becomes responsible for its part in the design activities as well as the realization of the project (Oyegoke et al., 2009).

Despite the clear benefits of integrated project delivery methods for improving constructability and stimulating incremental innovations, this delivery model has its drawbacks. Since, in the integrated project delivery method, the main contractor is held responsible for the design as well as the realization of the project, a large proportion of the risks is allocated to the main contractor. This is especially true when combined with fixed price contracting (Öztas and Ökmen, 2004). This skewed risk allocation becomes problematic if the contractor faces considerable uncertainties in a project. These uncertainties will not only hinder a reliable assessment of potential project risks and a realistic inclusion of these risks in the tender price, but will also reduce a contractor's ability to manage and bear these risks effectively (Öztas and Ökmen, 2004; Rijkswaterstaat, 2019). In addition, the integrated delivery method obliges contractors to take responsibility for risks that they cannot influence, such as deficient scoping of the work that needs to be realized and the timely issue of building permits, which may lead to considerable project delays and costs (Miller et al., 2009). If the integrated delivery method is applied, contractors may well be reluctant to develop and/or implement radical innovations. Radical innovations are associated with a higher risk profile. The risk profile of innovations is strongly related to the extent of the uncertainty in terms of: a) the required budget and development time, b) the performance of the innovation, and c) the ability of the innovation to comply with regulations. These uncertainties are logically higher when a potential innovative solution has a lower technology readiness level and requires more development and testing (Mankins, 2009). The risk of having to bear the consequences when things go wrong, take longer, or when the specified performance

levels turn out to be unachievable with the intended innovative solution, will make contractors reluctant to seek radical innovations (Rijkswaterstaat, 2019).

If the development and/or implementation of radical innovations is explicitly requested in the issued tender assignment, the reluctance of contractors to take innovation risks may result in a lack of offers from potential contractors. This, in combination with the discussed limitations of both the design-bid-build and integrated delivery methods to encourage innovation and facilitate the management of innovation risks, we argue that an alternative approach is needed for the development and implementation of radical innovations in civil engineering projects. In literature, little attention has been devoted so far on possible alternative procurement methods that facilitate and encourage the development and application of radical innovations in civil engineering projects. In order to contribute in closing this gap in literature, we will evaluate the effectiveness of a recent alternative procurement approach that was applied to develop and implement a new technology with a low readiness level in a civil engineering project in the Netherlands. The new technology concerns an innovative bio-based composite bridge deck that was developed and incorporated in the design and realization of a movable bridge. To evaluate the effectiveness of the alternative procurement approach, the following research questions will be answered in this paper:

1. What determining factors and mechanisms influence the successful development and implementation of a radical innovation in civil engineering projects?
2. To what extent can the theory on innovation risk management, government championship and coopetition in client-contractor relationships help to explain the successful development and implementation of radical innovations in civil engineering projects?

The rest of this paper is structured as follows. Section 2 provides a background of the literature that is considered relevant for this study. In section 3 the research methodology is introduced and the case study explained. The research methodology section is followed by a detailed description in section 4 of the application of the developed approach in the tendering process for a bicycle bridge project with an innovative movable bridge deck of bio-based composite materials. Section 5 includes an extensive analysis of the applied approach in the case study. Three major characteristics of the approach are derived and seven propositions are formulated for realizing radical innovations in civil engineering projects. The paper concludes by

identifying its contributions to literature, its policy implications, its research limitations and by highlighting the overall conclusions.

4.2. Background literature

In subsection 2.1 we first provide a general definition of innovation in the context of civil engineering projects. This is followed by subsection 2.2 with a more detailed characterization of radical innovation in civil engineering projects. Next, we discuss in subsection 2.3 the literature on Public Procurement of Innovation (PPI) and in subsection 2.4 the literature on procurement procedures that foster innovation in civil engineering projects. This is followed by a review of recent literature in subsection 2.5 about Government championship. In the last subsection we review strategies to manage innovation risk in general and more in particular in civil engineering projects.

A definition of innovation

Innovation in civil engineering projects can be defined as the development and successful implementation, of new ideas, products or processes in the design and realization of new civil engineering objects (Lenderink et al., 2020). Innovations in civil engineering projects can be classified according to their degree of innovation. In the literature (e.g. Slaughter (1998); Garcia and Calantone (2002); Lenderink et al. (2020)) the degree of innovation has been placed on a continuum based on the *level of change*: from incremental innovations (i.e. a small change) to fully radical innovations (i.e. completely new to the world, involving totally new technology). Besides the magnitude of change from the current state-of-the-art associated with the innovation, innovations can also be classified according to their *degree of complexity*, i.e. the expected linkages of an innovation to other components, modules and the system as a whole (Henderson and Clark, 1990; Lenderink et al., 2020; Magnusson et al., 2011; Slaughter, 1998).

A characterization of radical innovation in civil engineering projects

Researchers have used different definitions of radical innovations but seem to agree that opposed to incremental innovations, in radical innovations unprecedented improvements or performance features are achieved, representing major changes in technology that involve the discovery of new knowledge, radical technical risk, time, and costs (Cardinal, 2001; Keizer and Halman, 2009; Leifer et al., 2001; Majchrzak et al., 2004; Roussel et al., 1991). Variations on the theme often relate to the wish to highlight specific major changes, for example: newness to the market including

customers and trade, technological newness including materials and functions (Keizer and Halman, 2009).

With respect to civil engineering projects, Slaughter (1998) explains that different types of innovation require different activities and resources for their implementation in specific projects. First, where incremental innovations can be implemented at any time in a project, it is more advantageous to commit to the implementation of a radical innovation early in a project. Second, the need for coordination and supervision within a project increases when linkages between the innovation and other parts of the system increase. Third, radical innovations are more likely to require special equipment or expertise that needs to be provided by external specialized organizations or to be developed in-house.

In the context of construction and civil engineering we define radical innovations as: the development and realization of products and/or processes that either include one or more key technologies that are new to the field of the construction industry and create substantial value to the clients. This means that in the case of radical innovations a significant gap between required and acquired technological knowledge and skills needs to be bridged during the development and realization of the innovation project. This means that these types of projects inherently have a low technology readiness level (TRL) in their early phase of development. The concept of TRLs has been developed during the 1970's by NASA for estimating the maturity of a technology (Sadin et al., 1989). Since then, the TRL system has been further developed and has been put into use by many authorities. The European Commission has adopted the TRL system to stimulate specific phases of technology development. TRL as established by the European Commission has adopted the TRL system to stimulate specific phases of technology development. The TRL system as established by the European Commission distinguishes nine levels and four phases. The first three levels (TRL 1, 2, 3) belong to 'discovery', followed by TRL 4, 5 and 6 of the 'development' phase. TRL 7 and TRL 8 belong to the 'demonstration' phase, with TRL 9 'deployment' as the final development phase (EARTO, 2014). Typically, the development and realization of radical innovation projects have a Technology Readiness Level between TRL4 – TRL7.

Public Procurement of Innovation (PPI)

To tackle the grand challenges being faced by societies all over the globe, Public Procurement of Innovation (PPI) is increasingly seen as an essential element of innovation policy (Edquist et al., 2015; Edquist and Zabala-Iturriagagoitia, 2012; OECD, 2011). Edquist et al. (2015) explain in the Introduction of their book on Public

Procurement of Innovation, that traditionally, innovation policy initiatives have mostly come from the supply side. Countries and regions have actively implemented and used innovation policy instruments such as fiscal measures and public financing of research and development (R&D). Demand side policy procurement interventions are intended to increase the demand for innovations, to improve the conditions for the uptake of innovations and to improve the articulation of demand (Edler and Georghiou, 2007). Public Procurement of Innovation (PPI) occurs when a public organization places an order for the fulfillment of certain functions (that are not met at the moment of order or call) within a reasonable period of time through a new or improved product (Edquist et al., 2015). The objective of PPI is not only to enhance the development of new products, but also to target functions that satisfy human needs, solve societal problems or support agency missions or needs (Edquist et al., 2015; Edquist and Zabala-Iturriagagoitia, 2012).

The effectiveness of PPI is influenced by the way procurement is undertaken. Besides the potential benefits, much of the debate has centered in the last decades on the potential barriers to innovation in public procurement (Uyarra et al., 2014). Typical barriers and constraints to innovation include lack of interaction between procurers and suppliers, lack of advance communication about potential needs, risk aversion in the granting contracts, costly and over-bureaucratic tendering procedures, and rigid specifications among others (Edler et al., 2015). Edler et al. (2015) further observe indications that the incentive structures, capabilities and priorities in public organizations are not very conducive to risk taking.

Public procurement procedures that foster innovation in civil engineering projects

Eriksson (2008) cites Rahman and Kumaraswamy (2002) who have characterized the construction industry as a very high-risk, complex, and multiparty business, in which the transactions involve many complex processes. Projects often last for many years and the product design is often changed during the time because of changes in the client's preferences (Kadefors, 2004). Hence, as Eriksson (2008) argues, construction transactions are mostly characterized by high complexity and customization, long duration, and high uncertainty. Such transactions should therefore be governed within relationships that have a high emphasis on cooperation and a lower emphasis on competition, i.e. cooperation-based coopetition. Unfortunately, the study conducted by Eriksson (2008) shows that in the construction industry, clients' procurement procedures facilitate a focus on competition and not on cooperation. In view of the need of a cooperation focused procurement procedure in construction, Pesämaa et al. (2009) have proposed and validated an alternative procurement model, that facilitates cooperation between clients and contractors. The model is

based on four multi-item constructs – incentive-based compensation, limited bidding options, partner selection and cooperation. Risks are allocated to project actors through the contractual arrangements. As explained by Osipova and Eriksson (2011), the main purpose of incentives, is to facilitate collaboration in problem solving, and reward the actors on the basis of their performance. Incentives motivate actors to focus on joint objectives and significantly reduce disputes. Limited bidding invitation is a crucial part of a cooperative procurement procedure (Love et al., 1998). In such situations, the client only invites contractors that are perceived trustworthy and competent enough to perform to expectations and to contribute to the design work (Pesämaa et al., 2009).

The whole idea of partner selection on the basis of a limited bid invitation and incentive based compensation is to find and motivate suitable partners that can contribute to a better construction solution (Pesämaa et al., 2009). This is especially important in the case when specific unique knowledge is required to develop and implement a required radical innovation.

With respect to realizing innovation in construction projects, Eriksson and Westerberg (2011) have developed propositions in which they state the need for a high level of integration between clients and contractors; a high focus on soft parameters in the bid evaluation; a joint involvement in subcontractor selection and integration; an incentive based payment on innovation performance criteria and; the usage of collaborative tools such as the usage of joint IT-tools, joint risk management (JRM) and a joint project office. Unfortunately these propositions have not been validated yet in practice. In a more recent study Eriksson et al. (2019) observe that the early involvement of contractors may not be sufficient to facilitate radical innovations. The authors also indicate the importance of client priorities towards innovation.

Government championship

Today, countries around the world are seeking smart innovation-led growth, and hoping that this growth is also more "inclusive" and "sustainable" than it used to be in the past (Mazzucato, 2015). Such a feat, explains Mazzucato in her paper "Building the entrepreneurial state", requires rethinking of the role of government and public policy in the economy. This needs a new justification of government intervention that goes beyond the usual one of "fixing market failures". It also requires the shaping and creating of markets and attention to the ensuing distribution of "risks and rewards". This implies a constructive attitude in forming types of public-private interactions that can create new innovations.

This means that public organizations should be restructured so they also accommodate a risk-taking and explorative capacity, and the capabilities needed to envision and manage contemporary challenges. What we need, is an entrepreneurial government, a government that not only supports technology innovation, but also shows championship in actively approaching the innovation challenges of the future.

Government support is a popular instrument to foster technology innovation. It can take various forms such as financial aid, tax credits and technological assistance. There are many studies on the effectiveness and impacts of government support, mostly on the program-level or industry-level (Yue, 2017). However, with the intention to encourage technology development, governments can also play a more direct, championship role. Championship is defined as "expressing confidence in the innovation, involving and motivating other to support the innovation, and persisting under adversity" (Caerteling et al., 2013; Howell and Sheab, 2001; Yue, 2017). Morris and Hough (1987) analysed eight major technology projects, and found that in addition to roles such as owner, buyer and regulator, government could also act as the "champion" in an innovation process. Moon and Bretschneider (1997) discovered a positive association between innovation development and the active involvement of New York State Government. Similar type of positive findings of government championship on technology innovation performance are reported by Caerteling et al. (2013) and Yue (2017). However, with respect to government championship there are still many questions to be answered (Yue, 2017), such as: How and to what extent can government support the development and realization of technology innovations? How should government interact with the other participants in a technology innovation project? And what type of approaches are more effective in different stages and situations of technology innovation?

Managing innovation risks in civil engineering projects

Risk is defined in many ways which have changed only a little over the last decade. For example, risk is referred to as the probability of an effect (ISO 31000, 2009), as an uncertainty of outcome (UK Cabinet Office, 2002), as an event having a negative impact or outcome (Wang et al., 2010). As the magnitude of change and the complexity of developing an innovation increase, so does the uncertainty over the future performance of the system and the need to actively manage the development process and the risks associated with this innovation (Magnusson et al., 2011). Edler et al. (2015) cite Keizer and Halman (2007) who have mapped the risks involved in radical innovation projects according to three dimensions: the degree of uncertainty, the degree of controllability and the relative importance (in other words benefits).

When it comes to the management of project risks, there are in principle four possible risk management directions that can be taken: to accept, to reduce, to transfer or to reject the risk (Actuarial Profession and Institution of Civil Engineers, 2005; Gehner, 2008; Halman, 1994). Depending on the direction selected, various risk solution strategies can be taken (Halman (1994, 2008); Keizer et al. (2002)). See also Fig. 1:

- In case of *risk acceptance*, it will be necessary to monitor the diagnosed risk carefully and take precautionary actions through a contingency plan and/or incorporate sufficient slack (time and funds) to address the effects.
- In case of *risk reduction*, possibilities are to select a different solution by choosing a more reliable, already existing, solution or by altering the demands and specifications. Another option is to include more time and funds for research and testing; or incorporate quit options; or opt for a different team composition by, for example, including external experts.
- In case of *risk transfer,* the possibilities are to entirely outsource that part which is difficult to solve to an organization with significant knowledge, skills and experience in the specific area. Similarly, one could develop an alliance and allocate responsibility for developing a satisfactory solution to the alliance partner who can manage the specific innovation risk.
- In case of *risk rejection*, it is important to consider whether rejection will lead to a complete stop to project execution or whether it is still possible to adapt the project scope. When adaption is possible, the options for redefining or restructuring the project should be considered.

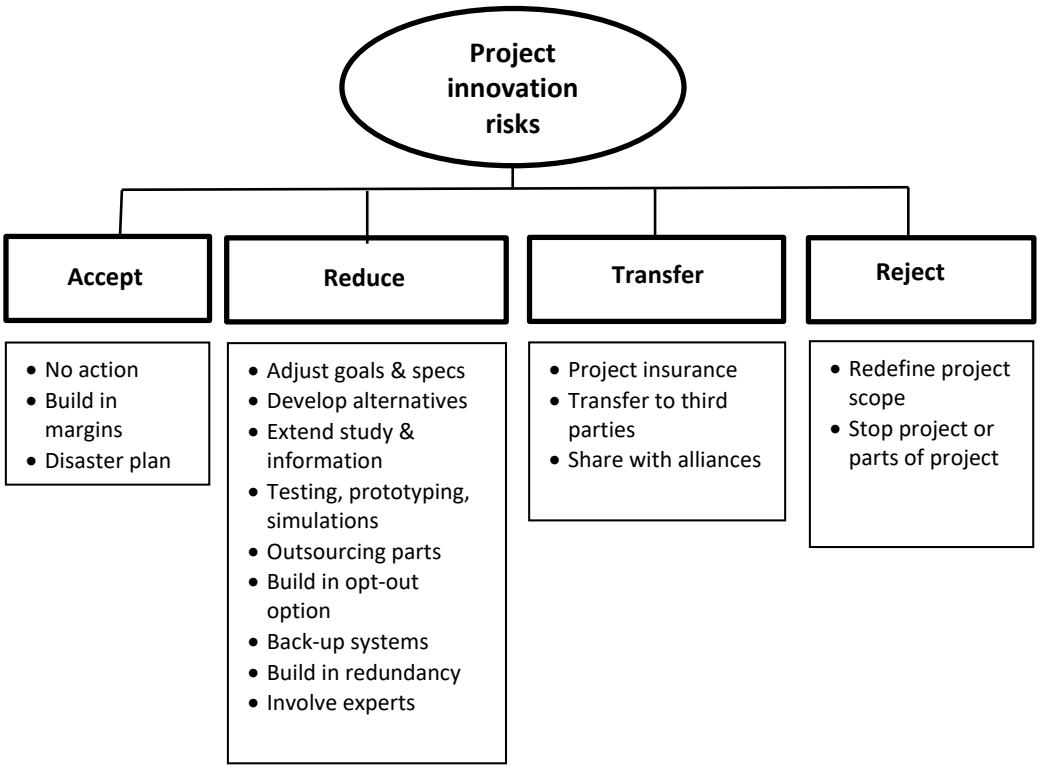

Figure 1: Options to accept, reduce, transfer or reject project innovation risks (adapted from Halman (1994, 2008).

There are numerous innovation management studies indicating that radical innovations are highly risky. This explains the reluctance of many civil engineering contractors but also public clients to engage in radical innovation projects. The procurement form determines to a great extent if a project provides sufficient incentives for a construction firm to undertake the innovation efforts (Hartmann, 2006). For example, when a procurement system focusses highly on price and/or time, it will not facilitate innovation (Kumaraswamy and Dulaimi, 2001). Functional specification instead of prescribing what a contractor has to do and Performance-based procurement are described as enablers for innovative behaviour (Rose and Manley, 2012). Also early contractor development has been demonstrated as a stimulant to innovate (Hartmann, 2006). And a study by Blayse and Manley (2004) shows that the presence of a well-integrated team not only improves communication and learning but also innovation outcomes. A very important factor to enable innovation is the mutual agreement between public client and contractor about the way how innovation risks will be allocated (Hartmann, 2006). Especially in the case of radical innovations, public clients are required to act more flexible with respect to

their expectations and acceptance of risks (Rose and Manley, 2014). Different studies have also shown the importance of government championship with respect to the management of innovation risk in the development and realization process of construction and civil engineering projects (Caerteling et al., 2013; Gattiker and Carter, 2010; Sergeeva and Winch, 2020; Yue, 2017).

4.3. Research methodology

An in-depth single-case study design was used to investigate the development and application of bio-based composite materials in the deck of a new to be build movable bridge project. Unlike the usual use of components with a high readiness level in the procurement of civil engineering projects, the readiness level of the bio-based composite materials was still in an early phase of development: the technology readiness had been validated as a prototype, but not demonstrated yet within a civil engineering project. As such, the movable bio-based cycle bridge can be characterized as a 'world first' innovation project.

Single case studies are particularly suitable, when the case is unusually revelatory, or when it is extremely exemplar, or when it offers opportunities for unusual research access (Eisenhardt and Graebner, 2007; Yin, 2013) as cited in (Mariotto et al., 2014). This case was specifcally selected because of its unique characteristics which would allow the generation of insights about the procurement of innovative projects with still a relatively low technology readiness level (Numagami, 1998; Siggelkow, 2007).

Data collection

Different sources of evidence were used to complement each other and to ensure the validity of the study (Yin, 2013). The research started with an extensive document study of policy documents issued by the relevant provincial authorities, tender documents for the movable bridge project and the website of the case study project: D.R.I.V.E (2019). This helped to develop an overview of the approach that was developed and applied by the public client in the project and to prepare for discussions with key informants. The document study was followed by three interviews with staff of the public client (Friesland, a province in the Netherlands), three interviews with staff of the engineering company supporting the public client, three interviews with the main contractor's staff, one interview with the producer of the bridge deck, and two interviews with other tenderers (see Table 1). All the interviewees held important managerial positions, possessed deep knowledge about the project organization, and were also directly involved in the project. An interview protocol was created for the interviews. A semi-structured approach was adopted to

enable follow-up questions and include aspects that were considered relevant during each interview. Each interview lasted between 50 and 70 min. All the interviews were recorded and transcribed. The transcripts were sent to the respondents to verify the content. None of the transcriptions had to be modified.

The interviewees also provided documents that enabled us to refine the description of the characteristics of the innovation project, the procurement approach that was followed including the use of contractual arrangements with respect to the goal of the project. The interviews also provided valuable information with respect to the role of the project client in the project, the use of risk management strategies in the development and implementation of the project's innovation as well as the collaboration process between all parties in the project.

Table 1: Overview of interviews

Organization	**Role of interviewee in project** (number of interviews)
Province of Friesland	Project leader (2) Programme manager/internal client (1)
Engineering company supporting client	Contract advisor (1) Project manager/advisor (1) Project coordinator (1)
Contractor	Tender/project manager (2) Local tender manager (1)
Producer bridge deck	Director/project manager (1)
Other tenderers	Tender manager contractor (1) Director contractor and composite materials (1)
Total number of interviews	12

The interviews with the public client focussed on the goals and context of the selected project, as well as the used project and procurement approach to developing and implementing the intended innovation as part of the project. In addition, specific questions were asked with respect to the management of innovation risks. The interviews with the representatives of the engineering company supporting the client went more in-depth into why certain decisions were made in the tender procedures, the use of contracts and the collaborative development process. The interviews with the contractor, the producer of the bridge deck and the other tenderers focussed on their incentives to participate in the project and the value as well as their view on the benefits and limitations of the selected approach for developing and implementing the intended innovation.

Data analysis

A content analysis of the interview reports, the project documents and relevant information that was found on the website, was undertaken using ATLAS. ti. 6.2. In

line with the procedure for content analysis recommended by Boeije (2010), every document was 'open coded'. In the next step, 'axial coding', was employed to reorganize and reassemble the codes identified in the first step. The output of the 'axial coding' step consists of identifying themes and concepts and is considered as an essential intermediary step towards 'theoretical coding'. In this last step of theoretical coding, relationships between data fragments that explain the nature of realizing radical innovations in civil engineering projects were identified. This last step was guided by deductively drawing on theory as discussed in Section 2. Identifying the first-order open codes, the themes and concepts and, subsequently, the research propositions was supported by a data structure that consisted of various research notes and matrices as suggested by Miles and Huberman (1994).

The data analysis helped to explain how and why a radical innovation, i.e. a movable bridge made of bio-based composite materials, was successfully developed and realized. Based on this analysis, seven propositions were derived concerning the development and implementation of radical innovations in civil engineering projects.

Validation workshop

To validate our research findings and analysis, a workshop was organized which was attended by the persons who were earlier involved as interviewees. This session allowed the participants to clarify their views and opinions and to discuss them with all the participants. Group discussions are inherently prone to bias such as group think. This was anticipated and guarded against in two ways. The first was to establish a clear focus on validating previous findings whereby the attendees were explicitly asked to add context to the identified factors and developed propositions. Second, the group discussions were moderated by an experienced facilitator who was not involved in the interview and coding steps of the research. The discussion session had a duration of approximately 90 min. All the interviewees that were invited participated. The session was recorded for later transcription. The discussion session provided support for the derived propositions. In addition, the discussion session also provided more insight about the way how all members of the tender team members experienced their own and also their joint contribution to act as an integral complementary team.

4.4. Case study: the Ritsumasyl bicycle bridge project

Project context and challenges

The Ritsumasyl bicycle bridge project was initiated by the Province of Friesland in the Netherlands. The province has strong ambitions with respect to circularity and

knowledge development in the region and has formulated as one of its policy goals to be among the Top 3 of circular development regions in Europe.

Being aware of the policy ambitions of the province, the internal client opted to use bio-based materials in the Ritsumasyl bicycle bridge project. Worldwide, such types of bio-based circular bridges have never been built before. This project therefore seemed to fit well with the ambition to experiment with the use of new sustainable materials. Compared to bridges intended for cars, trucks or trains, bicycle bridges require less load bearing capacities and the impact on society if a bridge needs to be closed for maintenance or repairs is also smaller.

At the start of the project, the public client determined five project goals which were published in the tender documents:

1. To replace the existing bridge across the canal in the village of Ritsumasyl with a movable bicycle bridge, and widen the canal below the bridge to 17 m to facilitate the passage of Class Va ships through the canal.
2. To use bio-based composite materials in the bridge wherever possible and to use 100% bio-based composite materials in the movable bridge deck.
3. To develop the bridge in a collaborative process with the contractor, the developer/producer of the bridge deck and educational organizations to: a) generate and disseminate knowledge on the sustainable application of bio-based composite materials in civil engineering, and b) improve collaboration in the supply chain.
4. To realize the bicycle bridge within the maximum budget allocated to the project.
5. To have political and societal support for the project at the start of the realization process of the bicycle bridge.

Challenges and innovation risks - At the start of the project there were three foreseeable challenges and risks related to the development and implementation of the innovative bridge deck in the project. First, there was limited knowledge on the properties of bio-based materials for bridges and potential changes in these properties due to aging, movements of the bridge and external influences over time. As such, it was uncertain if the bio-based composite bridge deck would meet the predefined design requirements. Second, the bridge deck needed to be co-developed and implemented in a movable bridge design that would allow larger ships to pass through the canal. This increases the complexity of the bridge system, the interdependencies between components, and the design requirements for the bridge

deck. Third, a market analysis conducted by the Province showed that there were only a few potential suppliers who possessed the knowledge and expertise to develop a bio-based composite bridge deck. The fear was that this could limit competition in the tender phase. Contrary to what is usual in integrated projects and in design-bid-build projects, the public client deliberately decided to bear the uncertainties and risks related to the development and implementation of the innovative bridge deck. This enabled the commitment to the project from all stakeholders. By doing this, the public client manifested itself as a government champion (cfm. Gattiker and Carter, 2010) for the Ritsumasyl bridge cycle project.

