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 *, Johan Boes, Hans Voordijk, André G. Dorée

University of Twente, School of Engineering Technology, Department of Civil Engineering and Management, PO Box 217, Enschede, 7500 AE, the Netherlands

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A B S T R A C T

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 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.

Subject classification codes: Managing Project Risk; Managing Project Innovation; Contract Procurement and Tendering

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 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 in which additional value can be offered. When a significant share of the criteria is used to assess the tender offers and guide the direction in which the project is developed, this reduces the freedom that the winner of the tender has in the realization of the project (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 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 (Oztas and Okmen, 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 (Oztas and Okmen, 2004; Rijkswaterstaat, 2019). In addition, the integrated delivery method obliges contractors to take responsibility for risks that they cannot influence, such as deficient scopeing 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.

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.

2.1. 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).

2.2. A characterisation 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 radical 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 been put into use by many authorities. 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 TRL 4 – TRL 7.

2.3. 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-Iturriaga, 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-Iturriaga, 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.

2.4. 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 competition. 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, Pesámaa 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 Ospíova 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 (Pesámaa 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 (Pesámaa 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 Erikson 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.

2.5. 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?

2.6. 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 contingence 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.

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 focuses 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; Gatikier and Carter, 2016; Sergeeva and Winch, 2020; Yue, 2017).

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 specifically 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).

3.1. 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 tenders (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

Table 1 Overview of interviewees.

| Organization                        | Role of interviewee in project (number of interviews) |
|-------------------------------------|------------------------------------------------------|
| Province of Friesland               | Project leader (2)                                   |
|                                    | Programme manager/internal client (1)                |
| Engineering company supporting     | Contract advisor (1)                                 |
| client                              | 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.

3.2. 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.

3.3. 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. Case study: the Ritsumasyl bicycle bridge project

4.1. 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.

4.1.1. 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.

4.1.2. 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.

4.2. 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 focused on the development of the bio-based bridge deck and the design of the movable bridge, and the second phase focused 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).

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 bio-based 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 bridge 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.
4.3. 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.

4.3.1. 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.

![Fig. 4. Tender procedures applied in the composite movable bicycle bridge project.](image-url)
4.3.2. 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 bio-based 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.

4.4. 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 focused 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.

4.4.1. 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”.

Fig. 5. Staged development procedure for the composite movable bicycle bridge project.
4.4.2. 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.

4.4.3. 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.

4.5. 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 mechanisms 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).

4.6. 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 Ritsumasayl 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’.

4.7. 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.

4.8. 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 (BQ) 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).

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.

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

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

5.1. 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

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**Table 2**

Characteristics of European and National public tendered infrastructure projects in The Netherlands (2019–2020).

| Contract form          | Total number of projects | Award | Quality/price | Percentage projects | Award Criteria | Responsibility |
|------------------------|--------------------------|-------|---------------|---------------------|---------------|----------------|
| Regular contracts      | 916                      | Best  | 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 |
| (Design-Bid-Built, Integrated Contracts etc.) |                        | Lowest | Price (LP) BQPR |                      |               | According to Contract |
| Two staged contract    | 103                      | 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%) | Price | 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 |
| Ritsumasyl             |                          | Cost based Design phase, Target Budget execution phase | 2                   | Contractor: Cooperation (50%), Risk management (33%), Tariffs design phase (17%) Producer/supplier bio based 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 |
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.

5.2. 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 Ritsumayl 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.

5.3. 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, Khallan 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.

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

6.1. 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 cooperation 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 joint 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.

6.2. 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.

6.3. 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.

6.4. 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.

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Authors statement

All authors have contributed in conceptualizing and conducting the research and in writing the original draft of the paper. The order of the authors reflects the relative contribution of the authors in writing and in revising the paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

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

Amram, M., Kulatilaka, N., 1999. Disciplined decisions. Harv. Bus. Rev. 77 (1), 95–96.

Arnoldussen, J., Groot, P., Halman, J., Van Zwet, R., 2017. Innovatie in de bouw: Opgaven en kansen. Economisch Institute of the Building Environment, Amsterdam.

Atena, P., 2019. Friese Wereldprimeur: Brug Van Biocomposiet Kan over Honderd Jaar Uitgereden Als Mest, 26 april 2019. Cobouw. Retrieved from: www.cobouw.nl.

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

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

Beeda, E., 2019. Friese Wereldprimeur: Brug Van Biocomposiet Kan over Honderd Jaar Uitgereden Als Mest, 26 april 2019. Cobouw. Retrieved from: www.cobouw.nl.

Blayce, A.M., Manley, K., 2004. Key influences on construction innovation. Construct. Innovat. 4 (3), 143–154.

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

Caerteling, J.S., Halman, J.J.M., Dorée, A.G., 2008. Technology commercialization in road infrastructure: how government affects the variation and appropriability of technology. J. Prod. Innovat. Manag. 25 (2), 143–161.

Caerteling, J.S., Halman, J.J.M., Song, M., Dorée, A.G., 2009. Impact of government and corporate strategy on the performance of technology projects in road construction. J. Construct. Eng. Manag. 135 (11), 1211–1221.

Caerteling, J.S., Halman, J.J.M., Song, M., Dorée, A.G., Van Der Bij, H., 2013. How relevant is government championing behavior in technology development? J. Prod. Innovat. Manag. 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. J. Purch. Supply Manag. 15 (3), 178–186.

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. J. Purch. Supply Manag. 15 (3), 178–186.

Cardinal, I.B., 2001. Technological innovation in the pharmaceutical industry: the use of organizational control in managing research and development. Organ. Sci. 12 (1), 19–36.

