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Innovation potential of megaprojects: a systematic literature review

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ABSTRACT
The interest in megaproject management and the role of innovation is increasing. However, the literature on this subject is fragmented, with studies focussing on 'standard' projects, failing to recognize the different nature of megaprojects, or discussing innovation dimensions as distinct components. The main aim of this paper is to provide a comprehensive understanding of innovation in megaprojects. By means of a systematic literature review this paper synthesizes and analyzes the current academic literature on innovation in megaprojects and identifies potential research gaps. The paper presents the results of the descriptive and content analysis of the identified body of knowledge. We contribute to the literature by developing a theoretical integrated model of innovation in megaprojects, identifying dimensions of innovation, and deriving some propositions on these dimensions as well as the interactions between them. Key findings of the paper for the successful implementation of innovation in megaprojects include the planning for dynamic capability bundles and an innovation process that fits with the innovation package and its actualizing and complementary innovation interactions.

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KEYWORDS
Innovation; megaproject; innovation interaction; systematic literature review; dynamic capability

1. Introduction

There has been a worldwide growth in megaprojects, currently constituting 8% of global GDP and they are even set to expand to 24% within a decade (Frey 2017). Megaprojects are defined as 'large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people' (Flyvbjerg 2014, 6). Megaprojects are seen in various sectors such as infrastructure, water and energy, ICT, defence, mining, big science, space exploration, industrial processing plants, and healthcare. Many of these cover the construction industry.

The increasing trend of megaproject implementation may be explained by the 'four sublimes' of megaproject management, the technological, political, economic, and aesthetic sublimes acting as drivers for scale and frequency of megaprojects (Flyvbjerg 2014). Sublimes refer to the repeated experience of awe people have had (Frick 2008) when confronted with the achievements of these impressive projects. For example, the technological sublime is described by the rapture engineers and technologists get in pushing the boundaries of what is possible in 'longest-tallest-fastest' types of projects (Flyvbjerg 2014, 8). Similarly, the other sublimes refer to the excitement politicians, business people, or designers get from building these megaprojects, whether this is because of the visibility they get from starting megaprojects, the potential of making money and jobs from megaprojects, or the pleasure of using and looking at something large and iconic (Flyvbjerg 2014).

These sublimes also suggest a degree of innovation is part of the megaproject nature. The innovations further increase the risk in megaprojects and may consequently extend the problems of delivering projects on time and on budget (Davies, Gann, and Douglas 2009; Gil, Miozzo, and Massini 2012).

Conversely, a lack of innovation may also contribute to project failure. In fact, Davies and Gann (2017) argue that one of the reasons megaprojects fail is due to the inability of their delivery model to innovate and adapt to changing and unexpected circumstances.

The interest in megaproject management is large (Söderlund, Sankaran, and Biesenthal 2017) and there is a rich literature on innovation with some studies focussing on the relation between project management and innovation. For example, a study by Severo et al. (2019) investigated the relation between project management practices and product and process innovations. While some research is done on innovation in 'standard' construction projects, so far innovation in megaprojects has received less attention. Studies investigating innovation in megaprojects are predominantly single case studies (e.g. Davies et al. 2014; Dodgson et al. 2015; Sergeeva and Zanello 2018; Winch 2000; Worsnop, Miraglia, and Davies 2016) and according to Davies et al. (2014), studies on innovation mostly focus on managing risks and uncertainty, learning, and impact on institutional structures. In general, studies on project innovations lack details on the initiator, the type, cause or driver, and the stage when innovation was conceived (Brockmann, Brezinski, and Erbe 2016).

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In order to address these issues, this article aims to provide a comprehensive understanding of the innovation in megaprojects by developing an integrative framework of innovation. Two research objectives facilitate the achievement of this aim. First, to consolidate and analyze the current knowledge on innovation in megaprojects and identify potential gaps that need further study. Second, to identify the extent to which innovation concepts have been adopted in megaprojects and reveal any relations between them. Two research questions are considered:

1. What is the current state of the art in innovation in the megaproject literature and how can it be characterized?
2. To what extent do innovation concepts interact and how can these interactions be described?