Project overview and approach - The project was split into four phases: the pre-tender phase, the tender phase, the design and development phase and the realization phase. This section now describes the successive phases of the Ritsumasyl bicycle bridge project. An overview of the topics discussed in each of these phases is indicated in Fig. 2.

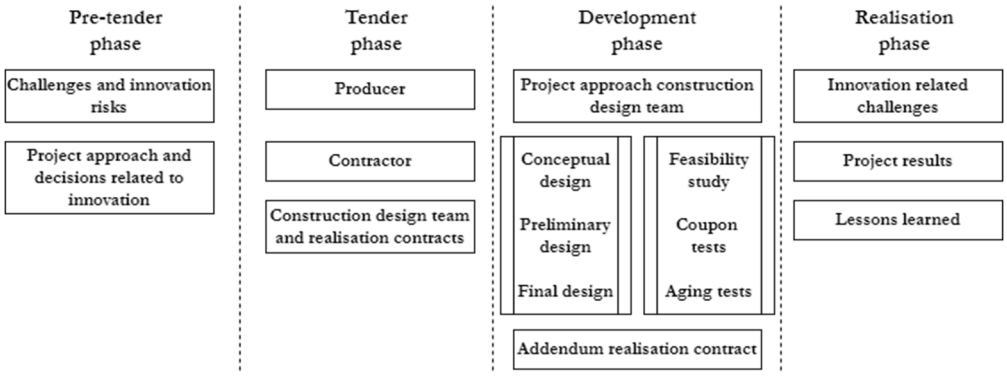

Figure 2: Project overview and structure for describing the application of the client-led innovation approach

Pre-tender phase

During the *pre-tender phase,* the approach to be used for the Ritsumasyl bicycle bridge project was developed by the public client with the aid of two engineering companies. Both engineering companies were already contracted as consultants in a larger Province program. The Ritsumasyl bicycle bridge project formed an iconic conclusion to the Province program. This phase included several important decisions related to the development and implementation of the innovation in the project.

The public client decided to separately tender for a developer/producer of the composite bridge deck and for a contractor for the bridge. Moreover, the public client

also decided to contractually split the tender into two successive phases as illustrated in Fig. 3. The first phase focussed on the development of the bio-based bridge deck and the design of the movable bridge, and the second phase focussed on the realization of the bridge. To achieve this, the decision was taken to use a two-staged open book tendering approach, which is similar to the two-stage open book tendering model used in the UK (Mosey, 2014).

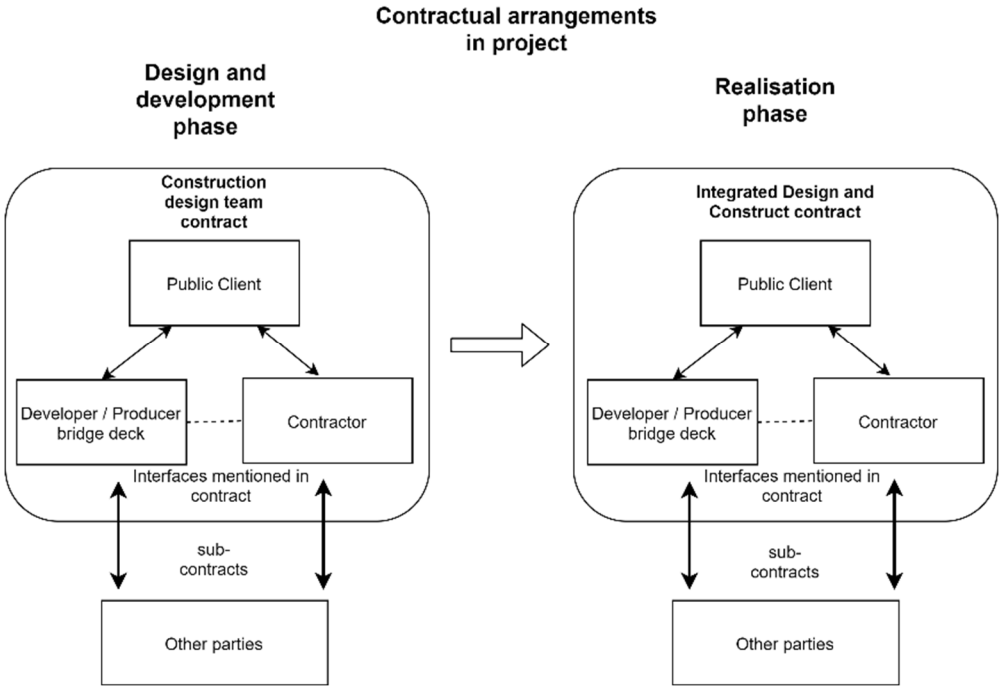

Figure 3: Contractual arrangements for the Ritsumasyl bicycle bridge project

An important reason for this contractual split was the fact that it was uncertain if a movable bridge with a bio-based composite bridge deck would meet the requirements for a bicycle bridge as part of the public road network and would continue to perform well over time. As such, the public client saw it as unreasonable to transfer these risks to a main contractor before a full design of the bridge had been developed and the innovative bridge deck tested.

By separating the project into two successive phases, the public client also created an opt-out possibility. This provided the public client with the opportunity to fall back on a traditional solution if a developed composite bridge deck would not perform as well as expected and/or could not meet the predefined design requirements.

The public client expected the use of separate contracts to increase competition since contractors would be able to submit an offer without having to subcontract one of the

few potential producers of bio-based composite bridge decks. Moreover, the use of separate contracts would improve the contractual position and the central role of the developer/producer of the bio-based composite bridge deck in the project compared to being subcontracted by the main contractor. Another advantage of the separate tenders was that it gave the public client the opportunity to have different tender criteria for the producer of the biobased composite bridge deck and the contractor of the bridge as a whole. However, this decision also created risks for the co-development of the bridge deck and the design of the movable bridge: the contractor of the bridge and the developer/producer of the bridge deck might be unfamiliar with one another, or worse, have bad experiences with working together.

The public client further decided to use a construction design team approach in the design and development phase of the project. In this phase, the public client, the contractor and the developer/producer were expected to closely collaborate on the development and the testing of the bridge deck in parallel with developing the design of the movable bridge. The details for the collaboration and the specific division of responsibilities between the public client, the contractor and the developer/producer of the bio-based composite bridge deck construction design team would be detailed in a construction design team contract that was signed by all parties.

For the realization phase of the project, the public client decided to use an integrated design and construct contract. This seemed realistic since it was expected that most of the uncertainties with respect to the properties of the materials, the dependencies between the components of the bridge and the ability to meet the design requirements would have been significantly reduced during the earlier design and development phase of the project.

Tender phase

A European open tender procedure (Directive 2014/24/EU, 2014) was used to select the developer/producer of the composite bridge deck, and a European restricted tender procedure with pre-selection (Directive 2014/24/EU, 2014) to select the contractor of the bridge. An overview of both tendering procedures with their respective eligibility requirements, pre-selection criteria and award criteria is presented in Fig. 4.

Developer/producer for the composite bridge deck - Since only a few potential developers/producers were known for the composite bridge deck, a European open procurement procedure was used in combination with a plenary information session to attract and inform potential producers. To ensure that the potential producers would have the required knowledge and capabilities, tenderers were required to

demonstrate their past experience with respect to the design as well as the production of composite bridge decks. The award of the contract was based on the quality of the action plans submitted by each of the tenderers. The public client evaluated each of the submitted plans against the following three criteria:

1. Knowledge and expertise on bio-based composite materials (max. 70 pt)
2. Experience and vision on collaboration in the construction design team (max. 30 pt)
3. Tariff rates for different employee categories (max. 20 pt)

The assignment was awarded to the tenderer who obtained the highest overall score. The plan of action in the winning tender offer was later included as an attachment to the contract of the construction design team. As such, it became an integral part of the contract.

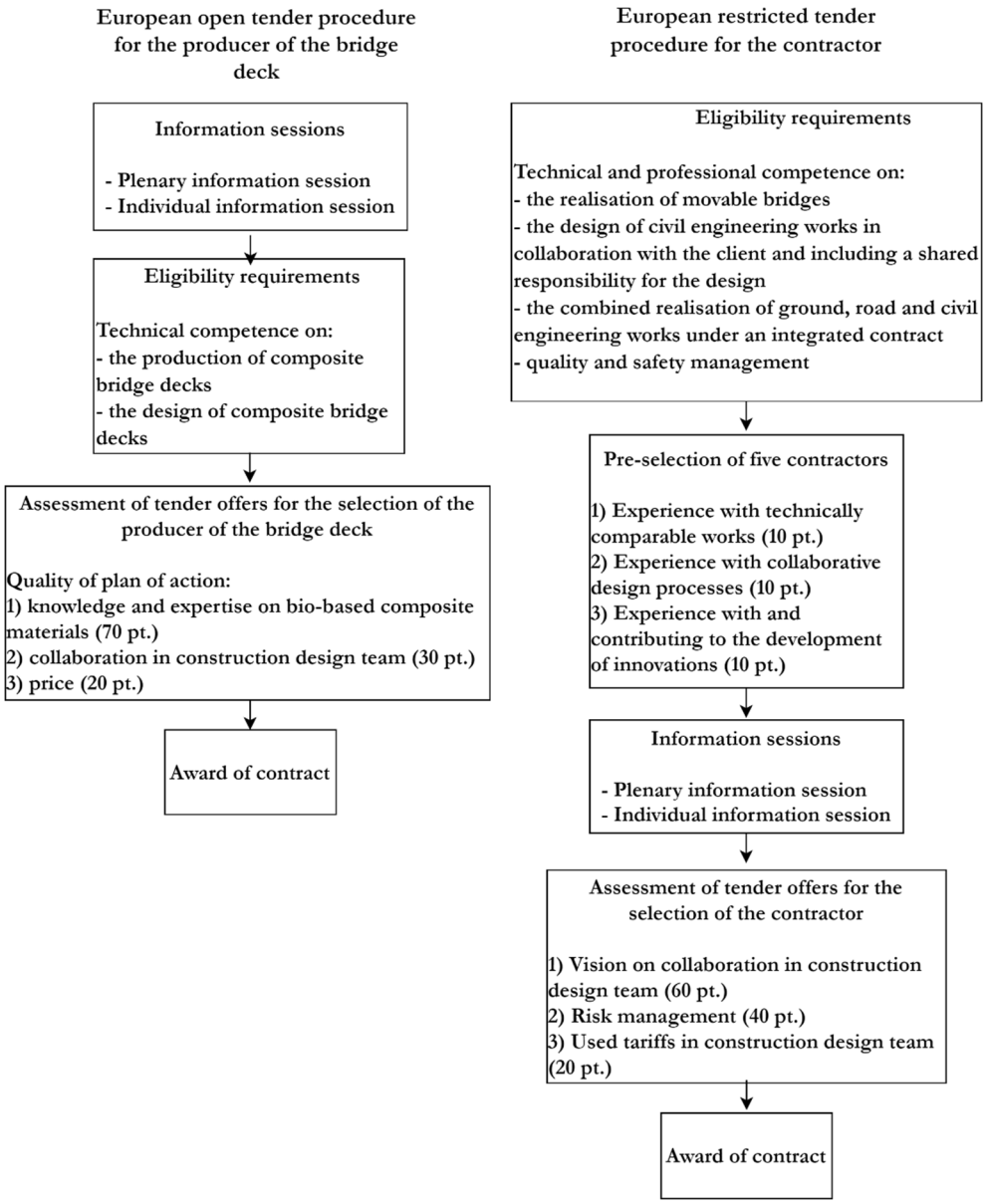

Figure 4: Tender procedures applied in the composite movable bicycle bridge project

Contractor for the movable bicycle bridge project - To find a suitable contractor for the co-development of the bridge deck and the movable bridge, the public client heavily focused on the contractor's experience with realizing movable bridges, designing civil engineering works in collaboration with a public client, and realizing ground, road and civil engineering works together in a single integrated contract. Five

contractors were pre-selected based on their experience with: (a) the realization of movable bridges including composite materials, (b) collaborative design processes, and (c) contributing to the development of innovations. In addition to the opportunity to submit questions on paper before the pre-selection process, the pre-selected contractors were invited to attend a plenary information session and an individual information session about the project before submitting their tender offer. Similar to the selection of the developer/producer of the composite bridge deck, the award of the contract was based on the quality of the proposed plan of action. The submitted plans were evaluated against three award criteria, again with different weights for each criterion:

1. The vision on collaboration in the construction design team (max. 60 pt)
2. Identification and management of risks (40 pt)
    a. In the design and development phase.
    b. In the realization phase.
    c. In the coordination between the contractor and the developer/ producer of the composite bridge deck.
3. Tariff rates for different employee categories (max. 20 pt)

The public client considered the abilities of the contractor to collaborate in a construction design team and to identify and manage the innovation and organization risks in the project as essential elements for a successful collaborative development and implementation of the biobased composite bridge deck in a movable bridge design.

The tariff statements were included in the tender to allow a limited competition based on price. Moreover, their inclusion allowed the public client to include what it considered to be a reasonable minimum and maximum hourly rate per function category, and to communicate their expectations regarding the required time investment by the contractor in the design and development phase.

Design and development phase

The design and development phase was split in two sub-phases. A simplified overview of the staged development procedure with multiple go/no-go moments is represented in Fig. 5. The first sub-phase included all activities up to and including the conceptual design. The goal of this sub-phase was to determine if the requirements stated in the tender specifications were feasible. The second sub-phase focussed on the further development of the design and the bridge deck, which was necessary to obtain an environmental permit for the realization of the bridge.

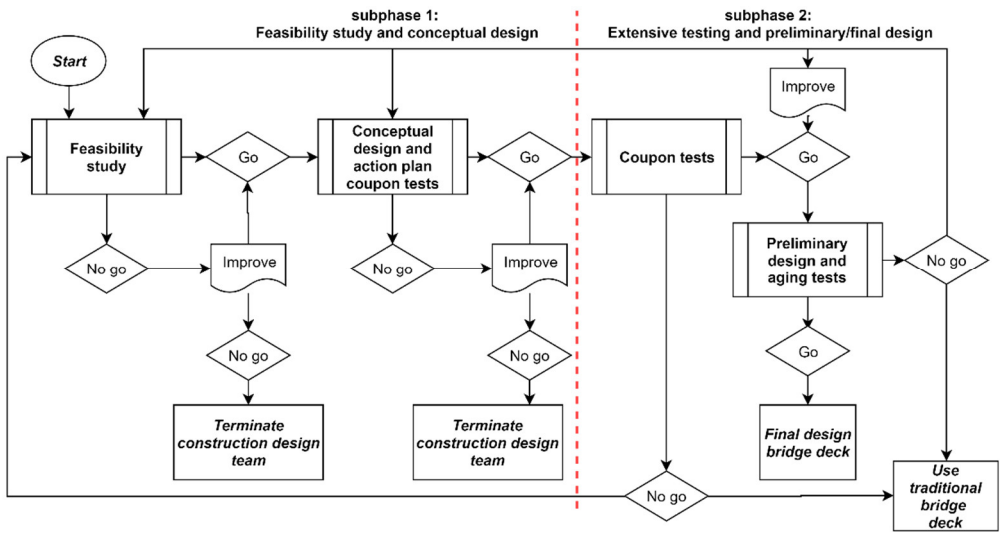

Figure 5: Staged development procedure for the composite movable bicycle bridge project

Roles and responsibilities - The public client, the contractor and the developer/producer of the bridge deck each had their own role within the construction design team. The public client had a leading role in the construction design team regarding: a) the coordination of activities, b) the assessment of plans, budgets and offers, c) specifying the requirements, and d) taking those decisions necessary for the progress of the project. The main contractor had a leading role on the design, realization and costs of movable bridges in order to develop the bridge design, budget and realization plan. Finally, the developer/producer of the bridge deck had a leading role on the design and realization of bio-based composite materials and cost assessments in order to develop the bridge design, budget and realization plan.

Further, each of the construction design team members were held responsible for their own design activities and any advice they provided in their field of expertise. However, financially, the liabilities of the main contractor and the developer/producer of the bridge deck were limited to a maximum of EUR 1 million per occurrence and EUR 2 million per year for any damage or loss that was not deliberately caused or the result of serious negligence. As such, the client limited the risks of the contractor and the developer/producer of the bridge deck and accepted these as its own risks. At the same time, the client had a major influence on all large decisions in the project. The team spirit in the project team may be characterized as highly motivated and with a strong drive to succeed. As one of the construction design team members stated:

"We all had a strong drive and the feeling that we were working on something special".

Development and testing of the bridge deck - One of the goals of the project was to use bio-based composite materials in the bridge wherever possible, and for the movable bridge deck to use 100% bio-based composite materials. To meet this goal, a desk study was carried out to determine which materials and production processes would be the most suitable for the bridge deck. Based on the desk study, vacuum injection tests were performed on five types of fibre and six types of resin to determine the suitability of the materials for the production process. Subsequently, in the second phase of the development process, a range of coupon tests were performed on different combinations of the selected materials to determine their mechanical properties, their behaviour in hot and wet conditions and their resistance to UV. Following these tests, expansion, creep and fatigue tests were performed on a full-scale model of the bridge deck to determine the life expectancy of the bridge.

Collaboration with knowledge institutions was an important part of the approach to the development, testing and realization of the innovative bicycle bridge. The decision to include the knowledge institutions in the project was from a perspective of knowledge dissemination a deliberate choice of the province. As one of the stakeholders of the province stated:

"This enables the translation of the developed knowledge into teaching material that is taught at the universities of applied sciences. This is also in line with the objectives of the province to become the preferred region for knowledge development in the Netherlands".

To realize this ambition, the province of Friesland closed contracts with four knowledge institutions. The constructive and aging properties of steel and concrete are well known. However, these properties were not yet known for biocomposites. That is why the TH Stenden and Windesheim (Zwolle) Universities of Applied Sciences have performed thousands of load tests with 36 different types of biocomposites. These laboratory tests made it possible to map out mechanical properties such as stiffness and strength. In addition, a required service life of at least 50 years had to be demonstrated. To this end, the Hochschule Osnabrück conducted the necessary tensile tests, compression tests, bending tests and fatigue tests. Further, the Technical University of Delft simulated the opening, turning and closing of the bridge 1 million times, using a 1:3 scale model of the bridge. This was necessary because the bridge is required to remain in operation for at least 50 years. When turning away, the movable segment rests on one concrete pillar. The simulation tests had to ensure that no significant deformation, creep or fatigue will occur during the

intended service life. Furthermore, the scale model was equipped with an elaborate bridge monitoring system to obtain data on the material properties and any changes over time. Finally, the contractor was also supported by several specialist engineering companies in the development of the bridge design.

Development of the design - In the design phase, a wide range of bridge design alternatives were compared by the construction design team based on criteria related to integrating costs, the environmental impact, percentage of bio-based materials used, maintenance and operation. This was possible because the design guidelines and requirements for the bridge that were included in the tender documents allowed for different design alternatives. The design alternatives explored included:

a) Bascule bridge with and without a counterweight;
b) Traditional drawbridge with a counterweight;
c) Lift bridge; and
d) Swing bridge.

Of these design alternatives, the bascule bridge design with a counterweight and the swing bridge design looked the most promising. Subsequently, both design variants were openly explored and discussed, based on the guidelines and requirements, within the construction design team as well as with stakeholders of the project. This open discussion led to a small modification to the design guidelines and the requirements of the stakeholders. These modifications made it possible to develop an asymmetrical swing bridge design. This swing bridge design enabled a longer movable bridge deck than possible with the bascule bridge design. Moreover, the longer bridge deck in combination with an asymmetrical design allowed one of the ship guiding works to be replaced by a quay wall, leading to significant cost reductions (D.R.I.V.E, 2019). In addition, further cost reductions could be obtained by integrating the other ship guiding works with one of the supporting points for the bridge deck.

Realization phase

The design and realization of the bridge took longer than initially expected. The project delivery was planned for May 2019 but was delayed with the actual delivery of the bridge occurring half a year later on 18 December 2019. The project was initially extended to October 2019 because of some setbacks in the engineering phase. After this, a second extension was necessary to solve problems with sensors in the bridge monitoring system which had been included to obtain more knowledge on the behaviour of bio-based composite materials in bridges (Atsma, 2019).

The results of the creep tests on the scale model of the bridge deck had important implications for the design of the bridge (Beerda, 2019). It appeared that the flexible bio-based composite material for the bridge deck could, with the bridge open, sag significantly over time under its own weight. This required modifications to the bridge's moving mechanism to lift the bridge deck to match the height of the road when closed. Furthermore, the bridge deck contracts more than steel in the winter and expands less in summer, due to its thermal expansion characteristics (D.R.I.V.E, 2019).

Results of the project

Given the flexibility in the design process and the positive test results obtained for the bio-based materials in the bridge deck, the original project goal of developing a movable bicycle bridge with a span of 17 m was exceeded by 5 m. In addition, several other fixed parts of the bridge deck were also made from the same bio-based composite material. It was not possible to develop a bridge deck of 100% bio-based composite materials since all resins considered in the project included synthetic materials. Based on the test results, the expected lifespan of the bridge is 50 years and the bridge is considered sufficiently safe to be part of the public road system.

In 2019 the biocomposite bicycle bridge project at Ritsumasyl was awarded the "National Circular Award Public". This annual prize goes to the most iconic circular project that shows what the circular economy can mean for the Netherlands. In the same year, the project also received the Dutch "Lighthouse Award". The jury was positively surprised and commented: "*It seldom happens that a newly developed material is directly applied in a fairly large infrastructure project*". All submissions were evaluated on their social relevance, market potential, sustainability, creativity and exemplary performance. Decisive was a demonstrable relationship with the themes 'climate (neutral)' and 'future proofing'.

Outcome of the validation workshop

During the discussion in the validation workshop that was organized to validate our research findings (see also section 3.3.) it became clear that the contractor convinced the other tender team partners that the client had formulated the assignment in such a way, that the risks for the providers were minimal. This with the aim that the team partners would focus on their joint challenge, without feeling the burden of bearing the risks and uncertainties inherent in developing radical innovations. During the validation workshop, all team members unanimously confirmed that the formulated tender assignment in combination with the selected team members, ensured that the team operated as an integral, complementary team. The common conclusion was that this has been key to the project success. The market parties reported that they did not

feel the burden of the risks, but felt a shared responsibility to achieve the 'maximum result' based on the ambition that was formulated by the public client. A stronger focus by the public client on allocating risks to specific parties, would have put pressure on the collaboration process and would not have led to the present result.

The Ritsumasyl tender compared to other public infrastructure tender projects

In the last few years, the Dutch Procurement Institute started to collect data about the type of public tenders in the field of infrastructure, building projects and infra-services. To compare the commonalities and differences between the Ritsumasyl tender and other tenders in the field of infrastructure projects, we used the available 2019–2020 data on public tenders for infrastructure works. In the period mentioned, a total of 1019 infrastructure works were put out to tender in the form of a European or a National public tender. About 2/3 of these public tenders were awarded based on a best price-quality (BPQ) ratio while in 1/3 of the tenders a lowest price selection criterion was used. Only 10 percent of all infrastructure projects were tendered as two-staged contracts. In the period 2019–2020 no single two-staged contract was tendered with the specific aim of product development. This makes the Ritsumasyl tender quite unique in its kind (see also Table 2).

Table 2a: Characteristics of European and National public tendered infrastructure project in the Netherlands (2019-2020)

Contract form	Total number of projects	Award	Quality/ price	Percentage projects	Award criteria	Responsibility
Regular contracts (design-bid-build, Integrated contracts etc.)	916	Best quality price ratio (BQPR)	Quality/price ratio or target budget (100% award on quality)	65	Price, Design, Plan of Action containing f.e. management of the surrounding area, Risk management, Changes, Communication, Limit disruption etc.	Bid by contractor becomes part of the contractual agreement between client and contractor. Control by client
		Lowest Price (LP)		35	Price	According to contract
Two staged contract	103	BQPR	Cost Based or fixed price Design phase, Target or Maximum budget execution (100% award on quality) or quality/price ratio	98	See BQPR criteria regular tenders design excluded, cooperation included (max. weight cooperation 40%)	Bid by contractor becomes part of the contractual agreement between client and contractor. Separated responsibilities (risk allocation) and liability during design phase. Control by client
		Lowest price		2	Price	According to contract

Table 2b: Characteristics of European and National public tendered infrastructure project in the Netherlands (2019-2020)

Contract form	Total number of projects	Award	Quality/ price	Percentage projects	Award criteria	Responsibility
Ritsumasyl	1	BQPR	Cost based Design phase, Target budget execution		Contractor: Cooperation (50%), Risk management (33%), Tariffs Design phase (17%) Producer/supplier biobased bridge deck: knowledge and competences (60%), cooperation (23%), and Tariffs (17%)	Bid contractor, Producer and cooperation approach by client merged and aligned into one document with shared responsibility. No risk allocation, client responsible for risk in the Design phase. Limited liability contractor/ producer

4.5. Analysis and interpretation of the applied approach

As explained in section 3.2, we identified, during the process of coding the interview transcripts, three main factors and seven underlying variables that together explain how public clients may successfully promote the development and implementation of radical innovations in civil engineering projects. Fig. 6 shows the conceptual model which is based on the three main factors identified in the case study analysis. Further, we were able to deduce seven propositions P1 – P7 that together provide instruments through which public clients can actively promote the development and implementation of radical innovations in civil engineering projects.