Courtney, H., Kirkland, J., Viguerie, P., 1997. Strategy under uncertainty. Harv. Bus. Rev. 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 25 February 2014 on Public Procurement and Repealing Directive 2004/18/EC, vol. 37. Official Journal of the European Union.
Kulatunga, K., Kulatunga, U., Amaratunga, D., Haigh, R., 2011. Client–consultant relationship characteristics that promote project innovation. Construct. Innovat. 11 (4), 380–398. https://doi.org/10.1080/1474171111578673.

Kumarashwamy, M., Dalaimi, M., 2001. Empowering innovative improvements through creative construction procurement. Eng. Constr. Architect. Manage. 8 (5/6), 344–354.

Lahdenpera, P., 2012. Making sense of the multi-party contractual arrangements of project partnering, project aligning and integrated project delivery. Construct. Manage. Econ. 30 (1), 57–74. https://doi.org/10.1080/02632283.2012.664947.

Leifer, R., O’connor, G.C., Rice, M., 2001. Implementing radical innovation in mature firms: the role of hubs. Acad. Manage. Perspect. 15 (3), 102–113.

Lenderink, B., Halman, J.M., Boe, H., Voedijck, H., 2020. A method to encourage and assess innovations in public tenders for infrastructure and construction projects. Construct. Innovat. 20 (2), 171–189. https://doi.org/10.1080/09680919.2019.164004.

Lenferink, S., Tillema, T., Arts, J., 2013. Towards sustainable infrastructure development through integrated contracts: experiences with inclusiveness in Dutch infrastructure projects. Int. J. Proj. Manage. 31 (4), 615–627.

Loosemore, M., Richard, J., 2015. Valuing innovation in construction and infrastructure: getting clients past a lowest price mentality. Eng. Constr. Architect. Manage. 22 (1), 38–53.

Love, P.E., Skimore, M., Earl, G., 1998. A suitable compliant procurement method for a building project. Construct. Manage. Econ. 16 (2), 221–233.

Magnusson, T., Lindstrom, G., Berggren, C., 2011. Architectural or modular innovation? Managing discontinuous product development in response to challenging environmental performance targets. Int. J. Innovat. Manage. 7 (1), 1–26.

Majchrzak, A., Cooper, L.P., Neece, O.E., 2004. Knowledge reuse for innovation. Manage. Sci. 50 (2), 174–188.

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

Manley, K., 2006. The innovation competence of repeat public sector clients in the Australian construction industry. Construct. Manage. Econ. 24 (12), 1295–1304.

Mariano, F.L., Zanni, P.P., Moraes, G.H.S., 2014. What is the use of a single-case study in management research? Rev. Emp. Des. 54 (4), 358–369.

Martin, S., Scott, J.T., 2000. The nature of innovation market failure and the design of public support for private innovation. Res. Pol. 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. Bard College Working Paper, 824.

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

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

Moon, M.J., Bretschneider, S., 1997. Can state government actions affect innovation and environmental performance targets. Int. J. Innovat. Manage. 7 (11), 1–26.

Numagami, T., 1998. Perspective—a longitudinal study of public innovation policy tool, EARTO inside the black box. Int. J. Proj. Manage. Procure. Law 172 (5), 197–205.

Rijkswaterstaat, 2019. Toekomstige Opgave Rijkswaterstaat: Perspectief op de aanpak van de problemen in de basismaatwerksector bij de infrastructuur. 559.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.

Roussel, P.A., Saad, K.N., Erickson, T.J., 1991. Third Generation R&D policy, economic incentives and private firm behavior. Res. Pol. 35 (2), 197–215.
Sadiq, S.R., Povinelli, F.P., Rosen, R., 1989. The NASA technology push towards future space mission systems. Acta Astronaut. 20, 73–77.
Sariola, R., 2018. Utilizing the innovation potential of suppliers in construction projects. Construct. Innovat. 18 (2) https://doi.org/10.1108/CI-06-2017-0050.
Sergeeva, N., Winch, G.M., 2020. Narrative interactions: how project-based firms respond to Government narratives of innovation. Int. J. Proj. Manag. 38 (6), 379–387.
Siggelkow, N., 2007. Persuasion with case studies. Acad. Manag. J. 50 (1), 20–24.
Slaughter, E.S., 1998. Models of construction innovation. J. Construct. Eng. Manag. 124 (3), 226–231.
Stokols, D., Misra, S., Moser, R.P., Hall, K.L., Taylor, B.K., 2008. The ecology of team science: understanding contextual influences on transdisciplinary collaboration. Am. J. Prev. Med. 35 (2), S96–S115.
Taofeq, D., Adeleke, A., 2019. Factor’s influencing contractors risk attitude in the Malaysian construction industry. J. Construct. Bus. Manag. 3 (2), 59–67.
Turner, J.R., 2005. The role of pilot studies in reducing risk on projects and programmes. Int. J. Proj. Manag. 23 (1), 1–6.
UK Cabinet Office, 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., Georgiou, L., Yeow, J., 2014. Barriers to innovation through public procurement: a supplier perspective. Technovation 34 (10), 631–645.
Wang, J., Lin, W., Huang, Y.-H., 2010. A performance-oriented risk management framework for innovative R&D projects. Technovation 30 (11–12), 601–611.
Wilden, R., Guaderran, S.P., Nielsen, B.B., Lings, I., 2013. Dynamic capabilities and performance: strategy, structure and environment. Long. Range Plan. 46 (1–2), 72–86.
Yin, R.K., 2013. In: Case Study Research: Design and Methods, fifth ed. ed. 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.