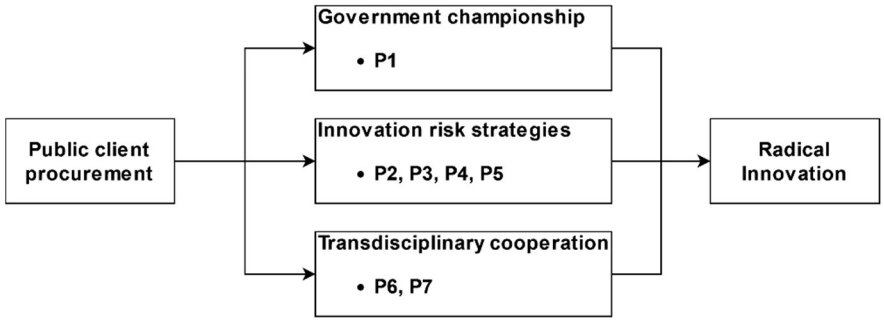

Figure 6: Conceptual model for the realization of radical innovations in civil engineering projects

The innovation approach that was followed in the Ritsumasyl bicycle bridge project can be characterized by:

a) A championing role performed by the public client
b) The use of risk management strategies to actively anticipate, reduce and manage the innovation risks
c) A strong focus on facilitating transdisciplinary cooperation

Government championship

The public client took on a championing role in sourcing the capabilities and coordinating the activities required for the development and testing of the radical innovation they desired, as well as in the integration of this innovation in the system. As such, the client actively participated in the innovation process together with the main contractor and the developer/producer of the innovation. As one of the stakeholders of the province stated:

"We want to be in the middle of it ourselves, because of the great interests it entails. And at the same time, we also had the idea that the risk profile was high, so if you already attract a lot of risk, why don't you actively participate? So we then said: well let's look for construction team partners, what do we need?"

The public client was also actively involved in important decisions concerning the design of the bridge, the development of the innovation, and had a final say as to whether the innovation would be implemented after its development.

Our findings on the critical role of the public client in realizing a radical innovation are supported by the studies of Yue (2017), Gattiker and Carter (2010), Kulatunga et al. (2011), Caerteling et al. (2008); and Caerteling et al. (2009). Kulatunga et al. (2011) found that public clients can, through championing, stimulate team dynamics and team action, which in turn can strengthen the innovation process that leads to an innovative product. Being a team player, promoting respect for people and

disseminating knowledge and information were identified as championing characteristics of public clients that successfully promote innovation in construction projects. The empirical findings of Caerteling et al. (2009); and Caerteling et al. (2013) emphasize the value of government's championing behaviour as an important contributing factor to technology success. As such, public client leadership is expected to positively affect the development and realization of radical innovations in civil engineering projects:

P1: Public clients that adopt a strong championing role increase the likelihood of developing and realizing radical innovations in civil engineering projects.

Innovation risk strategies

The public client took account of the capability of the contractor and the developer/producer of the innovation to bear the associated risks by limiting their liability to a maximum of EUR 1 million euro per occurrence and EUR 2 million per year. As the representative from the province commented:

"What really happened in this case, is that the Province of Friesland did something really special, since they did not only express their ambition, but they also put their wallet next to it to make that possible''.

The policy that was followed in the Ritsumasyl bicycle bridge project to limit the financial liability of the successful tenderer for the risks associated with the intended innovation had previously been applied elsewhere in at least nine major technology projects (Morris and Hough, 1987). Also Caerteling et al. (2008) concluded in their study that governments can create favourable market conditions by absorbing some of the financial risks. Together, these findings lead to our second proposition. In case of innovation projects characterized by a low technology readiness level:

P2: Limiting the financial risks of the contracted parties will reduce their risk aversion and increase the likelihood of developing and realizing radical innovations in civil engineering projects.

A risk management strategy adopted by the public client was to contractually split the development phase and the realization phase of the bridge project. This contractual split reduced the innovation risks for the project client, since it gave the possibility to fall back on a traditional bridge deck design in the project. This creation of a fall-back option as an effective innovation risk management strategy should the intended innovation prove impractical has also been reported in literature (e.g., Baldwin et al. (2006); Gassmann et al. (2010); Halman (1994, 2008) and leads to our next proposition:

P3: Having an existing solution as a fall-back option is a necessary requirement to reduce the risk aversion of public clients and contracted parties to realizing radical innovations in civil engineering projects.

Splitting the contract between development and realization provided an opportunity to investigate the feasibility of an innovative bio-based composite solution within a pre-agreed period. The agreement was made in this way so that if the development phase did not result in a satisfactorily performing bio-based composite solution, or that it would be difficult to adequately integrate the bio-based composite solution, the contractor and the developer were not bound to this solution. As such, it also reduced the associated risks for the contractor and the developer/producer of the innovation. Consequently, one may conclude that the contractual split between development and realization phases reduced the contractor's and the developer's risk-based aversion to engaging in this project tender (Taofeeq and Adeleke, 2019; Wilden et al., 2013).

P4: A contractual split between the development and the realization phase in civil engineering projects will reduce the risk aversion of tenderers to developing and implementing a radical innovation.

The public client decided to implement a staged development process with feedback loops for the development and testing of the innovation in parallel with the development of the bridge design. This risk management strategy provided a structure for coordinating the development process and supported the development of alternative design solutions based on the outcomes of the initial testing of the innovation. The development process also included explicit points for assessing the development and implementation of the innovation after each completed development stage. Based on these assessments, the innovation and/or the development and implementation process could be adjusted if necessary. Furthermore, they included the possibility to fully terminate the implementation of the innovation if it would become clear that the developed innovation would be unable to meet the predefined design requirements.

Turner (2005) had concluded that to deal with risks with a medium to high likelihood of occurrence, and a medium to high impact if they do, allowing a contingency may be the best option. The high uncertainty inherent in product development projects requires managers to develop proactive strategies to reduce risks (Amram and Kulatilaka, 1999; Courtney et al., 1997). The product development (PD) literature strongly supports generating multiple alternative solutions to development problems as an essential component of an effective PD process. In the process of

managing uncertainty, development teams can utilize various strategies involving appropriate contract terms, procurement methods and alternative technologies (Ford and Sobek, 2005).

P5: The availability of a staged development procedure will create flexibility to cope with technological uncertainties and consequently increase the likelihood of developing and realizing radical innovations in civil engineering projects.

Facilitating transdisciplinary cooperation

In the adopted project approach, there was a strong focus on maximizing the potential contributions of all parties to the development and implementation of the bio-based composite bridge project. This focus was for example evident in the decision to contract the developer/producer of the composite bridge deck separately from the contractor. This improved their contractual position and allowed them to have a more central role in the development and implementation of the innovation. The developer/producer of the composite bridge deck commented on this issue during his interview:

"We are not looking for a role as subcontractor who has to do everything for the lowest price. And if something deviates that you send the thickest bill to the client to make up for it, which was all pinched off before the actual price negotiation. This is not what we want. Our role as a company is changing, with respect to knowledge development and engineering we want an equal position instead of the role of subcontractor''.

Interorganizational cooperation is considered an essential aspect in realizing innovation in Complex Product Systems (CoPS) (Rutten et al., 2009) where physical and human resources are dispersed among various organizations (Barlow, 2000; Gann and Salter, 2000). Khalfan et al. (2008) and Caldwell et al. (2009) concluded that, through public clients' initiatives, there is a great potential to utilize the expertise and knowledge of suppliers and manufacturers in construction projects. This conclusion is important, given the findings of Pries and Doree (2005) that suppliers produce over sixty percent of all innovations in the construction industry. Unfortunately, the knowledge of manufacturers of components and materials, is still insufficiently used when it comes to construction innovation (Sariola, 2018). However, Khalfan et al. (2008), also concluded that a public client can act as a catalyst to promote innovative thinking through supporting public client-supplier-manufacturer collaboration. Hence, a separate tender to include the knowledge and expertise of a key subcontractor in the project team, can be considered as an important stimulus for realizing innovation in civil engineering projects.

P6: An equal position for the innovation developer/producer in the project team will positively affect the ability of the project team to cooperatively develop and implement a radical innovation in civil engineering projects.

One of the award criteria in both of the tendering procedures was the possession of collaborative skills. In both tendering procedures, tenderers were therefore required to submit a plan of action for the design and development phase of the project as part of their tender offer. This plan of action had to include the tenderer's vision on their role in the collaboration process.

Having a genuine intent to collaborate and support each other where possible, combined with a formal assignment of tasks and responsibilities based on the specific role and expertise of each party in the project, reduced the uncertainty in the development and implementation process and created favourable conditions for joint development and implementation of the intended innovation. As the contractor commented:

"We looked at the competencies of all team members, and we simply divided the different tasks. But we also looked at a good match with the people in the team to be sure that everyone felt comfortable and could be optimally productive and creative when necessary".

Stokols et al. (2008) have previously stressed the importance of preparation and practice in ensuring successful collaboration between members of transdisciplinary teams. Members need to be aware of the collaborative constraints, disagreements and conflicts that are likely to surface over the course of a project and be prepared to dedicate considerable time and effort towards establishing common ground, both intellectually and socially. Stokols et al. (2008) concluded that transdisciplinary collaboration, to be effective, requires radical preparation, practice and sustained effort. And Mouzas (2016) stresses in this respect that this is a complex process for which enough time needs to be reserved.

The importance of there being well-defined roles and responsibilities has been shown in the study by Gratton and Erickson (2007) into possible ways to build collaborative teams. These authors concluded that cooperation increases when the roles of individual team members are sharply defined, while the team is also given latitude in how to achieve their respective tasks. Unrealistic expectations for complete cooperation and harmony, along with ambiguous goals and intended outcomes, can impede a team's collaborative efforts.

P7: A jointly drawn up cooperation plan with clear agreements about the division of roles, and the conditions, expectations and principles for transdisciplinary cooperation, will increase the likelihood of developing and realizing radical innovations in civil engineering projects.

4.6. Contributions, implications, limitations and recommendations for future research

Contributions

This in-depth case study is among the first to study the mechanisms that affect the development and implementation of a radical green innovation in a civil engineering project. The study addresses an important gap in literature concerning the lack of empirical evidence on factors that enable or hinder the development and implementation of radical innovations in the construction and civil engineering sector. Our study was guided by two research questions:

1. What determining factors and mechanisms influence the successful development and implementation of a radical innovation in civil engineering projects?
2. To what extent can the theory on innovation risk management, government championship and coopetition in client-contractor relationships help to explain the successful development and implementation of radical innovations in civil engineering projects?

In addressing these research questions, this paper contributes in three ways. First, we have empirically investigated the application of an alternative procurement and project delivery method that we show facilitates and encourages the development and implementation of a radical green innovation in a civil engineering project. Given the barriers identified in realizing radical innovations in design-bid-build delivery methods as well as in integrated contracts, the investigated procurement method offers a way forward for governments to realize their policy goals on themes such as sustainability and circularity. Second, the results of this study show that in this approach, (1) government championship, through a proactive participation of the public client in the initiation, development and implementation of the project and the willingness of the public client to bear innovation risks; (2) the application of innovation risk management strategies and the availability of a fall back option; and (3) the establishing of favourable organizational and relational conditions were determinative factors to realize the intended radical green innovation project. As explained in section 5, the relevance of the three identified factors were also

confirmed in other studies. However, it is the well-considered conjoint application of these three factors by the public client, that explains the unique realization of a radical innovation in the field of civil engineering. This finding may be considered as an important contribution to literature and deserves further study in the near future. Third, a closer analysis of the three identified factors, also helped to develop seven propositions that together provide an integrated view on the potential successful development and implementation of radical innovations in civil engineering projects.

The investigated procurement and project delivery method combines features from existing methods with a few method-specific features that make it suitable for realizing radical innovations in civil engineering projects. A key feature taken from integrated contracts is the early involvement of the main contractor in the project, allowing it to play a major role in the design of the work. Nevertheless, there are also several important aspects of the investigated method that are not part of integrated contracts: 1) the contractual split between the design and realization phases; 2) the active roles of the public client and of the developer/producer of the innovation in the design process, and; 3) the timing of the design process which starts only after the tender phase. The method also shares features of relational project delivery arrangements (e.g. Halttula et al. (2015); Lahdenperä (2012)) such as the early involvement of all key parties, commitment to a single shared objective, joint decision-making and an integrated project team. However, the main differences between these relational project delivery arrangements and the investigated client-led method are the latter's explicit focus on realizing a radical green innovation, the championing role of the client, the application of several innovation-risk strategies and the creation of suitable organizational conditions to enable this.

Policy and management implications

Most policy efforts to realize innovation, so far, have been directed at providing capital, facilitating technology transfer and supporting universities and public research institutes (Feldman and Kelley, 2006; Klette et al., 2000; Martin and Scott, 2000). Unfortunately, these policy efforts have not resulted in substantial and radical innovations in the field of civil engineering. One might assert that incremental innovations in infrastructure projects are more likely to succeed under competitive bidding than significant innovations will. Public clients have difficulties in appraising the added value of significant improvements, because of cost-based selection criteria (Caerteling et al., 2009). However, to meet the great challenges such as climate change and future energy and water supply, we need entrepreneurial governments that take a leading role in the development and adoption of radical green innovations.

The findings of this study also have some specific policy and management implications. First, since the public client, taking on the role of champion was found to have a significant and positive influence on the development and implementation of a radical green innovation, governments could profitably extend the implementation of their innovation ambitions by adopting this role to encourage firms to develop and realize substantial and radical innovations. Second, as also concluded by Caerteling et al. (2008), governments can create favourable market conditions by limiting the financial risks of contracted parties and which distributes risk and opportunity fairly and openly (Loosemore and Richard, 2015). This will reduce their risk aversion and increase the likelihood of developing and realizing radical green innovations. Third, public clients can act as a catalyst to promote innovative thinking through supporting public client – supplier – manufacturer collaboration (Khalfan et al., 2008). This study showed how a separate tender to include the knowledge and expertise of a key subcontractor on an equal position in the project team, served as an important stimulus to cooperatively develop and implement a radical innovation in a civil engineering project. To ensure a high level of integration and cooperation among the members in the project team, the public client additionally included the possession of collaborative skills as one of the award criteria.

Limitations and research recommendations

Naturally, this paper is not without its limitations. The proposed alternative procurement and project delivery method has been developed, applied and evaluated within a single project in the civil engineering domain. Further evaluation of this alternative procurement and project delivery method, the conceptual framework and the seven propositions is needed to establish the validity of the findings. Since the alternative procurement method has been applied in a single bridge project, we would recommend not only evaluating its application in other innovative bridge projects but also its applicability in other types of civil engineering projects, such as viaducts, sluice constructions or new road projects. Further, with some modifications, the method may also be applicable in other domains, such as in the tendering process for utility building projects.

Conclusion

Procurement and contracting strategies based on both design-bid-build and on integrated contracting delivery methods have limitations when it comes to stimulating the development and implementation of radical innovations in civil engineering projects. In this paper, the development and application of a public-client-led method is investigated that enabled the development and implementation

of a radical green innovation in a civil engineering project. Addressing the implications and research opportunities of the findings of this study in future research, could make important contributions to the understanding of the determining factors and mechanisms that influence the successful development and implementation of radical innovations in civil engineering projects. This will also open up opportunities to find solutions for the grand challenges our physical environment is facing.

References

Actuarial Profession, Institution of Civil Engineers (2005), *Risk Analysis and Management for Projects*.

Amram, M., Kulatilaka, N. (1999), Disciplined decisions. *Harvard Business Review*. 77(1), 95–96.

Arnoldussen, J., Groot, P., Halman, J., Van Zwet, R. (2017), Innovatie in de bouw: Opgaven en kansen. Adviesrapport aan d paritaire organisaties in de bouw. Retrieved from University of Twente: https://research.utwente.nl/en/publications/innovatie-in-de-bouw-opgaven-en-kansen.

Atsma, P., (2019), Fietsbrug Ritsumazijl opniew later klaar. *Friesch dagblad*, 29 May 2019, Retrieved from. www.frieschdagblad.nl.

Baldwin, C., Hienerth, C., Von Hippel, E. (2006), How user innovations become commercial products: a theoretical investigation and case study. *Research Policy* 35(9), 1291–1313.

Barlow, J. (2000), Innovation and learning in complex offshore construction projects. *Research Policy*. 29 (7–8), 973–989.

Beerda, E. (2019), *Friese Wereldprimeur: Brug Van Biocomposiet kan over honderd jaar uitgereden worden als Mest*, 26 april 2019. Cobouw. Retrieved from. www.cobouw.nl.

Blayse, A.M., Manley, K. (2004), Key influences on construction innovation. *Construction Innovation*. 4 (3), 143–154.

Boeije, H. (2010), *Analysis in Qualitative Research*. SAGE Publications Ltd., London.

Caerteling, J.S., Halman, J.I.M., Dorée, A.G. (2008) Technology commercialization in road infrastructure: how government affects the variation and appropriability of technology. *Journal of Product Innovation Management*. 25(2), 143–161.

Caerteling, J.S., Halman, J.I.M., Song, M., Dorée, A.G. (2009), Impact of government and corporate strategy on the performance of technology projects in road construction. *Journal of Construction Engineering and Management*. 135(11), 1211–1221.

Caerteling, J.S., Halman, J.I.M., Song, M., Dorée, A.G., Van Der Bij, H. (2013), How relevant is government championing behavior in technology development? *Journal of Product Innovation Management*. 30(2), 349–363.

Caldwell, N.D., Roehrich, J.K., Davies, A.C. (2009), Procuring complex performance in construction: london heathrow terminal 5 and a private finance initiative hospital. *Journal of Purchasing Supply Management*. 15(3), 178–186.

Cardinal, L.B. (2001), Technological innovation in the pharmaceutical industry: the use of organizational control in managing research and development. *Organization Science*. 12(1), 19–36.

Courtney, H., Kirkland, J., Viguerie, P. (1997), Strategy under uncertainty. *Harvard Business Review*. 75(6), 67–79.

D.R.I.V.E (2019), ÚS NATOER. Retrieved from. https://www.drive.frl/.

Directive/24/Eu (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, vol. 57. Official Journal of the European Union.

EARTO (2014) *The TRL scale as a research & innovation policy tool*, EARTO recommendations. Retrieved from. https://www.earto.eu/wp-content/uploads/The TRL Scale as a R I Policy Tool - EARTO Recommendations - Final.pdf.

Edler, J., Georghiou, L. (2007), Public procurement and innovation—resurrecting the demand side. *Research Policy*. 36(7), 949–963.

Edler, J., Georghiou, L., Uyarra, E., Yeow, J. (2015), The meaning and limitations of public procurement for innovation: a supplier's experience. In: *Public Procurement for Innovation*. Edward Elgar Publishing.

Edquist, C., Vonortas, N.S., Zabala-Iturriagagoitia, J.M. (2015a.), Introduction. In: Edquist, C., Vonortas, N.S., Zabala-Iturriagagoitia, J.M., Edler, J. (Eds.), *Public Procurement for Innovation*. Edward Elgar Publishing.

Edquist, C., Vonortas, N.S., Zabala-Iturriagagoitia, J.M., Edler, J. (2015b), *Public Procurement for Innovation*. Edward Elgar Publishing.

Edquist, C., Zabala-Iturriagagoitia, J.M. (2012) Public Procurement for Innovation as mission-oriented innovation policy. *Research Policy*. 41(10), 1757–1769.

Eisenhardt, K.M., Graebner, M.E. (2007), Theory building from cases: opportunities and challenges. *Academy of Management Journal*. 50(1), 25–32.

Eriksson, P.E. (2008), Procurement effects on coopetition in client-contractor relationships. *Journal Of Construction Engineering Management*. 134(2), 103–111.

Eriksson, P.E., Volker, L., Kadefors, A., Lingegård, S., Larsson, J., Rosander, L. (2019) Collaborative procurement strategies for infrastructure projects: a multiple-case study. *Proceedings of the Institute of Civil Engineering Management Procurement Law* 172(5), 197–205. https://doi.org/10.1680/jmapl.19.00016.

Eriksson, P.E., Westerberg, M. (2011), Effects of cooperative procurement procedures on construction project performance: a conceptual framework. *International Journal of Project Management*. 29(2), 197–208.

Feldman, M.P., Kelley, M.R. (2006), The ex ante assessment of knowledge spillovers: government R&D policy, economic incentives and private firm behavior. *Research Policy*. 35(10), 1509–1521.

Ford, D.N., Sobek, D. (2005), Modeling real options to switch among alternatives in product development. IEEE Trans. Engineering Management. 52(2), 1–11.

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.

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.

Gassmann, O., Zeschky, M., Wolff, T., Stahl, M. (2010), Crossing the industry-line: breakthrough innovation through cross-industry alliances with 'non-suppliers. *Long Range Planning*. 43(5–6), 639–654.

Gattiker, T.F., Carter, C.R. (2010), Understanding project champions' ability to gain intraorganizational commitment for environmental projects. *Journal Operations Management*. 28(1), 72–85.

Gehner, E. (2008), *Knowingly Taking Risk; Investment Decision Making in Real Estate Development*. PhD thesis. Department of Real Estate & Housing, Faculty of Architecture, Delft University of Technology, The Netherlands.

Gratton, L., Erickson, T.J. (2007), Eight ways to build collaborative teams. *Harvard Business Review*. 85 (11), 100.

Hale, D.R., Shrestha, P.P., Gibson Jr., G.E., Migliaccio, G.C. (2009), Empirical comparison of design/build and design/bid/build project delivery methods. *Journal of Construction Engineering Management*. 135(7), 579–587.

Halman, J.I.M. (1994), *Risicodiagnose in produktinnovatie: Ontwikkeling van de risicodiagnosemethode RDM* (Diagnosing risks in product innovation; The

development of the Risk Diagnosing Methodology RDM). PhD Thesis. Technical University of Eindhoven, Eindhoven.

Halman, J.I.M. (2008), *Risicomanagement in de bouw. Nieuwe ontwikkelingen bij een aantal koplopers* (Risk management in construction; New developments among a number of frontrunners) Boxtel: Aeneas.

Halttula, H., Aapaoja, A., Haapasalo, H. (2015), The contemporaneous use of building information modeling and relational project delivery arrangements. *Procedia Economics and Finance* 21, 532–539. https://doi.org/10.1016/S2212-5671(15)00209-9.

Hartmann, A. (2006), The context of innovation management in construction firms. *Construction Management and Economics*. 24(6), 567–578.

Henderson, R.M., Clark, K.B. (1990), Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. *Adminstrative Science Quarterly*. 35(1), 9–30. https://doi.org/10.2307/2393549.

Howell, J.M., Sheab, C.M. (2001), Individual differences, environmental scanning, innovation framing, and champion behavior: key predictors of project performance. *Journal of Product Innovation Management*. 18(1), 15–27.

ISO (2009), In: *Risk Management — Principles and Guidelines*. International Organization for Standardization, Geneva.

Ivory, C. (2005), The cult of customer responsiveness: is design innovation the price of a client-focused construction industry? *Construction. Management and Economics*. 23(8), 861–870.

Kadefors, A. (2004), Trust in project relationships—inside the black box. International Journal of Project. Management. 22(3), 175–182.

Keizer, J.A. and Halman, J.I.M. (2007), Diagnosing risk in radical innovation projects. *Research Technology Management*. 50(5), 30–36.

Keizer, J.A. and Halman, J.I.M. (2009), Risks in major innovation projects, a multiple case study within a world's leading company in the fast moving consumer goods. *International Journal of Technology Management*. 48(4), 499–517.

Keizer, J.A., Halman, J.I.M. and Song, M. (2002), From experience: applying the risk diagnosing methodology. *Journal of Product Innovation Management*. 19(3), 213–232.

Kent, D.C. and Becerik-Gerber, B. (2010) Understanding construction industry experience and attitudes toward integrated project delivery. *Journal of Construction Engineering Management*. 136(8), 815–825.

Khalfan, M.M., McDermott, P., Li, X., Arif, M. and Kashyap, M. (2008), The integration of suppliers and manufacturers within construction supply chains

through innovative procurement strategies. *International Journal of Value Chain Management*. 2(3), 358–370.

Klette, T.J., Møen, J. and Griliches, Z. (2000), Do subsidies to commercial R&D reduce market failures? Microeconometric evaluation studies. *Research Policy*. 29(4–5), 471–495.

Kulatunga, K., Kulatunga, U., Amaratunga, D. and Haigh, R.,(2011), Client's championing characteristics that promote construction innovation. *Construction Innovation*. 11(4), 380–398. https://doi.org/10.1108/14714171111175873.

Kumaraswamy, M. and Dulaimi, M. (2001), Empowering innovative improvements through creative construction procurement. *Engineering Construction Architecture Management*. 8(5/6), 325–344.

Lahdenperä, P. (2012), Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. *Construction Management and Economics*. 30(1), 57–79.
https://doi.org/10.1080/01446193.2011.648947.

Leifer, R., O'connor, G.C. and Rice, M. (2001), Implementing radical innovation in mature firms: the role of hubs. *Academy of Management Perspectives*. 15(3), 102–113.

Lenderink, B., Halman, J.I.M., Boes, H. and 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.

Lenferink, S., Tillema, T. and Arts, J. (2013), Towards sustainable infrastructure development through integrated contracts: experiences with inclusiveness in Dutch infrastructure projects. *International Journal of Project Management*. 31(4), 615–627.

Loosemore, M. and Richard, J. (2015), Valuing innovation in construction and infrastructure: getting clients past a lowest price mentality. *Engineering, Construction and Architecture Management*. 22(1), 38–53.

Love, P.E., Skitmore, M. and Earl, G. (1998), Selecting a suitable procurement method for a building project. *Construction Management and Economics*. 16(2), 221–233.

Magnusson, T., Lindstrom, G. and Berggren, C. (2011), Architectural or modular innovation? Managing discontinuous product development in response to challenging environmental performance targets. *International Journal of Innovation Management*. 7(1), 1–26.

Majchrzak, A., Cooper, L.P. and Neece, O.E. (2004), Knowledge reuse for innovation. *Management Science*. 50(2), 174–188.

Mankins, J.C. (2009), Technology readiness assessments: a retrospective. *Acta Astronautica*. 65(9–10), 1216–1223.

Manley, K. (2006), The innovation competence of repeat public sector clients in the Australian construction industry. *Construction Management and Economics*. 24(12), 1295–1304.

Mariotto, F.L., Zanni, P.P. and Moraes, G.H.S. (2014), What is the use of a single-case study in management research? *Revista de Administraçao de Empresas*. 54(4), 358–369. https://doi.org/10.1590/S0034-759020140402

Martin, S. and Scott, J.T. (2000), The nature of innovation market failure and the design of public support for private innovation. *Research Policy*. 29(4–5), 437–447.

Mazzucato, M. (2015), *Building the Entrepreneurial State: A New Framework for Envisioning and Evaluating a Mission-Oriented Public Sector*. Levy Economics Institute of Bard College Working Paper, 824.

Miles, M.B. and Huberman, A.M. (1994), *Qualitative Data Analysis: an Expanded Sourcebook*. Sage Publications, Incorporated.

Miller, G., Furneaux, C.W., Davis, P., Love, P. and O'Donnell, A. (2009), *Built Environment Procurement Practice: Impediments to Innovation and Opportunities for Changes*. Curtin University of Technology, West-Australia.

Moon, M.J. and Bretschneider, S. (1997), Can state government actions affect innovation and its diffusion?: an extended communication model and empirical test. *Technology Forecasting and Social Change.* 54(1), 57–77.

Morris, P.W. and Hough, G.H. (1987), *The Anatomy of Major Projects: A Study of the Reality of Project Management*. Wiley, London.

Mosey, D. (2014), *Project Procurement and Delivery Guidance: Using Two Stage Open Book End Supply Chain Collaboration*. King's College, London.

Mouzas, S. (2016), Performance based contracting in long-term supply relationships. *Industrial Marketing Management*. 59, 50–62.

Na, L.J., Ofori, G. and Park, M. (2006), Stimulating construction innovation in Singapore through the national system of innovation. *Journal of Construction Engineering and Management*. 132(10), 1069–1082.

Numagami, T. (1998), Perspective—the infeasibility of invariant laws in management studies: a reflective dialogue in defense of case studies. *Organization Science*. 9(1), 1–15.

OECD (2011), *Demand-side Innovation Policies*. OECD Publishing.

Osipova, E. and Eriksson, P.E. (2011), How procurement options influence risk management in construction projects. *Construction Management and Economics*. 29(11), 1149–1158.

Oyegoke, A.S., Dickinson, M., Khalfan, M.M., McDermott, P. and Rowlinson, S. (2009), Construction project procurement routes: an in-depth critique. *Internationl Journal of Managing Projects in Business*. 2(3), 338–354.

Öztas, A. and Ökmen, Ö. (2004), Risk analysis in fxed-price design–build construction projects. *Building and Environment*. 39(2), 229–237.

Pesämaa, O., Eriksson, P.E. and Hair, J.F. (2009), Validating a model of cooperative procurement in the construction industry. *International Journal of Project Management*. 27(6), 552–559.

Pries, F. and Doree, A.G. (2005), A century of innovation in the Dutch construction industry. *Construction Management and Economics*. 23(6), 561–564.

Rahman, M.M. and Kumaraswamy, M.M. (2002), Joint risk management through transactionally effcient relational contracting. *Construction Management and Economics*. 20(1), 45–54.

Rijkswaterstaat (2019), *Toekomstige Opgave Rijkswaterstaat: Perspectief op de uitdagingen en verbetermogelijkheden in de GWW-sector*. Ministry of Infrastructure and Water Management, The Netherlands.

Rose, T.M. and Manley, K. (2012), Adoption of innovative products on Australian road infrastructure projects. *Construction Management and Economics*. 30(4), 277–298.

Rose, T.M. and Manley, K. (2014), Revisiting the adoption of innovative products on Australian road infrastructure projects. *Construction Management and Economics*. 32(4), 904–917.

Roussel, P.A., Saad, K.N. and Erickson, T.J. (1991), *Third Generation R&D* (Cambridge, MA).

Rutten, M.E.J., Dorée, A.G. and Halman, J.I.M. (2009), Innovation and interorganizational cooperation: a synthesis of literature. *Construction Innovation*. 9(3), 285–297.

Sadin, S.R., Povinelli, F.P. and Rosen, R. (1989), The NASA technology push towards future space mission systems. *Acta Astronautica*. 20, 73–77.

Sariola, R. (2018), Utilizing the innovation potential of suppliers in construction projects. *Construction Innovation*. 18 (2) https://doi.org/10.1108/CI-06-2017-0050.

Sergeeva, N. and Winch, G.M. (2020), Narrative interactions: how project-based firms respond to Government narratives of innovation. *International Journal of Project Management*. 38(6), 379–387.

Siggelkow, N. (2007) Persuasion with case studies. *Academy of Management Journal*. 50(1), 20–24.

Slaughter, E.S. (1998), Models of construction innovation. *Journal of Construction Engineering Management*. 124(3), 226–231.

Stokols, D., Misra, S., Moser, R.P., Hall, K.L. and Taylor, B.K. (2008), The ecology of team science: understanding contextual influences on transdisciplinary collaboration. *American Journal of Preventive Medicine* 35(2), S96–S115.

Taofeeq, D. and Adeleke, A. (2019), Factor's influencing contractors risk attitude in the Malaysian construction industry. *Jounal of Construction Business and Management*. 3(2), 59–67.

Turner, J.R. (2005), The role of pilot studies in reducing risk on projects and programmes. *International Journal of Project Management*. 23(1), 1–6.

UK Cabinet Offce (2002), *Improving Government's Capability to Handle Risk and Uncertainty,* Chichester, UK.

United Nations General Assembly (2015), *Transforming Our World: the 2030 Agenda for Sustainable Development*, New York.

Uyarra, E., Edler, J., Garcia-Estevez, J., Georghiou, L. and Yeow, J. (2014), Barriers to innovation through public procurement: a supplier perspective. *Technovation* 34(10), 631–645.

Wang, J., Lin, W. and Huang, Y.-H. (2010), A performance-oriented risk management framework for innovative R&D projects. *Technovation* 30(11–12), 601–611.

Wilden, R., Gudergan, S.P., Nielsen, B.B. and Lings, I. (2013), Dynamic capabilities and performance: strategy, structure and environment. *Long Range Planning*. 46(1–2), 72–96.

Yin, R.K. (2013), *Case Study Research: Design and Methods*, fifth edition. Sage Publications Inc.

Yue, X. (2017), *Influences of Government Championship on the Technology Innovation Process at the Project-Level*. PhD Thesis. Stony Brook University, New York.

Chapter 5

The development of a typology and guideline for selecting innovation-encouraging procurement strategies in civil engineering

Bart Lenderink, Hans Boes, Johannes I.M. Halman, Hans Voordijk and André G. Dorée[4]

This chapter is linked to the following sub-research question:

RQ 4: How to select an effective innovation-encouraging procurement strategy for specific projects or programmes in the field of civil engineering?

The answers to the sub-research questions are provided in section 6.1. of this thesis.

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5 The development of a typology and guideline for selecting innovation-encouraging procurement strategies in civil engineering

Abstract

Stimulating innovation through public procurement can lead to improved performance, contribute to organizational and policy goals, but can also play a key role in addressing societal challenges that cannot be adequately addressed by conventional solutions. A significant amount of research has been carried out on stimulating innovation through the public procurement of goods and services. However, there is still a lack of knowledge on which procurement strategies and tendering methods can be effectively used to encourage specific types of innovation within larger public initiatives such as civil engineering projects and programmes. The aim of this study is therefore to provide a coherent overview of innovation-encouraging procurement strategies and tendering methods, and to relate their potential effective use to the technology readiness of the targeted innovations, the required level of cooperation between public client and contractor and the willingness of public clients to bear innovation risks, and to provide incentives, budget and solution space for these innovations. Based on a literature review and a multiple case study in which different procurement strategies were identified and compared, an innovation-encouraging procurement typology is developed. The insights from this typology are further utilized to provide a guideline that can be used by public clients to select an appropriate procurement strategy for their innovation projects and programmes.

5.1. Introduction

Public procurement is increasingly used as a policy instrument to achieve horizontal policy goals in addition to its primary objective of obtaining required goods, works and services on the best possible terms (Arrowsmith, 2010; Grandia & Meehan, 2017). Three such horizontal policy goals are: to reduce long-term unemployment, stimulate small and medium enterprises and to reduce the environmental impact of procured goods, works and services. Furthermore, public procurement can play an important role in addressing societal challenges (Edquist & Zabala-Iturriagagoitia, 2012; OECD, 2017). As such, public procurement and innovation are recognized as two important

elements in the global effort to achieve the Sustainable Development Goals of the United Nations (United Nations Environment Programme, 2017; United Nations General Assembly, 2015).

Over the past two decades, public procurement has again captured the interests of policymakers as a demand-side innovation policy instrument that can complement supply-side policy instruments (Edler & Georghiou, 2007; Edquist & Hommen, 2000; OECD, 2017). With public spending representing 14% of the GDP in the European Union (Grandia, 2018), policymakers are becoming increasingly aware of the potential of innovation-friendly procurement to spur economic development and growth (OECD, 2011; Uyarra & Flanagan, 2010). Furthermore, public organizations can also insist on new solutions that address societal challenges and/or fulfil the needs of the procurement organization (Edler & Yeow, 2016; Edquist & Zabala-Iturriagagoitia, 2020; Wesseling & Edquist, 2018). This trend is also reflected in the European Directive 2014/24/EU for public procurement which gives high priority to innovation as an accelerator of social and economic development. As stated in Recital 95: "It is of utmost importance to fully exploit the potential of public procurement to achieve the objectives of the Europe 2020 strategy for smart, sustainable and inclusive growth".

In part due to the increased interest of policymakers, a significant amount of research has been carried out on the use of public procurement to stimulate and procure innovations over the last two decades. In their review on the different concepts, rationales and approaches to stimulate innovation through public procurement, Lenderink et al. (2019) also provide a review of existing typologies of public procurement to induce innovation. A first typology on Public Procurement for Innovation (PPI) was presented by Edquist and Hommen (2000). This typology has two dimensions. The first dimension relates to the end-user of the procured product or service and makes a distinction between the procurer as end-user of the procured product versus procurers as catalysts if the procuring organization primarily acts to satisfy the needs of others, either public or private. The second dimension relates to the level of innovation and makes a distinction between completely new created products, processes or systems versus products, processes or systems that are not new to the world, but still new to the country of procurement. This first typology was later modified by Hommen et al. (2005) by extending the first dimension with a third cooperative category, for cases in which the procurer shares the procured product, process or system with other organizations. A somewhat distinctive typology on public procurement in relation to innovation was provided by Uyarra and Flanagan (2010). This typology is based on Kraljic's model (1983) and Storper's categorization

(1997). One dimension makes a distinction between standardized versus specialised products while the other dimension distinguishes between products developed for a dedicated versus generic market. Based on the above mentioned studies and research conducted by Edler (2009), Edquist et al. (2002), and Hommen and Rolfstam (2009), Edquist and Zabala-Iturriagagoitia (2012) developed a taxonomy that categorizes Public Procurement for Innovation (PPI) according to three dimensions: (i) the user of the purchased good; (ii) the character of the innovation embedded in the resulting product; and (iii) the cooperative or non-cooperative nature of the process.

So far, research on public procurement for innovation has dedicated limited attention on the procurement of innovation oriented civil engineering projects and programmes. In contrast to the procurement of innovative goods and services, the procurement of innovative civil engineering projects and programmes requires a relative long time frame to develop and realize a specific project or programme (Davies et al., 2019). And inherent to the innovation ambitions of the public client, civil engineering projects and programmes also entail a high risk and uncertainty profile that needs to be allocated and managed by the public client (Lenderink et al., 2022). Further, civil engineering innovation projects and programmes always consist of a large number of interconnected parts, usually produced by different suppliers (Gann and Salter, 2000). As a consequence, an effective cooperation between all the supplying parties but also between client and these suppliers are of utmost importance (Erisson et al., 2019). Considering the typologies that have been developed so far, one may conclude that the dimension that relates to the degree of innovation and also the one that relates to the degree of cooperation among procurers, suppliers are also important to characterize public procurement for innovaton of civil engineering projects and programmes. However, they need further refinement and tailoring to the specific context of civil engineering. By contrast, the value of the dimension that relates to the end-user of the procured product or service is negligable. For the specific context of civil engineering, a dimension that relates to the aims, scope and time frame of projects and programmes would be of much more value. In conclusion, there is a need for a typology that captures the different categories and options of public procurement for innovation of civil engineering projects and programs. And in addition, there is also a lack of knowledge on which type of procurement strategies can be effectively used to stimulate innovation within civil engineering projects and programmes. In order to contribute in closing this gap in literature, the following research question will be answered in this paper:

How to select an effective innovation-encouraging procurement strategy for specific projects or programmes in the field of civil engineering?

The remainder of the paper is structured as follows. The paper starts with providing a literature background about important topics related to the realization of innovation in the field of civil engineering projects and programmes. This literature section is followed by a section in which the research methodology is explained that was used to collect and analyse the data of eight cases in which the encouragement of innovation played an important role in the procurement strategy. Next, a three-dimensional typology for the classification of innovation procurement in civil engineering projects and programs is introduced. This is followed by a section in which the eight cases are described in detail. This enabled to classify the cases and to evaluate their positioning in the developed typology. Furthermore, a guideline is provided to assist public clients to select an appropriate procurement strategy for their specific innovation projects and programmes. The paper concludes with a section about the main contributions of this study for literature and practice. Finally, suggestions are made for future research.

5.2. Background literature

In this section we first provide a general introduction about the characteristics of projects and programmes in the field of civil engineering. This is followed by a definition of innovation in the field of civil engineering and an explanation about the use of Technology Readiness levels (TRL's). Next, we discuss the literature about public procurement strategies and tendering methods to realize innovation in the field of civil engineering. The literature background section ends with a summary of recent insights about the importance of organisational cooperation between public clients and contractors to realise major innovations in civil engineering projects and programmes.

Projects and programmes in the field of civil engineering

As an industry, civil engineering and construction is geared towards the production of Complex Products and Systems (CoPS) (Gann & Salter, 2000; Winch, 1998). CoPs are seen as high-value capital goods which are designed and produced in one-offs, or small batches, to meet the specific needs and requirements of individual customers (Hobday, 1998, 2000). They consist of a large number of interconnected parts, usually produced by different suppliers, that have to be integrated in the final product or system before delivery to the client can take place (Gann & Salter, 2000). The low volume production, in comparison to mass-produced goods, allows greater customization and direct involvement of the client in the design and production process. The production of CoPS is usually organized in projects as this

organizational form provides an effective way to manage the complexities and uncertainties involved in the design and integration of the many interconnected parts in a final product or system (Hobday, 2000). Projects are organized around the achievement of one or more specific objectives within a predefined timeframe (Munns & Bjeirmi, 1996). In addition, they may also aim to contribute to secondary objectives such as sustainability, social return or the stimulation of innovation.

With the increasing use of projects over time, programmes and programme management have emerged as ways to improve coordination and balance the interests and priorities between projects, as well as to achieve benefits which cannot be obtained by managing projects individually (Pellegrinelli, 2011; Project Management Institute, 2017). Programmes can be defined as "a framework for grouping existing projects or defining new projects, and for focusing all the activities required to achieve a set of major benefits" (Pellegrinelli, 1997). In comparison to projects, the aims and objectives of programmes tend to be longer term, more abstract and strategic in nature, and are often defined in terms of outcomes rather than outputs. Furthermore, the aims and objectives of programmes are more likely to change as needs change over time, and programmes do not always have a fixed end date as projects tend to do (Pellegrinelli, 1997). Programme management is also better able to cope with higher levels of complexity, ambiguity and risk (Office of Government Commerce, 2011). Finally, due to their ability to translate strategic policy goals such as climate change adaptation and realising a circular economy into concrete projects (Pellegrinelli, 2011), one can expect programmes to become increasingly important as a tool to address these societal challenges (Volker, 2019; Vosman, 2020) and to develop major innovations through successive innovation projects in a close cooperation between project clients and contractors (Halman, 2004, 2018).

A characterization of innovation in the field of civil engineering

The Organisation for Economic Co-operation and Development (OECD) defines innovation as: "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD/Eurostat, 2005). In line with this definition, innovation in the field of civil engineering can be defined as the development and successful implementation, of new ideas, products or processes in the design and realization of new civil engineering objects (Lenderink et al., 2020). Innovations in civil engineering projects can be classified according to their degree of innovation. In the literature (e.g. Slaughter (1998); Garcia and Calantone (2002); Lenderink et al., (2020)) the degree of innovation has been placed

on a continuum based on the *level of change*: from incremental innovations (i.e. a small change) to fully radical innovations (i.e. completely new to the world, involving totally new technology). Besides the magnitude of change, innovations can also be classified according to their *degree of complexity*, i.e. the expected linkages of an innovation to other components, modules and the system as a whole (Henderson & Clark, 1990; Lenderink et al., 2020; Magnusson et al., 2011; Slaughter, 1998).

With respect to technological innovations, a distinction is made between *product innovation* and *process innovation* (conform e.g. Schilling, 2020; Tidd and Bessant, 2018). A product innovation can be characterized as an innovative solution which leads to a substantial improvement in the functionality and/or sustainability of an object, the extension of the functionality of an object or and/or the technical performance of an object. And a process innovation is defined as an innovative solution to increase the efficiency of the construction process (Lenderink et al, 2019). To realize technological innovations in the field of civil engineering, a gap between required and acquired technological knowledge needs to be bridged during the development and realization of the project or programme. For radical innovations this knowledge gap – expressed as a technology readiness level (TRL) - will naturally be more significant than for incremental innovations. The concept of TRLs has been developed during the 1970's by NASA for estimating the maturity of a technology (Sadin, Povinelli, & Rosen, 1989). Since then, the TRL system has been further developed and has been put into use by many authorities. The European Commission has adopted the TRL system to stimulate specific phases of technology development. TRL as established by the European Commission has adopted the TRL system to stimulate specific phases of technology development. The TRL system as established by the European Commission distinguishes nine levels and four phases. The first three levels (TRL 1, 2, 3) belong to 'discovery', followed by TRL 4, 5 and 6 of the 'development' phase. TRL 7 and TRL 8 belong to the 'demonstration' phase, with TRL 9 'deployment' as the final development phase (EARTO, 2014). Typically, the development and realization of incremental innovation projects have a Technology Readiness Level between TRL8 – TRL9 while radical innovation projects have a Technology Readiness Level between TRL4 – TRL6.

Procurement strategies and tendering methods to realize innovation in civil engineering

In the directives for public procurement of the European Union public procurement is defined as: "The acquisition by means of a public contract of works, supplies or services by one or more contracting authorities from economic operators chosen by those contracting authorities, whether or not the works, supplies or services are intended for a public purpose"(Directive 2014/24/EU, 2014). In adopting this

definition, we consider all stages of the process of acquiring works, supplies or services to be part of public procurement. Activities in these stages can range from the identification of needs up to the management of contracts. Further, in line with van Weele (2009) the tendering process is considered to be a specific part of the procurement process that focusses on the selection and contracting of a supplier.

Given the large influence of the project or programme on the procurement strategy in civil engineering, three strategic levels with respect to procurement can be distinguished. The first level is the procurement initiative, which refers to decisions on the level of the civil engineering project or program in which the procurement occurs. This includes decisions which characterise the initiative, such as scope, budget and duration, as well as, the predetermined aims and objectives which are pursued in the initiative. The second level is the overall strategy, which refers to the plans how the predetermined aims and objectives can be realized in the procurement process. Examples are e.g. to follow a two-stage approach to split the development phase from the realization phase. Or to provide a subsidy to support the needed R&D activities. The third level is tendering methods, which refers to the different procedures that can be followed as part of the procurement strategy. Examples of tendering methods are: the used procurement procedure, selection criteria, award criteria and contractual arrangements.

The most common project delivery model in civil engineering is the design-bid-build model where nearly all of the design activities are performed before a public tender for the realization of the work is published. This delivery model is widely used for straightforward projects of small to medium size where the additional value of involving the main contractor in design activities is expected to be limited. Integrated delivery models, on the other hand, are often used for larger and more complex projects to allow for incremental innovation and optimization between different stages of the project lifecycle (Blayse & Manley, 2004; Eriksson et al., 2019). Contracts for Integrated delivery models range from Engineering and Construct (E&C), and Design and Construct (D&C) up to the integration of Design, Build, Finance, Maintenance and Operation (DBFMO) activities in one contract (Lenferink, Tillema, & Arts, 2013).

Alongside widely used open, restricted and limited tender procedures, there are several public procurement procedures permitted under the European law which provide additional opportunities for stimulating innovation (Directive 2014/24/EU, 2014; Telles & Butler, 2014). The competitive dialogue and the competitive procedure with negotiation both allow greater communication and interaction between the

tenderers and the client by including one or more meetings in the tender procedure (Hoezen, Voordijk, & Dewulf, 2014). The client can also organize market consultations as part of the market approach to inform and consult the market about the assignment prior to the tender (Lenderink, Halman, & Voordijk, 2019; Semple, 2015). In comparison to the previous procedures, the design contest, pre-commercial procurement and innovation partnership approaches are most geared towards the development of new solutions (Georghiou, Edler, Uyarra, & Yeow, 2014; Semple, 2015). Here, one should note that a pre-commercial procurement is a targeted subsidy for the development of new solutions and is not regulated by procurement law (Edquist & Zabala-Iturriagagoitia, 2015).

One of the main ways for public clients to stimulate innovation is the use of high quality standards (Dalpé, 1994; Geroski, 1990) and innovation-oriented award criteria (Dreschler, 2009; Lenderink et al., 2020; Loosemore & Richard, 2015). This to provide incentives to tenderers to offer high quality and potentially innovative solutions. Public clients can also stimulate innovation in public tenders through the use of functional instead of technical specifications which provide more solution space to tenderers for offering alternative solutions (Edquist et al., 2015). Lastly, arrangements on intellectual property rights can also provide incentives to tenderers for offering innovations (Edler et al., 2015).

The importance of cooperation between public client and contractor

Interorganisational cooperation is considered an essential aspect in realizing innovation in Complex Products and Systems (CoPS) where physical and human resources are dispersed among various organisations (Rutten et al., 2009; Barlow, 2000; Gann & Salter, 2000). Khalfan et al. (2008) and Caldwell et al. (2009) concluded in their study that, through public clients' initiatives, there is great potential to utilize the expertise and knowledge of suppliers and manufacturers in civil engineering and construction projects. In this respect, a public client can act as a catalyst to promote innovative thinking through supporting public client-supplier-manufacturer collaboration.

In his study on procurement effects on coopetition in client-contractor relationships, Eriksson (2008) has positioned cooperation and competition as opposite sides of a continuum. He divides this continuum in a range from: 1) a state of pure competition to; 2) competition-based coopetition to; 3) a state of coopetition; to 4) cooperation based coopetition and ending with; 5) a state of full cooperation. To realize innovation in civil engineering projects, Eriksson and Westerberg (2011) indicated that a high level of integration between client and contractor should be taken care of

resulting in a joint involvement in subcontractor selection and integration; an incentive-based payment on innovation performance criteria and; the usage of collaborative tools such as the usage of joint IT-tools, joint risk management and a joint project office. Unfortunately, the study of Eriksson (2008) also shows that in the construction industry, clients' procurement procedures often facilitate a focus on competition and not on cooperation. This explains the relative low level of innovations in the construction industry.

In conclusion, since innovation in the field of civil engineering must take place in project or programme constellations consisting of a public client and supplying firms, these firms are much dependent on public clients to allow for innovation (Ivory, 2005; Loosemore, 2015; as cited by Lindblad & Rudolphsson Guerrero 2020). Public clients can play a central role in supporting innovation by establishing a supportive environment through their willingness to limit the financial innovation risks of the contracted parties and by providing incentives to encourage innovation. In addition, public clients have the power to act as a catalyst to promote innovative thinking through supporting public client-supplier-manufacturer collaboration. And as long-term infrastructure owners, they will benefit from more sustainable processes (Linderoth, 2010; Smith 2014; Singh, 2014; as cited by Lindblad & Rudolphsson Guerrero, 2020).

5.3. Research methodology

A multiple case study, involving eight different cases, was conducted to gain insight into the factors that influence the effectivity of innovation-encouraging procurement strategies and tendering methods. Case studies are well suited for understanding the "how and why" of phenomena in their natural settings (Yin, 2013). Furthermore, case studies are most suitable when the object under study is difficult to quantify, as in this case. A cross case comparison helped to identify and explain commonalities and differences between the cases in their procurement strategies and tendering methods. This cross case comparison helped to derive a typology of innovation encouragement procurement strategies.

Case selection

In searching for suitable cases, the national expertise centre on public procurement in the Netherlands was contacted, as well as several Dutch provinces and large municipalities who were known for their ambitions with respect to innovation in the field of civil engineering. We asked these organizations to provide us with specific

examples of innovations that were realized in the past five years. Further, the online Dutch tendering databases, Tenderned.nl and Aanbestedingskalender.nl, were searched to find innovation-oriented tenders within the field of civil engineering and construction. Next, we contacted the respective tendering authorities to also obtain additional tender documents. The initial search process resulted in a variety of 25 potential cases in which innovation was explicitly part of the scope, aims and objectives of the project and/or the used Procurement strategy. Next we made a purposefully selection (Eisenhardt & Graebner, 2007) that was based on developing a sample that covered:

- projects as well as programmes;
- incremental as well radical innovations;
- the identified variety of procurement strategies.

As explained in the literature background section, strategic policy goals such as climate adaption and the realization of a circular economy are defined in long-term innovation programmes which are decomposed into multiple successive and often interrelated innovation-oriented projects with a much shorter time-horizon. However, besides innovation-oriented projects being part of such an innovation programme, there are also innovation-oriented projects that are defined and procured on their own. We therefore decided to include examples of innovation programmes as well as examples of individual innovation projects in our sample of cases.

This case selection resulted in first instance into seven cases that were taken for further study. For comparison reasons, we added at a later stage, one case that did not have a specific focus on innovation, but in which the procurement strategy implicitly facilitated the implementation of innovation. This eventually resulted in a case sample consisting of three examples of innovation-encouraging programmes four examples of innovation-encouraging projects and one project in which innovation was not directly stimulated.

Data collection and analysis of the individual cases

The data collection and individual analysis for each of the cases in the multiple case study was performed in three steps. The first step was to contact the public client of the initiative and request the project/programme, procurement and concept contract documents where these could not be obtained from the public tender database in which the procurement had been published. The second step was to review these documents to identify the scope, aims and objectives of the initiative and to gain an initial grasp of the project and the procurement strategy used in the initiative. This

initial document study was also used to prepare questions for the planned semi-structured interviews and to then corroborate findings from these interviews. The third step was to carry out several semi-structured interviews with respondents from the public client side who had managerial roles in the initiative. For example, these could be the project leader, internal client, procurement advisor and, sometimes, external consultants who supported the client. In total, 32 interviews were performed with the clients and supporting external consultants. The questions in the interviews were structured in a chronological order reflecting the different phases of the initiative and dealt with: a) the development of the scope, aims and objectives of the initiative; b) the procurement strategy used and why this approach had been adopted; and c) the role of innovation in the initiative as well as in the procurement strategy.

For the selected cases, interviews were also carried out with the contracted organizations and other unsuccessful tenderers. A total of 18 interviews were performed with contracted organizations and tenderers. These interviews focussed on their incentives to participate in the project as well as their view on the pros and cons of the selected procurement strategy with respect to stimulating innovation. The interviews lasted between 50 minutes and two hours and were recorded and transcribed. The transcripts were sent to the respondents to verify the content. None of the transcriptions required modification. The cases were analysed from the perspective of public clients who initiated an innovation-encouraging procurement strategy to fulfil the aims and goals of a specific project or programme. This with the aim to increase knowledge on how the use of innovation-encouraging procurement strategies were related to the characteristics of the specific projects and programmes.

Development of the typology

The main strength of typologies is that they can be used to identify and understand relationships between combinations of variables rather than only separate variables, which makes them very suitable for midrange theory development (O'Raghallaigh et al., 2010). The development of the typology as described in this paper was based on the insights on typology development from the literature (Niknazar and Bougault, 2017; Shenhar and Dvir, 1996). In developing the typology we followed the steps proposed by O'Raghallaigh et al. (2010) in their paper on theory-building using typologies:

1. Define the purpose and limit the domain of the typology.
2. Identify and define the concepts used in the typology:
    a. Key constructs;

b. Ideal types.
3. Describe the logic which explains the relationships between the variable(s).
4. Make predictions and propose suggestions for future research.

Guideline development

The insights acquired during the literature review, the multiple case study and the typology development were helpful to derive a general guideline for the selection of an innovation-encouraging public procurement strategy. Depending on the type of project or programme a different approach was worked out.

In the remainder of this paper we will present the results of our research in the order in which it was performed. First, we will introduce the three key constructs that will be used to classify the different ideal types of innovation procurement in civil engineering projects and programmes.

5.4. Classifying innovation procurement in civil engineering projects and programmes

Based on the conducted literature review, a typology has been derived which consists of three dimensions. This typology will be used to classify the cases presented in the next section. The first dimension refers to the scope, aims and objectives of an initiative and makes a distinction between civil engineering projects and programmes. The second dimension refers to the degree of innovation that is embedded in the realised project or programme. The third dimension of the typology refers to the level of cooperation between public clients and contractors.

5.5. Details about the projects and programmes included in this study

This section first provides a brief description of each of the eight cases that were part of our multiple case study. The study includes five procured civil engineering projects and three civil engineering programmes. The characteristics of each of the procurement initiatives and the reasons for the public client in stimulating innovation are listed in Table 1. An overview of the different procurement strategies and the tendering methods that were used can be found in Table 2.

Table 3 provides an overview of the type(s) of innovation(s) the public client hoped to achieve in the respective projects and programmes, the innovation degree of the realized innovations, what kind of role the public client played during the whole process, and more specifically, the type of relationship between public client and contractor.

Brief case descriptions

1. Functional barriers - The municipalities of Amsterdam and Rotterdam and the Ministry of Infrastructure and Water Management published a Small Business Innovation Research (SBIR) procedure for the staged development and initial testing of four functional barriers to fence off construction sites . The SBIR procedure was followed by three pilot projects to test the developed product innovations in practise: (a) a modular barrier (the Wall for All), (b) a barrier which absorbs dust and reflect noise (the Greenbar) and (c) an aesthetically pleasing and strong barrier with benches for the public (the Parkbench).

2. Cycle Bridge Ritsumasyl - The public client opted for a two staged client-led approach for the development and realization of a movable cycling bridge of bio-based composite materials. Both the contractor and the supplier of the innovative bridge deck were involved early in the design process. In the first stage the innovative bridge deck was developed and tested in parallel with the development of the movable bridge design. After most uncertainties in the design and performance of the bridge were mitigated during the first stage, the movable cycle bridge with a swing design was realized under and integrated contract in the second stage with the inclusion of the developed bridge deck of bio-based materials.

3. Boekelo bridge - The public client requested tenderers to include up to three innovative solutions in their tender offer, for which they could gain a competitive advantage in the award of the tender. To calculate the extent of the competitive advantage of the offered innovations were assessed based on their degree of innovativeness, as well as, the scale on which they were applied in the design and realization of the initiative. One process and two product innovations were implemented the initiative: a) engineer and build in mixed reality, b) solar panels in the road surface, and c) low temperature baked powder coating. The bridge design itself was also innovative and made use of fully 3d modelled formworks to cast the abutments.

4. Northern ring road Gemert - The project focused on the realization of a new ring road including three roundabouts and a bicycle bridge, along with the restoration of

a creek. The public client used an integrated design and construct contract in combination with a European open tender for the project. Furthermore, they included the reduction of CO2 emissions as an award criterion in the tender next to project management and accessibility & traffic flow in the village during the realization of the project. Innovation was included as a sub-criterion of the award criterion reduction of CO2 emissions. The contractor to which the initiative was awarded provided three innovative solutions in their tender offer: (1) a 3d-printed bicycle bridge, (2) the construction of a roundabout next to its final location, and (3) the longest composite arch bridge at the time of construction.

5. Vechtdal Connection - The main challenge for the public client in this project was to realize as much of the scope of the project within a limited available budget. To tackle this challenge the province differentiated the scope of the project into: a) a package of necessary improvements which are a fixed part of the scope of the project and b) 15 optional optimization measures which could be included by the tenderers in their tender offer to receive a fictional reduction on their tender price as a competitive advantage in the award of the tender. Stimulating innovation was not an explicit goal in this program. Nevertheless, the use of an integrated contract in combination with sufficient design freedom allowed for the implementation of incremental product and process optimisations.

6. Quay Walls programme - A large share of the quay walls in the city of Amsterdam is in a deteriorated state since their upkeep has not been sufficient to offset their natural decay for many years. The municipality used an innovation partnership procedure for the development and testing of new solutions. So far, the innovation partnership resulted in the development of three new solutions for the renovation of quay walls: a) renovation of quay walls with the use of prefab elements (EZ-flow), b) renovation using a self-propelling pile driven system (GRB system), and c) circular renovation of quay walls from the water with electric equipment (Save).

7. Implementation of the Roadmap Urban Lighting - The public client has developed a roadmap for the transition of its urban lighting system into a smart open lighting grid up to 2030 in collaboration with the university of Eindhoven (den Ouden & Valkenburg, 2012). For the implementation of the roadmap the municipality opted for a long-term collaboration with a contractor using a scalable approach for the development and maintenance of the lighting systems. The municipality used the competitive dialogue procedure with elements from best value procurement for the tendering of this assignment. The initiative started with three pilot areas in which a four step approach was used: 1) replacing the existing light bulbs to led, 2) mapping

the needs and requirements, 3) developing ideas and solutions, and 4) realizing the developed solutions. Unfortunately, the client and the consortium jointly decided to terminate the initiative prematurely in 2019 before the realization phase for the innovations started (van Galen, den Ouden, & Valkenburg, 2020).

Table 1a: Characteristics of the procurement initiatives and reasons for stimulating innovation

	Case	Involved Public Organizations	Scope of the initiative	Aims and objectives of the initiative	Budget and duration of the initiative	Reasons for stimulating innovation
Project	1. Functional Barriers	- Municipality of Amsterdam - Municipality of Rotterdam - Rijkswaterstaat	Development and testing of new types of multifunctional physical barriers.	- To reduce construction nuisance and improve the experience of the public near construction sites.	- € 0.55 million - Approx. 18 months	- Contribute to policy goals including the stimulation of private sector innovation
	2. Ritsumasyl Cycle Bridge	- Province of Friesland	Development of a movable bridge deck made of bio-based composite materials. Replacement of a road bridge with the developed bicycle bridge using a movable bridge deck using bio-based composite materials.	- To develop and realize a movable bicycle bridge using bio-based composite materials. - To facilitate the passage of larger Va class ships through the channel. - Use an innovative and sustainable approach in the project. - To Realize the project in collaboration with businesses and educational institutes.	- € 6.6 million - Approx. 12 months for the development and 9 months for the realization of the bicycle bridge.	- Address a project goal which cannot be met by conventional solutions and contribute to innovation and sustainability as policy goals.

Table 1b: Characteristics of the procurement initiatives and reasons for stimulating innovation

	Case	Involved Public Organizations	Scope of the initiative	Aims and objectives of the initiative	Budget and duration of the initiative	Reasons for stimulating innovation
Project	3. Boekelo Bridge	- Municipality of Hengelo - Province of Overijssel - Rijkswaterstaat	Design and construction of a bridge to replace an old bridge.	- To realize an appealing bridge of high architectural and aesthetical quality. - To realize added value through product and process innovations. - To reduce construction hindrance.	- € 8.2 million - approx. 2.5 years	- Stimulate private sector innovation as a policy goal
	4. Gemert Northern Ring Road	- Province of Noord-Brabant	Design and construction of a new ring road and restoration of a creek.	- To realize a new traffic connection. - To maintain and improve the flora and fauna network. - Reduction of CO2 emissions in the project.	- Approx. € 4 million - € 6 million - 15 months	- Contribute to policy goals including the stimulation of private sector innovation
	5. Vechtdal Connection	- Province of Overijssel	Realization, renovation and improvement of three provincial roads, including junctions, civil engineering works and optimization measures.	- To realize a new traffic connection. - To renovate and improve three provincial roads. - To realize as many optimization measures as possible within the set budget. - To reduce construction nuisance and CO2 emissions.	- € 101.8 million - Approx. 5 years	- Contribute to project objectives and policy goals

Table 1c: Characteristics of the procurement initiatives and reasons for stimulating innovation

	Case	Involved Public Organizations	Scope of the initiative	Aims and objectives of the initiative	Budget and duration of the initiative	Reasons for stimulating innovation
Programme	6. Quay Walls Innovation Partnership	- Municipality of Amsterdam	Development and procurement of new solutions for the restoration of quay walls.	- To reduce costs, lead times and construction nuisance in the restoration of quay walls in the inner city.	- € 0.6 million to develop and max. 50% of future quay wall projects in a framework contract. - Two-year award and development, and 4+2+2 year framework contract.	- Address an organizational challenge which cannot be met by conventional solutions.
	7. Implementation of the Roadmap Urban Lighting	- Municipality of Eindhoven	- Development of the public lighting systems to a smart and open lighting grid. - Maintenance and exploitation of the public lighting grid.	- To create an open smart light grid. - Collaboration in quadruple helix. - Long-term continual innovation process. - To contribute to social and environmental sustainability of the city. - To maintain and enhance the reputation of the city as the “City of Light” and increase the quality of life in the city.	- € 20.5 million - Five-year contract with ten-year extension.	- Contribute to long-term policy goals.

Table 1d: Characteristics of the procurement initiatives and reasons for stimulating innovation

	Case	Involved Public Organizations	Scope of the initiative	Aims and objectives of the initiative	Budget and duration of the initiative	Reasons for stimulating innovation
Programme	8. Smart Way to Sustainable Municipal Buildings	- Municipality of Eindhoven	Renovation, maintenance and exploitation of seven municipal buildings in the city centre.	- To realize sustainable accommodation for civil servants in the city centre based on a solid business case and in the light of the transition to new ways of working.	- € 106 million - Ten-year contract with five-year extension	- Contribute to long-term policy goals

Table 2a: Procurement strategy; Overall strategy and applied tendering methods

	Case	Procurement strategy					
		Overall strategy	**Procurement Procedure**	**Project delivery model**	**Market approach**	**Selection criteria**	**Award criteria**
Project	1. Functional Barriers	Targeted subsidies and pilot projects for the development and testing of new solutions	SBIR procedure (Small Business Innovation Research, targeted R&D subsidy)	- Subsidy contract for R&D. - Small assignment for testing purposes	- Collaborative call for proposals. - Plenary information session. - Individual sessions during SBIR procedure	Feasibility research: - Impact on project goals - Technical feasibility - Economic perspective - Price	R&D phase - Same as selection criteria. - Opportunity to further explain the plan of action
	2. Ritsumasyl Cycle Bridge	A two-stage approach for the development, testing and implementation of a specific innovation within a bridge project	Contractor: - European restricted tender Producer: - European open tender	- Construction design team contract for the design and feasibility of the bridge - Integrated contract for the realisation of the bridge	Contractor: - Individual information session in award phase Producer: - Plenary information session - Individual information session	Contractor: - Experience with comparable technical works. - Experience with collaborative design processes. - Experience with development of innovations Not applicable for producer	Contractor: - Vision on collaboration in construction design team - Price Producer: Price and quality (based on plan of action) - Knowledge and expertise on bio-based composite materials. - Collaboration in construction design team

Table 2b: Procurement strategy; Overall strategy and applied tendering methods

	Case	Procurement strategy					
		Overall strategy	**Procurement Procedure**	**Project delivery model**	**Market approach**	**Selection criteria**	**Award criteria**
Project	3. Boekelo Bridge	Integration of design and construction activities in combination with the application of a specific model for assessing innovation	- European restricted standard tender procedure	Integrated contract: - Full design for the construction of the bridge. - Execution of the design and construction of a traffic lane.	- Traditional market approach (Publication and written information notices).	- Integration of core competences - Innovation	- Price - Architectural and aesthetical quality of the bridge - Innovation - Realization time
	4. Gemert Northern Ring Road	Integration of design and construction activities, in combination with the assessment of CO2 emissions in the tender	European public standard tender procedure	Integrated contract: Detailed design and realization of the work	- Plenary information session. - Opportunity for individual information session in the event of genuine commercial interest	- Not applicable	- Price - Ensured accessibility, safety and traffic flow - Project management. - Sustainability (CO2-emission, substantiation and innovation)

Table 2c: Procurement strategy; overall strategy and applied tendering methods

	Case	Procurement strategy					
		Overall strategy	**Procurement Procedure**	**Project delivery model**	**Market approach**	**Selection criteria**	**Award criteria**
Project	5. Vechtdal Connection	Integration of design and construction activities in a large contract in combination with an optional optimization measures package as part of the tender offer	- European restricted tender procedure	Integrated contract: - Design and realization of the work	- Traditional market approach (Publication and written information notices) - Bus tour	- Drawing of lots	- Price. - Offered optimization measures. - Reduced construction nuisance for road users and the environment - Sustainability in the realization of the project
Programme	6. Quay Walls Innovation Partnership	Targeted subsidies and pilot projects for the development and testing of new solutions followed by a framework contract	Innovation partnership (procedure for the development and implementation of innovations)	- Subsidy contract for development and testing of prototypes - Framework contract with multiple suppliers for the renovation of quay walls in the city	- Three plenary market consultations - Request for feedback on concept tender documents through information notices	- Vision on innovation development and innovativeness with respect to seven topics	Preliminary award criteria R&D phase: - Scalability of solutions - Impact on direct environment (time/nuisance) - Future value with respect to maintenance, sustainability and multi-functionality - Team, collaboration and plan of action - Price

Table 2d: Procurement strategy; overall strategy and applied tendering methods

	Case	Procurement strategy					
		Overall strategy	**Procurement Procedure**	**Project delivery model**	**Market approach**	**Selection criteria**	**Award criteria**
Programme	7. Implementation of the Roadmap Urban Lighting	Using the flexibility of a large and long-term contract to develop and implement new solutions	Competitive dialogue (procedure including dialogue sessions with the tenderers)	- Five-year concession agreement for five pilot areas. - Ten-year concession agreement for the entire city	- Plenary information session - Several individual consultations - Two rounds of dialogue sessions	- Operational management of public lighting installations - Innovativeness - Business models for public services - Anticipation of social needs - Sustainable business management	Best value procurement: - Underpinning performance of transformation to smart lighting-grid, quadruple helix, exploitation and sustainability. - Risk dossier - Opportunities dossier - Quality of key functionaries
	8. Smart Way to Sustainable Municipal Buildings	Using the flexibility of a large and long-term contract to develop and implement new solutions	Competitive dialogue (procedure including dialogue sessions with the tenderers)	Ten-year contract with option to extend for five years	- Elaborate market consultation involving five sessions - Two rounds of dialogue sessions	- Improvement of energy efficiency - System-oriented sustainability approach - Organizational flexibility	First funnel: - Underpinning collaboration performance Final award based on best value procurement: - Underpinning sustainability performance and business case - Risk dossier on collaboration and other subjects - Opportunities dossier - Quality of key functionaries

Table 3a: Realization of innovations

	Case	Aims of innovation	Targeted technology readiness levels (start/end)	Type of realized innovations	Based on tender documents: Role of public client in innovation process and client-contractor relationship
Project	1. Functional barriers	Development and testing of new types of construction fences to reduce construction nuisance and improve and improve the experience of the public around construction sites	TRL 6-7 at the end of the initiative	Three substantial product innovations	Supportive role; Competition based coopetition
	2. Cycle Bridge Ritsumasyl	Development and implementation of a cycle bridge with an openable bridge deck of bio-based materials	TRL 3 at the start of the initiative; TRL 8 at the end of the initiative.	One radical product innovation	Leading role; Cooperation based coopetition
	3. Boekelo bridge	Implementation of product innovations in the bridge and/or process innovations for the realization of the bridge	TRL 6 at the start of the initiative; TRL 8 at the end of the initiative	One incremental product innovation, one radical product innovation and one substantial process innovation.	Limited role; Competition based coopetition
	4. Northern ring road Gemert	Implementation of solutions to reduce CO2 emissions, and improving project management and traffic flow during the realization of the initiative	TRL 6 at the start of the initiative; TRL 8 at the end of the initiative	One substantial product innovation, one substantial process innovation, and one radical process innovation	Limited role: Competition based coopetition
	5. Vechtdal Connection	No specific focus. Potential innovations could improve sustainability and traffic flow during the realization of the initiative	TRL 7-8 at the start of the initiative; TRL 8-9 at the end of the initiative	Process optimisations	Very limited role; Competition

Table 3b: Realization of innovations

	Case	Aims of innovation	Targeted technology readiness levels (start/end)	Type of realized innovations	Based on tender documents: Role of public client in innovation process and client-contractor relationship
Programme	6. Quay Walls	Development and implementation of new scalable solutions for increasing the rate at which quay wall renovations can be performed while limiting nuisance to the public	TRL 3-5 at the start of the initiative; TRL 8-9 at the end of the initiative	One radical and two substantial innovations, each including both product and process innovation.	Supportive role; Competition based coopetition
	7. Implementation of the Roadmap Urban Lighting	Implementation of innovations on the lighting grid of the city to increase the quality of life of the citizens in the city.	Targeted TRL levels between 4 and 9	Innovative collaboration process (quadruple helix). Initiative ended prematurely before product innovations could be implemented	Supportive role; Competition based coopetition
	8. Smart way to Sustainable Municipal Buildings	Implementation of new solutions for the renovation and maintenance of municipal buildings with the aim to make them energy neutral and more sustainable	Targeted TRL levels between 4 and 9	One substantial process innovation and several incremental product innovations	Supportive, facilitating role; Coopetition;

8. Smart way to Sustainable Municipal Buildings - Similar to case seven, the pubic client used the competitive dialogue procedure with elements from best value procurement for the tendering of the assignment to make their buildings more energy efficient and sustainable. One of the first results of this project is the circular renovation of the city hall tower in which 95% of the materials was either reused, sold through a purpose build web shop, or recycled. The tower is also used as a living lab to test new technologies such as smart climate systems.

5.6. Positioning of the projects and programmes in the developed typology

Based on the tender documents, a cross case comparison is made in this section between the characteristics of each of the eight cases with respect to the three dimensions of the innovation-encouraging procurement typology:

- The scope, aims and objectives of the initiative;
- The type and degree of the realized innovation;
- The type of public client – contractor relationship.

Based on the identified characteristics of each case, it was possible to position each case into one of the cells of the developed typology. The result of this classification is visualised in Table 4. Note, that on the dimension "Public client – contractor relationship" none of the cases were classified as "pure cooperation". This is not strange, since the tender regulations prescribe at least a minimum level of competition.

The scope, aims and objectives of the projects and programmes

With respect to the scope, aims and objectives, a distinction is made between projects and programmes. As explained in the brief case descriptions and in tables 2-4, cases 1-5 were classified as civil engineering projects. They are characterized by a narrowly defined scope that focusses on achieving specific objectives and performing specific tasks within a short to medium time frame. In contrast, cases 6-8 could be classified as civil engineering programmes due to their broadly defined scope and the multiple projects to realize the aims and objectives in relative long to very long timeframe.

Table 4a: Three-dimensional typology populated with the cases from the multiple case study: Degree of innovation VS Scope and timeframe

		Degree of Innovation		
		Low	**Moderate**	**High**
Scope and timeframe	**Project** (fixed scope and timeframe)	*Regular* 5. Vechtdal Connection	*Innovation-oriented* 1. Functional Barriers 3. Boekelo Bridge 4. Gemert Northern Ring Road	*Innovation-driven* 2. Ritsumasyl Cycle Bridge
	Programme (adjustable scope and timeframe)	*Regular*	*Innovation-oriented* 8. Smart Way to Sustainable Municipal Buildings 7. Urban Lighting Roadmap Implementation	*Innovation-driven* 6. Quay Walls Innovation Partnership

Table 4b: Three-dimensional typology populated with the cases from the multiple case study: Degree of innovation VS Client-contractor relationship

		Degree of innovation		
		Low	**Moderate**	**High**
Client-contractor relationship	**Pure Cooperation**			
	Cooperation based coopetition			2. Ritsumasyl Cycle Bridge
	Coopetition		8. Smart Way to Sustainable Municipal Buildings	
	Competition based coopetition		1. Functional Barriers 3. Boekelo Bridge 4. Gemert Northern Ring Road 7. Urban Lighting Roadmap Implementation	6. Quay Walls Innovation
	Pure Competition	5. Vechtdal Connection		

The type and degree of the realised innovations

Table 3 provides an overview of the type and TRL levels of the realized innovations in the eight cases. Case 2 (the Ritsumasyl bridge project) and case 6 (the Quay walls programme) are characterised by a low TRL level (3) and are therefore classified as a high degree of innovation. Case 1 (the Functional Barriers project), Case 3 (the Boekelo bridge project) and case 4 (Gemert Northern Ring project), case 7 (Urban Lighting Roadmap Implementation programme) and case 8 (Smart way to sustainable Municipal Buildings programme) are characterised by a moderate TRL level (4-6) and are therefore classified as having a Moderate degree of innovation. Finally, case 5 (Vechtdal Connection project) is characterised by a high TRL level (7-8) and has there been classified as a Low degree of innovation. Note that all three

civil engineering programmes (cases 6-8) also include projects with a lower degree of innovation. However, we have classified these cases according to their lowest TRL level, since the successful realisation of the projects with a low TRL Level, will ultimately also determine the successful completion of the programme.

The type of public client – contractor relationship

Table 3 provides an overview of the type of public client – contractor relationships for each of the eight cases. The public client-contractor relationships varied, according to Eriksson's (2008) continuum for client-contractor relationships, from "Cooperation based coopetition" to "Pure competition". In case 5 (Vechtdal connection project), the role of the public client in the innovation process was the most limited. It only consisted of providing solution space by providing a list of alternatives in the tender requirements from which the tenderers could select one alternative to implement. The public client-contractor relationship was purely based on competition. In cases 3 (Boekelo bridge project) and 4 (Gemert Northern ring road project), the role of the public client in the innovation process was also fairly limited. In both cases the public client-contractor relationship can be characterised as a "competition based coopetition", although case 3 was a slightly more focused on competition if compared to case 4. This was due to the inclusion in case 4 of a market consultation and the option for individual information sessions. In both cases, the public client actively stimulated the implementation of innovations in the tender, but played a limited role in the innovation process. The main role of the public client was to assess if the proposed solutions could be realized within the tender requirements. For case 3 this required the development of a new assessment method for assessing the innovative design of the bridge. In cases 7 (Implementation of the Urban Lighting programme) and 8 (Smart way to sustainable municipal buildings programme) the public client played a more supportive role in the innovation process. For example by allowing for optimizations in the scope during the tender for the proposed business cases. Later, in the realization phase of the cases the public client discussed the potential of the proposed solutions with the contractor and assisted in providing the needed boundary conditions for the implementation of these innovations. However, if compared to case 8, case 7 can also better be classified as a "Competition based cooperation" while case 8 fits with a "Coopetition" based relationship. One of the main differences between the two cases was a stronger focus in case 8 on collaboration in the selection and assessment criteria, as well as the market approach.

In cases 1 (Functional Barriers project) and 6 (Quay walls programme) the public client also played a supportive role in the innovation process. However, there were two major differences between these two cases in comparison to cases 7 and 8, which

effected the role of the public clients. First, the development of innovations played a more prominent role in both cases 1 and 6. Second, it was much clearer which innovations needed to be developed and tested in cases 1 and 6 at the time of the tender contract closure. Within the innovation process the tenderers provided their client perspective and expertise on the feasibility and desirability of the proposed innovations on a regular basis. Furthermore, multiple information sessions were organized as part of the market approach. As such, the public client-contractor relationship can be characterized as a "competition based coopetition".

Case 2 (Ritsumasyl bridge project) clearly stands out from the other cases. Prior to the tender phase the public client stated the ambition to develop and implement a specific radical innovation. To this end, the public client used a two stage approach for the development and realization of the engineering work with the inclusion of the innovation. The first part consisted of a collaborative development and testing of the innovation, and the development of the design of the civil engineering work including the innovation. Only after extensive testing, the public client signed the design and construct contract for realizing the civil engineering work including the developed innovation. The public client also significantly reduced the financial liability for the contractor and the producer of the innovation and strongly collaborated with both parties during the development and realization of this bridge project. As such, the public client-contractor relationship can be classified as a "Cooperation based coopetition".

5.7. The cases and their selected procurement strategy

The scope, aims and objectives of the cases and the degree of innovation were found to have a major influence on the selection of a procurement strategy with respect to innovation in several ways.

Case 2: A Project characterised by a high degree of innovation

In case 2 (Cycle bridge Ritsumasyl project) the development and testing of a radical innovation was a major part of the scope of the project. For this reason, the public client developed a procurement strategy that was specifically geared towards the development of this innovation. The *standard open and restricted procurement procedures* used in case 2 seem to suggest the stimulation of innovations with higher TRL levels. However, these procedures were used within a two staged approach that enabled the development and realization of the intended innovation, which makes the use of these procedures suitable for the developed innovations.

Case 1, 3 and 4: Three Projects characterised by a moderate degree of innovation

In Case 1 (Functional barriers project) the public organizations included a small assignment for testing purposes in addition to the *SBIR procedure.* This with the aim to provide tenderers the opportunity to test their developed innovations in a real life situation. Case 3 (Boekelo bridge project) and 4 (Northern Ring Road Gemert) were similar in terms of scope, aims and objectives in the sense that they both aimed to stimulate the implementation of innovations in a project for the design and realization of public infrastructure with a budget under 10 million euro and a planned duration of less than three years. Due to the relative short duration of these cases the public organizations could only stimulate innovations which required limited time for development and testing prior to implementation. The procurement strategies were similar in that they allowed for design freedom through the use of *integrated contracts* and they both used *standard tendering procedures*. Despite this, the reasons for stimulating innovation and the used tendering methods for stimulating innovation differed significantly. In case 3, innovation played a strong role in the selection as well as the award phases of the restricted tender procedure used in the project. In the selection phase, the number of candidates was reduced based on: (a) their ability to integrally perform five pre-defined core competences; and (b) the extent to which candidates could convincingly prove that innovation is not only part of their corporate strategy but had also resulted into the development and application of innovations in projects comparable to case 3. In addition, innovation was chosen in the award phase as one of the award criteria in determining the quality of the tender offers. In case 4, innovation was primarily stimulated to reduce CO2 emissions in the realization of the work. To achieve this, innovation was introduced as a sub criterion of the award criterion for reducing CO2 emissions. In addition, innovative solutions with respect to project management, accessibility and traffic flow during the realization of the work were indirectly stimulated as well since these subjects were included as the other award criteria.

Case 5: A Project characterised by a low degree of innovation

With a budget of more than 100 million case 5 (Vechtdal Connection project) is expected to be completed within five years. The public client decided to combine a number of projects in the tender of case 5. This was done with the underlying assumption that this could lead to possible optimizations. Innovation was considered of minor importance in case 5 and was therefore not explicitly part of the procurement strategy. An integrated contract and standard tender procedure were used for this project. Despite this selection, innovations that contributed to sustainability improvement and toward a limitation of construction nuances could

still be implemented. But it was fully left to the tenderers if they saw sufficient benefits in proposing alternative solutions to reduce construction nuance and improve sustainability in the realization of the Vechtdal Connection project.

Case 6: A Programme characterised by a high degree of innovation

In Case 6 (Quay wall programme) new scalable solutions for the restoration of quay walls had to be developed and implemented. This required one radical and two substantial innovations, each including both product and process innovations. To this end the *Innovation Partnership procedure* was chosen. An approach that is specifically suitable for the development of new solutions.

Case 7 and 8: Two Programmes characterised by a moderate degree of innovation

Cases 7 (Implementation of the Roadmap Urban Lighting) and 8 (Smart way to sustainable Municipal Buildings programme) are two long term programmes of considerable size in which the implementation of innovations was important for reaching the aims and objectives of the programmes. The large size and long duration of these cases allowed for the use of economies of scale and provided a significant amount of time which could be used to recoup investments in innovative solutions. In both cases the public client decided to not fully determine the scope of the case before the tender to allow for optimizations in the scope based on the input of the tenderers. As a result, tenderers were able to optimize their business case with respect to the development and implementation of innovations. To make the optimizations in the scope possible, in both cases the client consulted the market before the tender and used a *competitive dialogue in combination with elements of best value procurement* in both cases. The use of the competitive dialogue allowed for more negotiation and communication with respect to the scope of the assignment in comparison to traditional tender procedures.

5.8. A theory-based reflection on the positioning of the cases in the typology

Based on what is known in literature, we hereby evaluate on the positioning of the respective cases in the typology. We also reflect on the suitability of the different configurations of the typology to encourage innovation.

Case 1 (Functional Barriers): A project classified as a Moderate degree of innovation and with a Competition based coopetition.

The innovation risks that are involved in the development of multifunctional construction fences such as in case 1, are relatively low (The Ministry of Infrastructure and Water management reports a TRL 6). This type of developing products are pre-

eminently assignments that can be asked out to the market in competition. However, from the public client a supporting role is still required to harmonize the requirements and to formally approve the designs to be installed on roadways. The SBIR procedure that was chosen in case 1, has specifically been designed to facilitate these types of pre-commercial developments (Rigby, 2016).

Case 2 (Ritsumasyl project): A project classified as a High degree of innovation and with a Cooperation based coopetition.

For radical innovations, such as the Ritsumasyl project, the unilateral allocation of innovation risks to the main contractor is undesirable since most of the associated innovation risks are difficult to assess and manage due to the inherent uncertainties. A study conducted by Lenderink et al. (2022) showed that a proactive participation of the public client in the initiation, development and implementation of the project and the willingness to bear innovation risks were essential to successfully realise this innovation project. In addition, Khalfan, McDermott, Li, Arif, and Kashyap (2008), concluded that a public client can act as a catalyst to promote innovative thinking through supporting public client-supplier-manufacturer collaboration. Hence, a separate tender- as happened in Case 2 - to include the knowledge and expertise of a key subcontractor in the project team, was also considered an important stimulus for realizing the intended radical green innovation.

Case 3 (Boekelo bridge) & Case 4 (Gemert Northern Ring Road): Two projects classified as a Moderate degree of innovation and with a Competition based coopetition.

Lenderink et al. (2020) conducted a study about the procurement of the Boekelo bridge project and the way how the project client encouraged innovation in this specific project. Their findings show that the public client triggered innovation by providing sufficient financial incentives for innovation and by using innovation awarding selection criteria. The results show that with respect to the innovation degree of the provided solutions, all solutions were assessed as incremental or moderate innovations on the module or system level of the bridge project. This is not surprising giving the limited time frame in which the tenderers were expected to develop and implement their innovative solutions (Klein and Sorra, 1996). The general conclusion that may be drawn here is that in tenders such as in case 3 and 4, one may not expect radical innovations. An important reason for this is that the development risks are perceived as too high by the contracting parties and that they do not outweigh any returns. To gain tender advantages, contractors will therefore primarily focus on process innovations. Public clients are expected to have a supporting and testing role in cases such as the Boekelo Bridge project and the Gemert Northern Ring project.

Case 6 (Quay Walls): A programme classified as a High degree of innovation and with a Competition based cooperation

In this case the public client requested an innovative approach for renewing the quay walls in Amsterdam. For this approach both product and process innovations were needed. The innovative approach had to be developed from TRL 1 to TRL9. Consequently, the programme entailed a great deal of uncertainty for the market parties involved. Besides technological uncertainty, market parties were also unsure if their investment would result profitable. The public client decided to use the Innovation Partnership procedure as an instrument to develop, together with market parties, the required innovations. Agreements regarding the available fixed budget and Intellectual Property were made in a phase in which the TRL was still on a 2-3 level. Given the uncertainties and related high innovation risks the fixed budget understandably led to tensions between public client and contracting parties. In a comparative study between the Quay walls programme and the "Sterke Lekdijk" programme, Heming (2021) concluded, that an open budget during the development and engineering phase, followed by a fixed budget in the construction phase such as in the "Sterke Lekdijk" programme, are to be preferred for cases characterized by a High degree of innovation. The arrangement that was followed in the "Sterke Lekdijk" programme considerably decreased the uncertainty and innovation risks for the market parties. In conclusion, for projects and programmes characterized by a high degree of innovation, a Cooperation based coopetition (such as in the Ritsumasyl project) or at least a Coopetition based public client – contractor relationship is required.

Case 7 (Urban Lighting Roadmap Implementation) & Case 8 (Smart Way to Sustainable Municipal Buildings): Two programmes classified as a Moderate degree of innovation and with Competition based coopetition (Case 7) and a Coopetition based cooperation (Case 8).

Dubois and Gadde (2002) view learning as the sine qua non of technological innovation. From a learning perspective, a programme offers the opportunity to co-ordinate, re-use and progressively develop technology across projects over time. Dorée and Holmen (2004) have convincingly illustrated the successive development of an offshore assembly technology for large bridges across five large projects. Similarly, the technology development process in cases 7 and 8 can be characterised as a process that was designed to successively develop, implement and further upgrade incremental innovations across projects. To realise a successful business case in a long-term programme such as in case 7 and 8, it must be possible to adjust, if necessary, the requirements and the wishes of the involved stakeholders. From a risk management perspective, a Coopetition based relationship between public client and

contractor is by far preferred above a Competition based coopetition (as was applied in case 7).

Note, that some of the configurations along the three dimensions of the typology do not meet the requirements to serve as ideal types for innovation-encouraging procurements. As earlier mentioned, "Pure cooperation" on the dimension "Public client – contractor relationship", is an "empty set", since the tender regulations prescribe at least a minimum level of competition. Also, "Pure competition" on the dimension "Public client – contractor relationship" can be characterised as an empty set, since at least a minimum of coopetition between public client and contractor is required to realize innovation in civil engineering projects and programmes (Eriksson, 2017). This explains why the procurement strategy for Case 5 (Vechtdal connection project) - not having any innovation-encouraging awarding procurement criteria - could be classified as "Pure competition". In case the focus on innovation is missing or less relevant, public clients may apply standard procedures and fulfil their testing role. An increase in scope, through the merging of projects, or in case a project has a long duration, there will be room for incremental innovations and optimisations. In such cases, a public client may also support the implementation of incremental innovations that do not correspond to the standards that are used. Another configuration which may be considered as an "empty set" are the projects or programmes with a low degree of innovation and with a "Cooperation based coopetition" type of cooperation. These low risk type of projects or programmes do not require such an intense involvement from the public client and can be realised with traditional competitive procurement procedures (Eriksson, 2010). And, as concluded for case 6 (Quay walls programme), from an effective innovation procurement strategy perspective, also the configuration with a High degree of innovation and Competition based coopetition should be treated as an "empty set". In Table 4 a dotted line has been drawn in the cells which are considered as "empty sets".

5.9. Guideline for selecting an innovation-encouraging procurement strategy

This section provides a general guideline for the selection of an innovation-encouraging public procurement strategy. Depending on the type of project or programme, a different procurement strategy is suggested. Table 5 (project perspective) and 6 (programme perspective) provide an integral picture of three different Procurement Strategies: Regular procurement (Low degree of Innovation,

particularly product and process improvements); Innovation oriented procurement (Moderate degree of Innovation); and Innovation driven procurement (High degree of Innovation).

Based on the conducted literature review and analysis of the case results, the most important characteristics for procurement projects (Table 5) and procurement programmes (Table 6) are included. Depending on the degree of Innovation, the changes per characteristic and the steps that are required to take are specified in respectively Tables 5 and 6. Both Tables 5 and 6 show that with a higher degree of innovation and consequently higher innovation risks, public clients should be open to bear at least a part of the innovation risks. And due to the inherent uncertainties in the development process, a more intense collaboration between public client and contracting parties is required. Rather than impose conditions unilaterally in the tender contract, the aim should be to arrive at jointly supported agreements. The public client should also create sufficient space for adaptation after tendering. This to prevent that promising solutions are excluded in advance.

As stated, Table 5 and 6 provide a general guideline. Depending on the specific project or programme, further details need to be elaborated.

Table 5a: A general guideline for the selection of an innovation-encouraging procurement strategy for civil engineering projects

Project				
		Procurement Strategy		
Initiative	**Characteristics**	**Regular project**	**Innovation oriented project**	**Innovation driven project**
	Aim & objectives (project goals)	Product & process Improvements	Product & process Development	Product & process Innovation
	Scope	Optimizations in general	Inventory of possibilities, to develop specific parts	Focussed at specific topic/part of the project
	TRL level	High TRL level, Deployment phase	Moderate TRL Level, Demonstration Phase	Low TRL level, Development Phase
	Budget for innovation	Not Applicable	Direct or indirect (through criteria)	Separate Development budget
Tendering Methods	Procedure	Restricted/open bid procedure	Restricted bid procedure	Two staged bid procedure, special procedures (SBIR)
	Project delivery model	Integrated Contract	Integrated or Two staged contract	Two staged contract
	Awarding criteria	Quality of suggested improvements/ price ratio	Quality of suggested innovative solutions/ price ratio and Collaboration	Quality of Collaboration & Innovation competencies
	Pricing	In competition	In competition or fixed	Negotiated

Table 5b: A general guideline for the selection of an innovation-encouraging procurement strategy for civil engineering projects

Project				
		Procurement Strategy		
	Characteristics	**Regular project**	**Innovation oriented project**	**Innovation driven project**
Public Client-contractor relationship	Client – Contractor Relationship	Competition based, with separated responsibility	Competition based coopetition or Coopetition with separated responsibilities	Collaboration based coopetition with joined responsibilities
	Role of the Client	Supporting	Supporting or Facilitating	Participating, bearing a significant part of the risk

Table 6a: A general guideline for the selection of an innovation-encouraging procurement strategy for civil engineering programmes.

Programme				
		Procurement Strategy		
Initiative	**Characteristics**	**Regular programme**	**Innovation oriented programme**	**Innovation driven programme**
	Aim & objectives (long term goals)	Product & process Improvements in multiple projects	Product & process Development through subsequent projects	Product & process Innovation through subsequent projects
	Scope	Continuous Improvements & Optimizations	Development and implementation of promising possibilities	Innovation focussed at a specific topic
	TRL level	High TRL level, To be realised by projects with demonstrated technology	Moderate TRL Level, Technology developed, but still to be demonstrated in subsequent projects	Low TRL level, Technology still to be developed and demonstrated in subsequent projects
	Budget for innovation	Not Applicable	Integrated in total programme budget	Dedicated in total program budget
Tendering Methods	Procedure	Competitive Dialogue	Competitive Dialogue (Best Value)	Innovation Partnership, SBIR
	Project delivery model	Concession, DBFM	Two staged contract (Development/Frame-work Agreement)	Two staged contract (Development/Framework Agreement)
	Awarding criteria	Quality / price ratio	Quality achieving programme goals / price ratio and Collaboration	Quality of Collaboration & Innovation Competencies, Achieving programme goals
	Pricing	In competition	Negotiated as business case (adjustable scope)	Negotiated as business case (adjustable scope)

Table 6b: A general guideline for the selection of an innovation-encouraging procurement strategy for civil engineering programmes.

Programme				
		Procurement Strategy		
		Regular programme	**Innovation oriented programme**	**Innovation driven programme**
Public Client-contractor relationship	Client – Contractor Relationship	Competition based, with separated responsibility	Competition based coopetition or Coopetition with separated responsibilities	Collaboration based coopetition with joined responsibilities
	Role of the Client	Supporting	Supporting and facilitating	Pro-active, shared risk bearing of additional developments

5.10. Contributions and recommendations for future research

The role of demand, as an enabler and source of innovation has been a topic in innovation studies and innovation policy for quite some time (Edquist et al. 2015). Both public procurement and innovation are nowadays well-established research themes in contemporary social science and are recognized as two essential elements in the global effort to achieve the Sustainable Development Goals of the United Nations (United Nations Environment Programme, 2017; United Nations General Assembly, 2015). In the wake of the Lisbon strategy in 2000, also EU heads of state and government identified public procurement and innovation as instruments for qualitative change, for example to develop and implement green sustainable or energy efficient technologies (Rolfstam, 2015). However, in their review of the different streams of literature, dichotomies and typologies on public procurement with respect to inducing innovation, Lenderink et al. (2019) concluded that the various innovation approaches provided little insight into the suitability of these approaches in specific situations that are encountered in procurement practice. In line with the conclusions drawn by Lenderink et al. (2019) we have pointed in the Introduction section of this article on the lack of a systematic overview of innovation-stimulating procurement strategies from which, depending on the specific goals and aims of a public civil engineering project or programme, an effective public procurement strategy could be selected.

The conducted multiple-case study, as described in this article, is among the first to classify the different types of innovation-encouraging procurement strategies in the field of civil engineering. Based on an extensive literature review and the multiple-case study, we were able to deduce that the selection of an effective innovation-encouraging procurement strategy, particularly depends on three important factors. These are: The scope and time frame of the intended project or programme; The degree of innovation to be realized in the specific project or programme; and The level of cooperation that is required between public client and contractor(s) to realize the envisioned project or programme. Based on these three distinguished factors we were able to compose a typology consisting respectively of 15 configurations of innovation-encouraging procurement projects and 15 configurations of innovation-encouraging programmes. After a closer analysis of the configurations, the cases positioned in the typology and relevant literature, we dropped 8 of the 15 configurations of innovation-encouraging procurement projects and also 8 of the 15 configurations of innovation-encouraging programmes.

The developed typology combines and integrates the insights from three streams of research: the management of product and process innovation in the field of civil engineering (Schilling, 2020; Tidd and Bessant 2018; Slaughter, 1998; Lenderink et al, 2020); the insights about public client – contractor collaboration in the field of civil engineering (Love et al, 1998; Eriksson, 2008; Pesämaa et al., 2009; Osipova and Eriksson, 2011); and the available knowledge about the management of scope, aims and objectives to realize civil engineering projects and programmes (Morris and Hough, 1987; Winch, 1998; Gann and Salter, 2000; Pellegrinelli, 2011; Project Management Institute, 2017).

The multiple case study and the literature review also helped us to design (cfm. Van Aken, 2005; Van Aken et al., 2016) a corresponding guideline for selecting a specific procurement strategy. When considering new initiatives, public clients can benefit from the developed guideline as a tool to select the most appropriate procurement strategy considering the aims, goals and objectives of their intended new project or programme.

To a large extent, civil engineering firms depend on public clients to create a market/demand for innovations (Loosemore (2015); Caerteling et al., (2008); Lenderink et al., (2022)). However, Loosemore (2015) and Loosemore and Richard (2015) have also pointed out that many public clients are unwilling to pay for innovations or lack the tools to assess and drive innovation in projects. The results of this paper indicate that to realise innovation in the field of civil engineering, an active role of the public client is essential. To encourage innovation in civil engineering projects and programmes, public clients should at least be willing to limit the financial innovation risks of the contracted parties, and to provide additional incentives, solution space and time for developing and implementing the required innovations.

Naturally, this paper is not without its limitations. First, the case study findings and the developed typology with its corresponding guideline, are based on a multiple case study consisting of eight cases in the field of civil engineering. As such, further case studies are required to establish the external validity of the findings, the developed typology and guideline. Second, the developed typology and the corresponding guideline to select an appropriate innovation-encouraging procurement strategy, provide a general direction for a procurement strategy. More detailed information on the exact scope, timeframe, goals and context of the initiatives will be required to further define and tailor an appropriate and effective procurement strategy. Addressing the research opportunities of the findings of this

study in future research, could make important contributions to the understanding of the determining factors and mechanisms that influence the successful development and implementation of innovations in civil engineering projects. This will also open up opportunities to find solutions for the grand challenges our physical environment is facing.

References

Arrowsmith, S. (2010). Horizontal policies in public procurement: a taxonomy. *Journal of Public Procurement*, 10(2), 149-186.

Blayse, A. M., & Manley, K. (2004). Key influences on construction innovation. *Construction Innovation*, 4(3), 143-154.

Caerteling, J. S., Halman, J. I. M., & Dorée, A. G. (2008). Technology Commercialization in Road Infrastructure: How Government Affects the Variation and Appropriability of Technology. *Journal of Product Innovation Management*, 25(2), 143-161.

Caerteling, J. S., Halman, J. I. M., Song, M., Dorée, A. G., & Van Der Bij, H. (2013). How relevant is government championing behavior in technology development? *Journal of Product Innovation Management*, 30(2), 349-363.

Dalpé, R. (1994). Effects of government procurement on industrial innovation. *Technology in society*, 16(1), pp. 65-83.

Dorée, A.G. & Holmen, E. (2004) Achieving the unlikely: innovating in the loosely coupled construction system. *Construction Management and Economics*, 22(8): 827-83.

Dubois, A. & Gadde, L.-E. (2002) Construction industry as a loosely coupled system. *Construction Management and Economics*, 20(7), 621–631

European Parliament and the Council of the European Union (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. Official Journal of the European Union, 57.

Davies, A., MacAulay, S.C., Brady, T. (2019) Delivery Model Innovation: Insights From Infrastructure Projects, *Project Management Journal*, 50(2), 119-127.

Dreschler, M. (2009). *Fair competition: how to apply the 'economically most advantageous tender'(EMAT) award mechanism in the Dutch construction industry*. PhD thesis, Delft University of Technology, Delft.

EARTO. (2014). *The TRL Scale as a Research & Innovation Policy Tool*, EARTO Recommendations. Retrieved from https://www.earto.eu/wp-content/uploads

Edler, J., Ruhland, S., Hafner, S., Rigby, J., Georghiou, L., Hommen, L., Rolfstam, M, Edquist, C., Tsipouri, L. & Papadakou, M. (2005). *Innovation and public procurement. Review of issues at stake*. ISI Fraunhofer Institute Systems and Innovation Research, Karlsruhe.

Edler, J., & Georghiou, L. (2007). Public procurement and innovation—Resurrecting the demand side. *Research policy*, 36(7), pp. 949-963.

Edler, J. (2009). *Demand Policies for Innovation in the EU CEE Countries*. Manchester Business School Working Paper No 579, The University of Manchester.

Edler, J., Georghiou, L., Uyarra, E., & Yeow, J. (2015). The meaning and limitations of public procurement for innovation: a supplier's experience. In *Public Procurement for Innovation*. Edward Elgar Publishing.

Edler, J., & Yeow, J. (2016). Connecting demand and supply: The role of intermediation in public procurement of innovation. *Research policy*, 45(2), 414-426.

Edquist, C., & Hommen, L. (2000). Public technology procurement and innovation theory. In C. Edquist, L. Hommen, & L. tsipouri (Eds.), *Public technology procurement and innovation* (Vol. 16): Kluwer Academis Publishers.

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2012). Public Procurement for Innovation as mission-oriented innovation policy. *Research policy*, 41(10), 1757-1769.

Edquist, C., Vonortas, N. S., & Zabala-Iturriagagoitia, J. M. (2015). Introduction. In C. Edquist, N. S. Vonortas, J. M. Zabala-Iturriagagoitia, & J. Edler (Eds.), *Public Procurement for Innovation*. Edward Elgar Publishing.

Edquist, C., Vonortas, N. S., Zabala-Iturriagagoitia, J. M., & Edler, J. (2015). *Public Procurement for Innovation*. Edward Elgar Publishing.

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2020). Functional procurement for innovation, welfare, and the environment. *Science and Public Policy*. doi:10.1093/scipol/scaa046

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2015). Pre-commercial procurement: a demand or supply policy instrument in relation to innovation? *R&D Management*, 45(2), pp. 147-160.

Edquist, C., Hommen, L., Tsipouri, L. (Eds.), *Public Technology Procurement and Innovation*. Kluwer Academic Publishers, Dordrecht.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of management journal*, 50(1), 25-32.

Eriksson, P. E. (2008). Procurement effects on coopetition in client-contractor relationships. *Journal of Construction Engineering and Management*, 134(2), 103-111.

Eriksson, P. E., & Westerberg, M. (2011). Effects of cooperative procurement procedures on construction project performance: A conceptual framework. *International Journal of Project Management*, 29(2), 197-208.

Eriksson, P. E., Volker, L., Kadefors, A., Lingegård, S., Larsson, J., & Rosander, L. (2019). Collaborative procurement strategies for infrastructure projects: a multiple-case study. *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law*, 172(5), 197-205. doi:10.1680/jmapl.19.00016

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.

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.

Georghiou, L., Edler, J., Uyarra, E., & Yeow, J. (2014). Policy instruments for public procurement of innovation: Choice, design and assessment. *Technological Forecasting and Social Change*, 86, pp. 1-12.

Geroski, P. A. (1990). Procurement policy as a tool of industrial policy. *International Review of Applied Economics*, 4(2), pp. 182-198.

Grandia, J. (2018). Public Procurement in Europe. In E. Ongaro & S. Van Thiel (Eds.), *The Palgrave Handbook of Public Administration and Management in Europe* (pp. 363-380). London: Palgrave Macmillan UK.

Grandia, J., & Meehan, J. (2017). Public procurement as a policy tool: using procurement to reach desired outcomes in society. *International Journal of Public Sector Management*, 30(4), 302-309.

Halman, J. I. M. (2004). *Platformgedreven innoveren in de bouw* (in English: platform driven development in construction): University of Twente, Enschede.

Halman, J. I. M. (2018). *Met zekerheid in onzekerheid: over innovatie en het nemen van innovatierisico's* (in English: With certainty in uncertainty: About innovation and taking innovation risks): University of Twente, Enschede.

Heming, S. (2021) *Balancing of interests between the clients and contractors within infrastructure Innovation Partnership projects. A comparative study between the Quay walls and the Sterke Lekdijk programmes*. Master thesis study, University of Twente, Enschede.

Henderson, R. M., & Clark, K. B. (1990). Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly*, 35(1), 9-30. doi:10.2307/2393549

Hobday, M. (1998). Product complexity, innovation and industrial organisation. *Research policy*, 26(6), 689-710.

Hobday, M. (2000). The project-based organisation: an ideal form for managing complex products and systems? *Research policy*, 29(7), 871-893.

Hoezen, M., Voordijk, H., & Dewulf, G. (2014). Procuring complex projects using the competitive dialogue. *International journal of project organisation and management*, 6(4), 319-335.

Hommen, L., Rolfstam, M. (2009). Public procurement and innovtion: Towards a taxonomy. *Journal of Public Procurement* 9(1), 17-56.

Khalfan, M. M., McDermott, P., Li, X., Arif, M., & Kashyap, M. (2008). The integration of suppliers and manufacturers within construction supply chains through innovative procurement strategies. *International Journal of Value Chain Management*, 2(3), 358-370.

Klein, K. and Sorra, J.S. (1996) The Challenge of Innovation Implementation. *The Academy of Management Review*, 21(4), 1055-1080.

Kleinschmidt, E.J. and Cooper, R.G. (1991) The impact of product innovativeness on performance. *Journal of Product Innovation Management*. 8(4), 240-251.

Kraljic, P. (1983) Purchasing must become supply management, *Harvard Business Review*, 61(5), 109–117.

Lember, V., Kattel, R., & Kalvet, T. (2014). *Public Procurement, Innovation and Policy: International Perspectives*. Springer Science & Business Media.

Lenderink, B., Halman, J. I. M., & Voordijk, H. (2019). Innovation and public procurement: from fragmentation to synthesis on concepts, rationales and approaches. *Innovation: The European Journal of Social Science Research*, 1-25. https://doi.org/10.1080/13511610.2019.1700101

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. doi:10.1108/CI-05-2019-0044.

Lenderink, B., Halman, J.I.M., Boes, J., Voordijk, H. and Dorée, A.G. (2022) Procurement and innovation risk management: How a public client managed to realise a radical green innovation in a civil engineering project. *Journal of Purchasing and Supply management*, https://doi.org/10.1016/j.pursup.2022.100747

Lenferink, S., Tillema, T., & Arts, J. (2013). Towards sustainable infrastructure development through integrated contracts: Experiences with inclusiveness in Dutch infrastructure projects. *International Journal of Project Management*, 31(4), 615-627.

Loosemore, M. (2015). Construction innovation: Fifth generation perspective. *Journal of Management in Engineering*, 31(6), 04015012. DOI: 10.1061/(ASCE)ME.1943-5479.0000368

Loosemore, M., & Richard, J. (2015). Valuing innovation in construction and infrastructure: Getting clients past a lowest price mentality. *Engineering, Construction and Architectural Management*, 22(1), 38-53.

Love, P. E., Skitmore, M., & Earl, G. (1998). Selecting a suitable procurement method for a building project. *Construction Management & Economics*, 16(2), 221-233.

Magnusson, T., Lindström, G., & Berggren, C. (2011). Architectural or modular innovation? Managing discontinuous product development in response to challenging environmental performance targets. *International Journal of Innovation Management*, 7(1), 1-16. .

Mankins, J. C. (2009). Technology readiness assessments: A retrospective. *Acta Astronautica*, 65(9-10), 1216-1223.

Morris, P. W., & Hough, G. H. (1987*). The anatomy of major projects: A study of the reality of project management*. Wiley, London

Munns, A. K., & Bjeirmi, B. F. (1996). The role of project management in achieving project success. *International Journal of Project Management*, 14(2), 81-87.

Niknazar, P. Bourgault (2017) Theories for classification vs. classification as theory: Implications of classification and typology for the development of project management theories. *International Journal of Project Management* 35(2), 191-203.

OECD. (2011). *Demand-side Innovation Policies*. OECD Publishing.

OECD. (2017). Public Procurement for Innovation.

OECD/Eurostat. (2005). *Oslo manual: Guidelines for collecting and interpreting innovation data*. OECD publishing.

Office of Government Commerce. (2011). *Managing successful programmes*. London: The Stationary office.

Osipova, E., & Eriksson, P. E. (2011). How procurement options influence risk management in construction projects. *Construction management and economics*, 29(11), 1149-1158.

O'Raghallaigh, P., Sammon, D., & Murphy, C. (2010). *Theory-building using Typologies-A Worked Example of Building a Typology of Knowledge Activities for Innovation*. Series

Frontiers in Artificial Intelligence and Applications, E-book: Volume 212: Bridging the Socio-technical Gap in Decision Support Systems. https://doi.org/10.3233/978-1-60750-577-8-371.

Ouden, P. H. den, & Valkenburg, R. (2012). *Vision and roadmap urban lighting Eindhoven 2030*. Eindhoven, The Netherlands: University of Eindhoven.

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

Pellegrinelli, S. (2011). What's in a name: Project or programme? *International Journal of Project Management*, 29(2), 232-240.

Pesämaa, O., Eriksson, P. E., & Hair, J. F. (2009). Validating a model of cooperative procurement in the construction industry. *International Journal of Project Management*, 27(6), 552-559.

Project Management Institute. (2017). *A Guide to the Project Management Body of Knowledge* (sixth ed.). Pennsylvania: Project Management Institute.

Rolfstam, M (2015) Public procurement of innovation for a better world: a consolidation or a new beginning? *Innovation: The European Journal of Social Science Research*, 28(3), 211-219.

Rugby, J. (2016) The impact of pre-commercial procurement on innovation. In: Edler, J.Cunningham, P. Gök, A. and Shapira, P. *Handbook of Innovation Policy Impact*, EU-Esprit Forum on Science Technology and Innovation Policy Series, Edward Elgar Publishing, Cheltenham, UK, pp. 382-402.

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.

Schilling, M. (2020) *Strategic Management of technological innovation*. New York: McGrawHill/Irwin

Semple, A. (2015). A practical guide to public procurement (M. Cook Ed.): Oxford University press.

Shenhar, A.J. & Dvir, D. (1996). Toward a typological theory of project management. Research Policy 25(4), 607-632.

Slaughter, E. S. (1998). Models of construction innovation. *Journal of Construction Engineering and Management*, 124(3), 226-231.

Smith, K. B. (2002). Typologies, taxonomies, and the benefits of policy classification. *Policy Studies Journal*, 30(3), 379-395.

Storper, M. (1997) *The Regional World: Territorial Development in a Global Economy*. New York: Guilford.

Telles, P., & Butler, L. R. A. (2014). Public Procurement Award Procedures in Directive 2014/24/EU. In F. Lichere, R. Caranta, & S. Treumer (Eds.), *Modernising Public Procurement: The New Directive*. Copenhagen: Djof Publishing.

Tidd, J. and Bessant, J.R. (2018) *Managing innovation: integrating technological, market and organizational change*. John Wiley & Sons, West Sussex PO19 1UD England.

United Nations Environment Programme. (2017). *Global review of sustainable public procurement*. Retrieved from: https://www.unep.org/resources/report/2017-global-review-sustainable-public-procurement.

United Nations General Assembly. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. New York. Sustainabledevelopment.un.org.

Uyarra, E., & Flanagan, K. (2010). Understanding the innovation impacts of public procurement. *European Planning Studies*, 18(1), pp. 123-143.

Uyarra, E., Zabala-Iturriagagoitia, J. M., Flanagan, K., & Magro, E. (2020). Public procurement, innovation and industrial policy: Rationales, roles, capabilities and implementation. *Research policy*, 49(1). https://doi.org/10.1016/j.respol.2019.103844.

Aken, J.E. van (2005) Management Research as a Design Science: Articulating the Research Products of Mode 2 Knowledge Production in Management, *British Journal of Management*, 16(1), 19-36.

Van Aken, J.E., Chandrasekaran, A. and Halman. J.I.M. (2016) Conducting and publishing design science research: Inaugural essay of the design science department of the Journal of Operations Management. *Journal of Operations Management* 47-48, 1-8.

van Galen, W. P. L., den Ouden, E., & Valkenburg, R. (2020). *Your light on 040: innovation process: an evaluation*. Eindhoven: Technical University of Eindhoven.

van Weele, A. (2009). *Purchasing and Supply Chain Management* (5th Edition ed.). Hampshire: Cengage Learning Emea.

Volker, L. (2019). *Just a little of that human touch: towards a value-based ecosystem for delivering infrastructure services.* Inaugural lecture, University of Twente, Enschede.

Vosman, L. (2020). *From project to programme : drivers to a programmatic procurement approach in the Dutch construction industry*. University of Twente, Enschede. http://purl.utwente.nl/essays/81329.

Wesseling, J. H., & Edquist, C. (2018). Public procurement for innovation to help meet societal challenges: a review and case study. *Science and Public Policy*, 45(4), 493-502. doi:10.1093/scipol/scy013

Winch, G. (1998). Zephyrs of creative destruction: understanding the management of innovation in construction. *Building Research & Information*, 26(5), 268-279.

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.

Yeow, J., & Edler, J. Innovation procurement as projects. *Journal of Public Procurement*, 12(4) pp. 472-504.

Chapter 6

6 Main findings, contributions, and further research

The aim of this study has been to contribute to addressing the increasing societal and environmental challenges we are facing around the world by:

1. Investigating how public clients can effectively encourage innovation through public procurement in civil engineering initiatives.
2. Providing managerial and policy recommendations for improving the use of innovation encouraging procurement strategies and tendering methods in civil engineering initiatives.

These goals resulted in the following research question:

> *"What are the main options for public clients to stimulate innovation through public procurement in civil engineering projects and programmes?"*

This research question has been decomposed into four sub-questions. The answers for these sub-questions will be provided in section 6.1 by presenting their respective main research findings. An overall answer to the main research question is given in section 6.2. In section 6.3 the main scientific contributions of this PhD thesis are discussed. This chapter ends by making a number of suggestions for future research.

6.1. The four sub-questions of this PhD study

This section provides the answers to the four sub-questions that were raised in chapter 1.

RQ 1: "What reasons, approaches and methods for stimulating innovation through public procurement can be found in literature?"

As explained in chapter 2, there are different approaches for stimulating innovation through public procurement. These approaches vary in their reasons for encouraging innovation and the methods used. One of the main ways to differentiate these approaches is to distinguish them in three categories based on the categorization of the OECD (2011):

1. Regular procurement, which can be made more innovation-friendly;

2. Strategic procurement of innovations, where public clients demand new technologies products and services to address a specific need or societal challenge;
3. Procurement of R&D services.

Regular procurement approaches can for example be made more innovation-friendly by using functional specifications, performance-based tendering and requesting high quality standards. Strategic procurement of innovation approaches are more specifically geared towards procuring innovative products and services, such as pilot studies for testing new innovations and tenders aimed at procuring innovative goods and services which are not yet available on a commercial basis. In many cases this is accompanied by the use of market consultations, more complex tender procedures and innovation-oriented award criteria. Approaches for the procurement of R&D services are geared toward developing innovations with low Technology Readiness Levels that cannot be implemented or used before a significant amount of development and testing has been performed. In many cases this involves the use of targeted R&D subsidies. Yet, these R&D services can also be part of a commercial procurement, as is the case with the use of the innovation partnership tender procedure.

> *RQ 2: How can the implementation of innovations be encouraged and assessed in public tenders for the award of civil engineering projects?*

Chapter 3 revealed that three important ways for encouraging the implementation of innovations in tenders for civil engineering projects are:

1. Providing incentives to tenderers for including innovations as part of their tender offer;
2. Providing solution space within the description and requirements of tender assignments to allow for the inclusion of innovations by tenderers;
3. Using innovation as a selection criterion in shortlisting tender candidates to determine which candidates are invited to submit a tender offer for the civil engineering project.

The most direct way of providing incentives to include innovations in tender offers is to include the implementation of one or more innovations in the tender assignment and subsequently assess these innovations as part of the assessment of the tender offers. An alternative and less direct way of providing such incentives is to translate specific project aims, needs or challenges into award criteria to which innovative

solutions can significantly contribute. To enable this first option, a transparent and generally accepted innovation assessment method is needed to rank the innovations that are offered by the tenderers in their tender offers. Chapter 3 describes the development and successful application of such an innovation assessment method.

> *RQ 3: What determining factors and mechanisms influence the successful development and implementation of radical innovations in civil engineering projects?*

In the case of radical innovations, a significant gap between required and acquired technological knowledge and skills needs to be bridged during the development and realization of a civil engineering project. This means that this type of projects inherently bears a much higher degree of risk if compared with incremental innovation projects. As a result, contractors and suppliers are much more reluctant to implement radical innovations when they are expected to bear the consequences when things go wrong. Given the barriers that were identified in realizing radical innovations in design-bid-build delivery methods as well as in integrated contracts, chapter 4 offers a way forward for governments to realize their ambitious policy goals for which radical innovations are required on themes such as sustainability and circularity. The study findings as described in chapter 4, show that the determinative factors to realize radical green innovation appeared to be:

1. Government championship, through a proactive participation of the public client in the initiation, development and realization phases of the project and the willingness of the public client to bear innovation risks;
2. The application of innovation risk management strategies and the availability of a fall-back option;
3. The establishing of favourable organizational and relational conditions.

It is the well-considered conjoint application by the public client of these three factors that explains the unique realization of a radical innovation in the field of civil engineering.

> *RQ 4: How to select an effective innovation-encouraging procurement strategy for specific projects or programmes in the field of civil engineering?*

A significant amount of research has been carried out on stimulating innovation through the public procurement of goods and services. However, there is still a lack of knowledge on which procurement strategies and tendering methods can be effectively used to encourage specific types of innovation within larger public initiatives such as civil engineering projects and programmes.

The conducted multiple-case study, as described in chapter 5, is among the first to classify the different types of initiatives with respect to the use of innovation-encouraging procurement strategies in the field of civil engineering. Based on an extensive literature review and the multiple-case study the conclusion was drawn that the selection of an innovation-encouraging procurement strategy, particularly depends on three important factors. These are:

- The scope and time frame of the intended project or programme;
- The degree of innovation that needs to be realized in the specific project or programme;
- The level of cooperation that is required between public client and contractor(s) to realize the envisioned project or programme.

Based on the three above mentioned factors, a typology has been developed consisting respectively of 7 configurations of innovation encouraging procurement projects and 7 configurations of innovation encouraging programmes. In addition, a general guideline has been developed and is proposed in chapter 5, that enables the selection of an effective innovation encouraging public procurement strategy.

6.2. An overall answer to the main research question

Main Research Question: "What are the main options for public clients to stimulate innovation through public procurement in civil engineering projects and programmes?"

The findings of the conducted research as presented in section 6.1 together provide the answer to the main research question. Based on these research findings, the overall conclusion can be drawn that public clients need to implement a coherent, triple-sided innovation policy by:

1. *Designing and implementing innovation stimulating procurement approaches by:*
   - Redesigning regular procurement approaches to become more innovation-friendly. E.g. by using functional specifications, implement performance based tendering and requesting high-quality standards;
   - Increasing the demand for new not yet tested technologies that may be implemented in innovative projects, goods and services to address societal challenges;
   - Procuring R&D services which are geared toward developing innovation with Low Technology Readiness (TRL) levels.

2. *Encouraging tenderers to develop and implement innovations in their tender offers by.*
   - Providing incentives to tenderers for including innovations as part of their tender offer;
   - Providing solution space within the description and requirements of tender assignments to allow for the inclusion of innovations by tenderers;
   - Using innovation as a selection criterion in shortlisting tender candidates to determine which candidates are invited to submit a tender offer for the civil engineering project.

3. *Adopting an innovation championship role in the development and realization of radical innovations in civil engineering projects and programmes by:*
   - Adopting a proactive participation role in the initiation, development and realization of innovative projects and programmes;
   - Adopting effective risk management strategies and bearing an acceptable level of the innovation risks in innovative projects and programmes;
   - Establishing favourable organizational and relational conditions to develop and realize innovative projects and programmes.

6.3. The main scientific contributions of this PhD study

This PhD thesis addresses an important gap in the literature with respect to the suitability and effectiveness of different strategies and methods for encouraging innovation through public procurement (OECD, 2011; Georghiou et al., 2014; Uyarra et al., 2014). Due to a lack of an overview on the use of concepts, rationales and approaches to stimulate innovation through public procurement in literature and practice, it remains difficult for public organizations to decide why, how, and to what extent they will stimulate innovation in the private sector through public procurement. Chapter 2 in this PhD contributes to mitigate this identified problem in three ways. First, it provides a review of the different streams of literature, dichotomies and typologies on public procurement with respect to inducing innovation. Second, it discusses various approaches to stimulate innovation through public procurement individually and compares them in a structured overview. Finally, it provides guidance on the suitability of the use of these approaches in different situations.

The findings from the study as described in Chapter 3 in this PhD thesis, suggest that it is possible to trigger and assess innovations in tenders for civil engineering projects in line with procurement regulations and their underlying values using the developed method. As such, Chapter 3 makes three scientific contributions. First, it contributes to the debate on how to operationalize the terms innovation and innovativeness given that these terms are used in numerous ways in the literature and in practice. The innovativeness typology proposed by Garcia and Calantone (2002) has been adapted to the specific context of innovation in bridge projects. Chapter 3 provides clear definitions and examples of product and process innovations within the context of bridge projects. Further, it provides definitions to distinguish different *degrees of innovativeness* and *levels* on which product and process innovations can be applied within bridge projects. Second, chapter 3 provides a method based on objective criteria to assess and rank innovations in tenders for bridge projects. This method enables public clients to assess if the offered solutions should be considered as an innovation within the tender and to assess the innovativeness of the proposed solution. Third, the study contributes to and supports existing findings in the literature on how to stimulate and trigger innovation through public procurement in civil engineering and construction. This was achieved through explaining how tenderers were triggered to provide innovations as part of their tender offers in the case of a specific bridge project. In short, innovation was triggered in three different ways. First, by providing sufficient incentives to offer innovative solutions (Dreschler, 2009; Edquist & Zabala-Iturriagagoitia, 2012). Second, by providing sufficient solution space to offer innovative solutions (Dalpé, 1994; Uyarra, Edler, Garcia-Estevez, Georghiou, & Yeow, 2014). Third, by using innovation as a selection criterion in shortlisting tendering candidates to go forward and submit a tender offer. Fourth, by providing sufficient time in the project to deal with potential delays related to the implementation of innovations.

The study described in Chapter 4 of this PhD thesis is among the first to study the mechanisms that affect the development and implementation of a radical green innovation in a civil engineering project. The study addresses an important gap in literature concerning the lack of empirical evidence on factors that enable or hinder the development and implementation of radical innovations in the construction and civil engineering sector. Chapter 4 contributes in three ways. First, the empirical investigation of the application of an alternative procurement and project delivery method showed to facilitate and encourage the development and implementation of a radical green innovation in a civil engineering project. Given the barriers identified in realizing radical innovations in design-bid-build delivery methods as well as in

integrated contracts, the investigated procurement method offers a way forward for governments to realize their policy goals on themes such as sustainability and circularity. Second, the results as described in Chapter 4 show that in this approach, (1) government championship, through a proactive participation of the public client in the initiation, development and implementation of the project and the willingness of the public client to bear innovation risks; (2) the application of innovation risk management strategies and the availability of a fall back option and; (3) the establishing of favourable organizational and relational conditions were determinative factors to realize the intended radical green innovation project. As explained in Chapter 4, the relevance of the three identified factors were also confirmed in other studies. However, it is the well-considered conjoint application of these three factors by the public client, that explains the unique realization of a radical innovation in the field of civil engineering. This finding may be considered as an important contribution to literature and deserves further study in the near future. Third, a closer analysis of the three identified factors, also helped to develop seven propositions that together provide an integrated view on the potential successful development and implementation of radical innovations in civil engineering projects.

Finally, the conducted multiple-case study, as described in Chapter 5, is among the first to classify the different types of initiatives with respect to selecting innovation-encouraging procurement strategies in the field of civil engineering. Based on an extensive literature review and the multiple-case study, it became possible to deduce that the selection of an effective innovation-encouraging procurement strategy, particularly depends on three important factors. These are: the scope and time frame of the intended project or programme; the degree of innovation to be realized in the specific project or programme; and the level of cooperation that is required between public client and contractor(s) to realize the envisioned project or programme. Based on these three factors a typology was derived consisting respectively of 7 configurations of innovation-encouraging procurement projects and 7 configurations of innovation-encouraging programmes. The developed typology combines and integrates the insights from three streams of research: the management of product and process innovation in the field of civil engineering (Schilling, 2020; Tidd and Bessant 2018; Slaughter, 1998; Lenderink et al, 2020); the insights about public client – contractor collaboration in the field of civil engineering (Love et al, 1998; Eriksson, 2008; Pesämaa et al., 2009; Osipova and Eriksson, 2011); and the available knowledge about the management of scope, aims and objectives to realize civil engineering projects and programmes (Morris and Hough, 1987; Winch, 1998; Gann and Salter, 2000; Pellegrinelli, 2011; Project Management Institute, 2017).

The multiple case study and the literature review also helped to design (cfm. Van Aken, 2005; Van Aken et al., 2016) a corresponding guideline for selecting a specific procurement strategy. When considering new initiatives, public clients can benefit from the developed guideline as a tool to select the most appropriate procurement strategy considering the aims, goals and objectives of their intended new project or programme.

6.4. Suggestions for future research

For each of the four conducted studies, their limitations and directions for future research are provided in the respective chapters 2-5 of this thesis. In this section the main directions for future research are summarized.

The developed measure to assess the innovation degree and scale of innovation and the inclusion of innovation as a separate award criterion (as described in chapter 3) has worked out well in practice and led to the inclusion of a broad range of innovations in the tender offers for the Boekelo bridge project. Despite the broad support for the defined criteria, there were some differences in the way the criteria were interpreted by the public procurement team and by the tenderers. A further refinement of the method to prevent different interpretations is therefore recommended. Further, since the definitions for the degree and scale of innovation were tailored to a bridge project, it would be interesting to extend the research and tailor the assessment method to other types of civil engineering projects such as viaducts, sluice constructions or new road projects. And, with some modifications, the method may also be applicable in other domains, such as in tendering processes for utility building projects.

In chapter 4 three determinative factors for the successful development of an intended radical innovation were derived. A closer analysis of the three identified factors, also helped to develop seven propositions that together provide an integrated view on the potential successful development and implementation of radical innovations in civil engineering projects. Further evaluation of the derived three factors and the seven propositions is needed to establish the validity of the findings. It is also recommended to evaluate generalizability of the factors and propositions in other types of public infrastructure projects.

Chapter 5 provides a general guideline for the selection of an innovation-encouraging public procurement strategy. Depending on the type of project or programme, a different procurement strategy is suggested. Table 5.5 (project perspective) and 5.6

(programme perspective) provide an integral picture of three different Procurement Strategies: Regular procurement (Low degree of Innovation, particularly product and process improvements); Innovation oriented procurement (Moderate degree of Innovation); and Innovation driven procurement (High degree of Innovation). Further research is needed to further validate and refine the proposed guideline for the selection of innovation-encouraging public procurements strategies.

The domain of the empirical studies of this PhD thesis has been The Netherlands. This raises the question to what extend the findings are also generalizable to other countries. Future research could extend the research outside the Netherlands and collect cross-national data. Further, large-scale studies are needed to investigate the generalizability of the developed innovation assessment method, the propositions that have been derived in Chapter 4 and the guidelines developed in Chapter 5. Ideally, these large-scale studies may also have a cross-national character. This will also enable to investigate to what extent possible cultural differences may influence the outcome of the findings of this PhD study.

Finally, continuous learning and knowledge exchange on the use of innovation-encouraging procurement approaches, and how these can be supported, were identified as important topics for further study. This can be a valuable line of inquiry since the lack of knowledge, skills and resources in public organizations has been identified as an important barrier for the use of public procurement of innovation (OECD 2011; Georghiou et al. 2014; Uyarra et al. 2014).

References

Ali, S. H. (2014). Social and environmental impact of the rare earth industries. *Resources, 3*(1), 123-134.

Arnoldussen, J., Groot, P., Halman, J., & Van Zwet, R. (2017). *Innovatie in de bouw: Opgaven en kansen. Adviesrapport aan de paritaire organisaties in de bouw*. Retrieved from University of Twente: https://research.utwente.nl/en/publications/innovatie-in-de-bouw-opgaven-en-kansen

Blayse, A. M., & Manley, K. (2004). Key influences on construction innovation. *Construction Innovation,* 4(3), 143-154.

Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., Monnahan, C. C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G.H., Hilleary, M. A., Eriksen, M., Possingham, H.P., De Frond, H., Gerber, L.R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., & Rochman, C.M. (2020). Predicted

growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science,* 369(6510), 1515-1518.

Caerteling, J. S., Halman, J. I. M., & Dorée, A. G. (2008). Technology Commercialization in Road Infrastructure: How Government Affects the Variation and Appropriability of Technology. *Journal of Product Innovation Management,* 25(2), 143-161.

Covert, T., Greenstone, M., & Knittel, C. R. (2016). Will we ever stop using fossil fuels? *Journal of Economic Perspectives,* 30(1), 117-138.

Dalpé, R. (1994). Effects of government procurement on industrial innovation. *Technology in society,* 16(1), 65-83.

Directive 2014/24/EU. (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. *Official Journal of the European Union, 57*.

Dorée, A. G., & Holmen, E. (2004). Achieving the unlikely: innovating in the loosely coupled construction system. *Construction management and economics,* 22(8), 827-838.

Dreschler, M. (2009). *Fair competition: how to apply the 'economically most advantageous tender'(EMAT) award mechanism in the Dutch construction industry.* (PhD), TU Delft, Delft University of Technology,

EARTO. (2014). *The TRL Scale as a Research & Innovation Policy Tool, EARTO Recommendations*. Retrieved from https://www.earto.eu/wp-content/uploads

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2012). Public Procurement for Innovation as mission-oriented innovation policy. *Research policy,* 41(10), 1757-1769.

Egan, J. (1998). Rethinking Construction, Construction Task Force Report for Department of the Environment, Transport and the Regions. In: HMSO, London.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of management journal,* 50(1), 25-32.

Eriksson, P. E., Volker, L., Kadefors, A., Lingegård, S., Larsson, J., & Rosander, L. (2019). Collaborative procurement strategies for infrastructure projects: a multiple-case study. *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law,* 172(5), 197-205. doi:10.1680/jmapl.19.00016

Finer, M., Novoa, S., Weisse, M. J., Petersen, R., Mascaro, J., Souto, T., Stearns, F., & Martinez, R. G. (2018). Combating deforestation: From satellite to intervention. *Science,* 360(6395), 1303-1305.

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.

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.

George, G., Schillebeeckx, S. J., & Liak, T. L. (2018). The management of natural resources: An overview and research agenda. In *Managing Natural Resources*. https://doi.org/10.4337/978178643572

Georghiou, L., Edler, J., Uyarra, E., & Yeow, J. (2014). Policy instruments for public procurement of innovation: Choice, design and assessment. *Technological Forecasting and Social Change,* 86, pp. 1-12.

Hoezen, M., Voordijk, H., & Dewulf, G. (2014). Procuring complex projects using the competitive dialogue. *International journal of project organisation and management,* 6(4), 319-335.

Hoornweg, D., Bhada-Tata, P., & Kennedy, C. (2013). Environment: Waste production must peak this century. *Nature News,* 502(7473), 615.

Huang, L., Krigsvoll, G., Johansen, F., Liu, Y., & Zhang, X. (2018). Carbon emission of global construction sector. *Renewable and Sustainable Energy Reviews,* 81, 1906-1916. https://doi.org/10.1016/j.rser.2017.06.001

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Workin Group 1 to the Sixth Assesment Report of the Intergovernmental Panel on Climate Change*. Retrieved from: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FrontMatter.pdf

Khalfan, M. M., McDermott, P., Li, X., Arif, M., & Kashyap, M. (2008). The integration of suppliers and manufacturers within construction supply chains through innovative procurement strategies. *International Journal of Value Chain Management,* 2(3), 358-370.

Lenderink, B., Halman, J. I. M., & Voordijk, H. (2019). Innovation and public procurement: from fragmentation to synthesis on concepts, rationales and approaches. *Innovation: The European Journal of Social Science Research*, 1-25. https://doi.org/10.1080/13511610.2019.1700101.

Lenferink, S., Tillema, T., & Arts, J. (2013). Towards sustainable infrastructure development through integrated contracts: Experiences with inclusiveness in Dutch infrastructure projects. *International journal of project management,* 31(4), 615-627.

Lindblad, H., & Guerrero, J. R. (2020). Client's role in promoting BIM implementation and innovation in construction. *Construction management and economics*, 38(5), 468-482.

Loosemore, M. (2015). Construction innovation: Fifth generation perspective. *Journal of management in engineering*, 31(6), 04015012. DOI: 10.1061/(ASCE)ME.1943-5479.0000368

Loosemore, M., & Richard, J. (2015). Valuing innovation in construction and infrastructure: Getting clients past a lowest price mentality. *Engineering, Construction and Architectural Management*, 22(1), 38-53.

O'Raghallaigh, P., Sammon, D., & Murphy, C. (2010). *Theory-building using Typologies-A Worked Example of Building a Typology of Knowledge Activities for Innovation.* Series Frontiers in Artificial Intelligence and Applications, E-book: Volume 212: Bridging the Socio-technical Gap in Decision Support Systems. https://doi.org/10.3233/978-1-60750-577-8-371.

OECD. (2011). *Demand-side Innovation Policies*: OECD Publishing.

Rose, T. M., & Manley, K. (2012). Adoption of innovative products on Australian road infrastructure projects. *Construction management and economics*, 30(4), 277-298.

Rutten, M. E. J., Dorée, A. G., & Halman, J. I. M. (2009). Innovation and interorganizational cooperation: a synthesis of literature. *Construction Innovation*, 9(3), 285-297.

Semple, A. (2015). *A practical guide to public procurement*. Oxford University press.

Slaughter, E. S. (1998). Models of construction innovation. *Journal of Construction Engineering and Management*, 124(3), 226-231.

Telles, P., & Butler, L. R. A. (2014). Public Procurement Award Procedures in Directive 2014/24/EU. In F. Lichere, R. Caranta, & S. Treumer (Eds.), *Modernising Public Procurement: The New Directive*. Copenhagen: Djof Publishing.

United Nations. (2020). *The Sustainable Development Goals Report 2020*. New Yourk: United Nations Publications.

United Nations Environment Programme. (2017). *Global review of sustainable public procurement*. Retrieved from: https://www.unep.org/resources/report/2017-global-review-sustainable-public-procurement

United Nations General Assembly. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. New York.

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.

van Aken, J., Chandrasekaran, A., & Halman, J. I. M. (2016). Conducting and publishing design science research: Inaugural essay of the design science department of the Journal of Operations Management. *Journal of Operations Management*, 47, 1-8.

van Belzen, T. (2021, 22-12-2021). Experts: 'IJdel Rijkswaterstaat drijgt grip op renovatiegolf te verliezen'. *Cobouw*. Retrieved from www.cobouw.nl

van de Ven, A. (2007). *Engaged Scholarship: a guide for organizational and social research*. New York: Oxford University Press.

van den Berg, M. C. (2019). *Managing Circular Building Projects.* PhD thesis University of Twente, Enschede.

van Weele, A. (2009). *Purchasing and Supply Chain Management* (5th Edition ed.). Hampshire: Cengage Learning Emea.

Wang, Z., Zhang, B., & Guan, D. (2016). Take responsibility for electronic-waste disposal. *Nature,* 536(7614), 23-25. doi:10.1038/536023a

Wientjes, B., Buitendijk, G., Meyboom, J., Verhagen, M., Nelissen, E., Reiner, C., & Van Wingerden, R. (2016). De bouwagenda: Bouwen aan de kwaliteit van leven. In: Delft: *De Bouwagenda*.

Wieringa, R. J. (2014). *Design science methodology for information systems and software engineering*: Springer.

World Economic Forum. (2016). *Shaping the Future of Construction: a Breakthrough in Mindset and Technology*. Retrieved from: https://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_report_020516.pdf

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.

Yin, R. K. (2013). *Case Study Research: Design and Methods* (fifth edition ed.). Sage Publications Inc.

Yuan, H., & Shen, L. (2011). Trend of the research on construction and demolition waste management. *Waste Management,* 31(4), 670-679. https://doi.org/10.1016/j.wasman.2010.10.030

Zhou, S., Smith, A. D., & Knudsen, E. E. (2015). Ending overfishing while catching more fish. *Fish and Fisheries,* 16(4), 716-722.

Appendix I: Declaration of contribution

This thesis consists of a literature review article and three empirical articles. The three empirical papers are based on a multiple case study of 5 projects and 3 programmes with respect to the use of innovation encouraging public procurement in civil engineering.

Data collection and analysis (empirical articles)

The interviews and transcription of five out of the eight cases were performed by the author and the interviews for the three other cases were performed by three master/PDEng students: the Boekelo Bridge project by Ruth Sloot, the Cycle Bridge Ritsumasyl project by Ernst Kleinhuis and Bas Ebbelaar, and the Northern ring road Gemert project by Ernst Kleinhuis. The interviews performed by Ernst Kleinhuis and Bas Ebbelaar were part of their master thesis, which were supervised by Prof. Halman and Ing. Hans Boes and co-supervised by the author. The interviews performed by Ruth Sloot were part of the a PDEng assignment for the course Technology Development which was supervised by prof. Halman. The data analysis of the interviews, the procurement documents and the input from the master thesis's for the articles were mostly performed by the author. For the Cycle Bridge Ritsumasyl case Ing. Hans Boes assisted in the data analysis.

Writing and rewriting of articles

The order of the authors as published in the articles and chapters of this thesis reflect the relative amount of time and effort spend in writing and rewriting the articles and chapters.

For the second chapter (literature review) all research activities were performed by the author with regular feedback and advise from prof. Halman and Dr. Voordijk.

For the third chapter (Boekelo Bridge) the analysis and writing of the article was largely performed by the author, with specific parts written by prof. Halman. Regular feedback and advise for writing and rewriting the article was provided by Prof. Halman, Dr. Voordijk and Ing. Hans Boes. Additionally, prof. Halman and Ing. Hans Boes were involved as part of the assessment committee in this tendering phase of this project. As part of this committee, prof. Halman and Ing. Boes have developed the method to assess innovations in public tenders for infrastructure projects.

For the fourth chapter (Ritsumasyl) the analysis and writing of the first version of the article was largely performed by the author with some assistance from Ing. Hans Boes, regular feedback from prof. Halman, and less regular feedback from Dr. Voordijk and Prof. Dorée. The rewriting of the article in response to the comments of

the journal was performed by the author with assistance and feedback of Prof. Halman and Ing. Hans Boes, and feedback from Dr. Voordijk and Prof Dorée.

For the fifth paper (typology) the analysis and writing of the first version of the article was largely performed by the author with regular feedback from Prof. Halman and Dr. Voordijk and less frequent feedback from Prof. Dorée and Ing. Hans Boes. The rewriting of the article in response to the comments of the journal was performed by the author with assistance and regular feedback of Ing. Hans Boes and Prof. Halman, and feedback from Dr. Voordijk and Prof. Dorée. In addition, the general guidelines for the selection of an innovation-encouraging procurement strategy (tables 5 and 6) were developed by Ing. Boes in this phase.

Epilogue

This epilogue reflects on my journey as a PhD student performing research on public procurement of innovation in civil engineering. A journey in which the desire to learn together and improve the use of innovation encouraging procurement strategies in practice played a major role. Since the activities with respect to knowledge sharing and learning together in this research project did not lead to major scientific contributions, my supervisors and I decided to discuss this part of the project in the epilogue.

Origin of the research

The desire to perform a PhD research on public procurement of innovation started in 2014-2015, when I was working on my master thesis at Rijkswaterstaat. Under the wings of Mieke Hoezen, Arend Nagel, Joop Halman and Hans Boes I developed a quantitative instrument for measuring the extent to which public procurement practices are used which facilitate the inclusion of innovations. After almost a year the development and evaluation of the instrument was a success and everyone involved was more than content with the study. Yet, during the time I was working on my master thesis I started to realize two things. First, I was not ready to give up my interest in public procurement of innovation and definitely wanted to explore this topic further. Second, although developing an instrument to measuring the use of procurement practices that encourage innovation was quite a challenge, it felt far more useful to investigate how the use of innovation encouraging procurement strategies can be improved in practice.

When the master thesis was almost completed Joop suggested to me that it would be possible to start a PhD study on this topic if I was interested. There was no predefined scope or budget for this study at that time, but these were things that could probably be figured out along the way. A bit unsure if I would be able to realize such an endeavor including raising the necessary funding, I went to Mieke to ask for her advice. In short, her advice was to fake until you make it if you really want it. This advice has helped me a lot along the way and I hope it may inspire other students who are thinking about starting a PhD study.

Setting up the coalition

The next phase in my journey was to reach out to different public organizations to set up a collaboration and achieve funding for this research. Although this was an

uncertain time for me personally, it was a highly valuable experience to rally for support for my PhD research and collaboratively determine its scope without preset boundaries. The support from my supervisors together with a small funding from the university, the chance to work part-time at the municipality of Amsterdam and highly favorable conditions for research on innovation-oriented procurement at the time allowed for a coalition to be formed and the research to take off.

This research was financially supported by the municipalities of Amsterdam and Eindhoven and was performed in close collaboration with these municipalities and the Dutch expertise center on public procurement (PIANOo). One of the prime motives of the municipalities to financially support this research was the ability of the research to facilitate the exchange of knowledge and experiences between them and other public organizations who were pioneering with the use of innovation encouraging procurement strategies. As such, learning together and exchanging knowledge between public organizations was given an important role in this research as a way to improve the use of innovation encouraging public procurement strategies in practice.

Learning together and spreading the news

During my research I had the pleasure, and luck, to be supervised by both my supervisors at the university of Twente and my supervisors from practice who played important roles and have considerable knowledge about public procurement in practice. Floris den Boer, who worked as an expert on innovation-oriented public procurement at PIANOo at the time; Marten Klein who works as one of the directors of the engineering company of the municipality of Amsterdam; Jaap Strating who worked as the CPO of the municipality of Eindhoven and Ali Cidem who was the successor of Jaap as interim CPO. As one can imagine, this coalition of supervisors from the university and experts from practice, coming together for steering group meetings to discuss the progress of the research, provided a fertile ground for discussing recent developments on public procurement and innovation. These steering group meetings were more than a way to discuss the direction and progress of the research. They were also a way to learn together and share insights with respect to the use of innovation encouraging procurement strategies.

The second way to encourage collaborative learning and sharing knowledge with respect to the use of innovation encouraging procurement strategies within civil engineering was through creating a community of practice (CoP). The community

was developed and managed in active collaboration with PIANOo and the municipality of Amsterdam. Aside from the input from different public organizations in the sessions, Baldwin Henderson (PIANOo), Hans Boes (University of Twente) and Marten Klein (Amsterdam) played a substantial role in moving the community forward. After a gentile push to get started, five meetings with 9 to 13 participants were organized within the CoP.

Table1: CoP sessions

CoP Session	Date	Location
Exploration session	17 September 2018	Utrecht
Innovation partnership Quay walls	14 November 2018	Utrecht
Two innovative bridge projects	20 February 2019	Utrecht
Typology and process market approach	6 May 2019	Rotterdam
Sustainable municipal buildings and barriers in transitional challenges	22 November 2019	Eindhoven

Although the creation and management of the CoP took a substantial amount of time, which arguably could be used more effectively in terms of research output, it was one of the most fulfilling parts of the research project to me. To see experts from a range of different public organizations form a community over time, and have substantial discussions and share insights on the challenges they encounter with respect to innovation encouraging procurement, brought an additional spark of joy and relevance to the research project.

Currently I am working as an expert on public procurement and contracting at the procurement center for civil engineering of Rijkswaterstaat. My hope and expectation is that I will continue to have many more insightful discussions with policy makers, project teams and contract managers to improve the use of public procurement to address the sustainability challenges we will face in the years to come. Last but not least, the world of academia and the use of innovation encouraging procurement strategies will remain to have a special place in my heart.

Acknowledgements

In contrary to most PhD studies, this PhD study started out without funding and a predetermined scope. For this reason, I would like to start by thanking those who contributed to create the research opportunity for this PhD study. This includes my supervisors for obtaining short term funding from the university and the municipality of Amsterdam for offering me a part time job, which allowed me to financially bridge the year prior to the official start of my research. Moreover, I want to thank the municipality of Eindhoven, and the engineering company and the metro/tram department of the municipality of Amsterdam for funding this research. Without their support this research would not have been possible.

Second, I want to thank my supervisors from academics for their time, support and guidance during my time as a PhD student. Prof. Joop Halman, you have been my supervisor since the start of my master thesis in 2014, after which you encouraged me to start a PhD study and supported me throughout this journey. From discussing the research design, to attending a conference in Turkey and polishing research papers. Under your wings it always felt save to openly explore the realms of science with a gentle push here and there to guide me in the right direction. Of course, we had some disagreements in the many hours we spend, but your feedback has always been constructive and fair. Moreover, I am grateful for the way you helped me to manage the last part of my PhD study during somewhat turbulent times. To note: over the last couple of years I moved to Amersfoort, got married, became a father, got a new job and moved again within Amersfoort.

Dr. Hans Voordijk, it has been a joy to have you as a second supervisor for my PhD research. I appreciate that your door was almost always open for discussing things related to the research, arranging practical stuff or the casual small talk. Furthermore, you have a keen eye for seeing opportunities or things that can be improved. In addition, I want to thank you for your excellent feedback, especially when you put in the time, and the way you always keep a helicopter view on the research trajectory as a whole.

Prof. André Dorée, although from my supervisors I spend the least amount of time with you, I think I learned the most from the time that I did spend with you. One of the reasons for this is that we tend to approach things differently, and think and communicate on a slightly different wavelength (which took me some time to get used to). For example, where I normally start to plan by thinking what needs to be done and how much time that would take, you start to plan by marking the deadline

at the end and start planning back to the front. Second, when writing a research paper, I tend to start with analyzing the obtained data and determine what could be concluded from this. In contrast, you would start a paper by thinking about potential storylines based on the data and determine what the major message is that you want to get across. Needless to say, over time I learned the benefits from your ways of reasoning and doing things. Furthermore, I want to thank you in particular for your role and helpful insights during the steering group meetings, which substantially influenced the trajectory of this PhD study.

Ing. Hans Boes, similar to prof. Halman you have been my supervisor during my master thesis. Despite the fact that you are not formally a supervisor for my PhD study we have spent quite some time during my journey as a PhD student and you are a co-author on three of the articles in this thesis. Your enthusiasm and knowledge with respect to collaboration and public procurement in civil engineering significantly contributed to the quality of the articles. In addition, I am grateful for your considerable support and participation in the community of practice which means a lot to me.

The third group of people I want to thank are my supervisors from practice who supported me throughout my PhD journey with feedback, as well as offering insights on the newest developments and a practical perspective on innovation encouraging public procurement. Furthermore, I want to thank Marten Klein for the many insightful conversations at the plaza and his role and support in the community of practice. In addition, I want to thank Marten for showing me what facilitating leadership is, including the subtle act of giving way to colleagues at the coffee machine. I also want to thank Jaap Strating for sharing his knowledge on organizational structures, including theory from Mintzberg and the practical organizational challenges at the municipality. Furthermore, I want to thank Jaap sharing his deep knowledge on addressing transitional challenges that, among other things, require a long-term perspective, flexibility and sufficient scope in order for a business case to be viable. Floris den Boer, I want to thank you for your including your feedback and perspectives from a policy stance in this PhD study. In many steering group meetings these insights were a welcome addition. Ali Cidem, I want to thank you for taking over the role of Jaap Strating when he retired at times you already got a lot on your plate as interim CPO of Eindhoven. Baldwin Henderson, in a similar way to Hans Boes you have not been a formal supervisor. Despite this, you have significantly contributed to this PhD study through good discussions and assisting in the management of the community of practice. I want to thank you for this.

I also want to thank all my colleagues at the CME department for the many great moments we spend together, including the nice discussions over a cup of fresh brewed coffee, strolls through the park, conferences and off course the outings. I have many fond memories of the time I spend with you all, for which I am grateful. Over the years, I have seen many PhD and PDeng students come and go (some even returned). During the early days at the Aquarium, where it could be quite cold, and later on at the PhD/PDeng room in the Horstring. Yet, despite all the changes in the composition and location of the group, it was always a pleasant environment to work in and to have some fun. Furthermore, I want to thank Yolanda and Jacqueline for always being there, including the nice talks, the planning of steering group meetings and arranging other practical matters. All your work behind the scenes is greatly appreciated.

Another group of people who always have been there for me are my close friends from my year club. Whether it is arranging things for my marriage, discussing the difficulties in my PhD study, meeting for Christmas dinner or just have a beer and talk about life; it is nice to know you can always count on them. Off course I also want to thank my family for their support and helping out by watching over Sophie Esmee, which allowed me some additional time to work on this thesis. Dear Judith, thank you for your support, lifting my spirit when needed, and all the small sacrifices you made to make it possible for me to finish this PhD.

Last but not least, I want to thank the interviewees and members of graduation committee for their input and feedback.

Publications related to this research

Journal papers

Lenderink, Bart, Johannes I.M. Halman, and Hans Voordijk. (2019) Innovation and public procurement: from fragmentation to synthesis on concepts, rationales and approaches, *Innovation: The European journal of social science research*: https://doi.org/10.1080/13511610.2019.1700101.

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.

Lenderink, B., Halman, J. I.M., Boes, J., Voordijk, H., & Dorée, A. G. (2022). Procurement and innovation risk management: How a public client managed to realize a radical green innovation in a civil engineering project. *Journal of purchasing and supply management*, 28(1), https://doi.org/10.1016/j.pursup.2022. 100747.

Lenderink, B, Boes, H., Halman, J.I.M., Voordijk, H.& Dorée, 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 .

Conference papers

B. Lenderink, J. I. M. Halman and J. T. Voordijk, (2016) Public procurement of innovation in construction: A design science approach. IEEE International Conference on Management of Innovation and Technology 2016, Bangkok, Thailand.

Lenderink, B., Voordijk, H., Halman, J., & Dorée, A. (2018). Public procurement and innovation: A conceptual framework for analysing project-based procurement strategies for innovation. 27th IPSERA Conference 'Purchasing & Supply Management: Fostering Innovation', Athens, Greece.

Lenderink, B., Boes, H., Voordijk, H., Kleinhuis, E., & Halman, J. (2019) Managing risks in the development and implementation of product innovations in construction projects: The case of a movable bio-based composite bridge deck. 28th IPSERA Conference 'Purchasing & Supply Management: Art and Science of Procurement', Milan, Italy.

Lenderink, B., Voordijk, H., Dorée, A., & Halman, J. (2019) Innovation-oriented procurement approaches in civil engineering and construction. International civil engineering and architecture conference 2019, Trabzon, Turkey.

Lenderink, B., Voordijk, H., Dorée, A., & Halman, J. (2019) The struggle to capitalize on the value of communities of practice. ARCOM 2019: Productivity, Performance and Quality Conundrum, Leeds, United Kingdom

Master's theses

Lenderink, B. (2015). *Development of a measurement instrument for innovation facilitating procurement* (Master's thesis, University of Twente).

Co-supervised Master's theses:

Kleinhuis, E. (2019). *Public Procurement of innovation in Infrastructure projects; Strategies for stimulating innovation* (Master's thesis, University of Twente).

Brinkerink, J. I. D. (2019). *Provoking innovation in the innovation partnership procedure: a market perspective* (Master's thesis, University of Twente).

Ebbelaar, B.P. (2019) *Designing a process for procuring biocomposite bridge decks based on Technology Readiness Levels* (Master's thesis, University of Twente).

Involved organizations

Type of involvement	Involved organizations			
Direct support (Financial and in kind)	Municipality of Amsterdam	Municipality of Eindhoven	PIANOo	
Case study research	Municipality of Amsterdam	Municipality of Eindhoven	Municipality of Rotterdam	Province of Friesland
	Municipality of Hengelo	Province of Noord Brabant	Province of Overijssel	
Community of Practice	Municipality of Amsterdam	Municipality of Eindhoven	PIANOo	Municipality of Rotterdam
	Province of North Holland	Province of South Holland	University of Twente	

About the author

Bart Lenderink was born in Apeldoorn, the Netherlands. After graduating from high school, he moved to Enschede in 2008 to study Advanced Technology (BSc.) and Civil Engineering and Management (MSc.) at the University of Twente. During his time as a student, he was active at the student association AEGEE Enschede and study association S.A. Astatine. Furthermore, he was treasurer of the ballroom and Salsa association D.S.V. 4 happy feet for one year. For his master thesis he developed a measurement instrument for innovation facilitating public procurement at Rijkswaterstaat.

After graduating in 2015 he worked parttime as a researcher at the University of Twente and parttime as an advisor on public procurement at the engineering company of the municipality of Amsterdam. In 2016 he officially started his PhD study at the department of Construction Management and Engineering under the faculty of Engineering Technology. As a part of this PhD study Bart co-supervised three master student and had a leading role in creating a community of practice on innovation encouraging public procurement in civil engineering.

In May 2021 he started working at the procurement center for civil engineering works (ICG) of Rijkswaterstaat, under the division of large projects and maintenance (GPO). Here he works as an advisor on public procurement and contracting where he gives advice with respect to procurement policy, interpretation of tendering regulations and the use of procurement and contract documents related to civil engineering works.