To address our research objectives we conducted a Systematic Literature Review as this allows us to identify, analyze, evaluate and synthesize the body of knowledge relevant to our study (Denyer and Tranfield 2009). This paper contributes to the current literature on innovation in megaprojects by providing a framework of the main innovation concepts and interactions between them. This provides policy-makers, project managers, and organizations with a better understanding of what is required for successful implementation of innovations in megaprojects. Moreover, it enables them to appraise innovations' value to the project more accurately.

The paper is structured as follows. Section 2 gives a brief introduction of innovation in relation to megaprojects and the innovation model that is utilized in this paper. Section 3 describes the methodology for conducting the systematic literature review. Sections 4 and 5 report the patterns and trends in innovation in megaprojects literature and the result of the content analysis. Section 6 presents a theoretical framework and propositions about innovation in megaprojects. This is followed by the discussion and future research areas in Section 7. Finally, Section 8 presents the main conclusions.

2. Innovation model for megaprojects

Innovation is generally considered as 'the successful commercial exploitation of new ideas. It includes the scientific, technological, organizational, financial, and business activities leading to the introduction of a new (or improved) product or service' (Dodgson, Gann, and Salter 2008, 2). In megaprojects, these new ideas may come from both the permanent and temporary organization of the megaproject itself.

Megaprojects are considered temporary (special purpose) organizations (e.g. Lundin and Söderholm 1995) established to design and build an unique product, system or outcome (Davies and Gann 2017). The temporariness of megaprojects influences their innovation potential (Ozorhon, Oral, and Demirkesen 2016; Sydow, Lindkvist, and DeFillippi 2004). Developing capabilities to leverage innovative ideas generated inside the organization or from external sources (Dodgson et al. 2015) is limited because the client organization and coalition of delivery partners will be disbanded on project completion. Dodgson et al. (2015, 80) further argue that megaprojects are 'usually not endowed with independent innovation capabilities, and do not have specific incentives to develop them'.

Besides the temporariness, a megaproject's organization is particularly complex (Brookes and Locatelli 2015) influencing innovation prospects. Because of these organizational features of megaprojects, this paper adopts an organizational perspective in evaluating innovation in megaprojects. The need for an organizational approach to innovation is also seen by Slaughter (1998) who argue that the organizational context of construction innovations differs significantly from many other innovations (for example from the manufacturing sector).

Different models of innovation have emerged and have been discussed in the literature, typically recognizing Rothwell's five generations of innovation (e.g. Hobday 2005). Well-known innovation models include the stage-gate model (Cooper 1987), funnel model (Wheelwright and Clark 1992), product and process innovation. Slaughter (1998) identified five models of construction innovation as incremental, modular, architectural, system, and radical innovation. Similarly, Gopalakrishnan and Damanpour (1997) identify three dimensions of innovation: level of analysis (reference against which the innovation is defined, within an industry, organization, organizational subunit, or innovation itself), stage of the innovation process (how organizations encounter an innovation), and type of innovation (nature of the innovation activity).

Considering our focus on organizational innovation, this paper adopts the framework proposed by Crossan and Apaydin (2010). This framework is based on an extensive literature review. Similarly, Eveleens (2010) developed a model using a literature review on innovation process model. Their model's five dimensions are covered in Crossan and Apaydin (2010) framework, but the latter framework also includes additional dimensions making it a more comprehensive model.

The framework by Crossan and Apaydin (2010) incorporates the two roles of innovation. First, innovation as a *process* focussing on how innovation takes place, for example by considering novel ways in which projects can be more efficiently delivered. Second, innovation as an *outcome* focussing on the product and services that were produced. The framework includes ten dimensions of innovation over the two roles of innovation. Five dimensions are distinguished for innovation as a process: level, driver, direction, source, and locus. Innovation as an outcome includes the four dimensions: form, magnitude, referent, and type. The nature dimension applies to both innovation as a process and innovation as an outcome. These determinants will be further discussed in the content analysis.

3. Methodology

A systematic literature review is characterized by a methodical and reproducible design for identifying and evaluating the current state of the art in a research field (Fink 2005). It synthesizes research in a systematic, transparent, and replicable manner to enhance knowledge and inform policy and practice (Tranfield, Denyer, and Smart 2003). This paper conducted a literature review as content analysis as it allows for an objective, systematic 'description of the manifest content of communication' (Berelson 1952, 55 in Gold, Seuring, and Beske 2010). Hence, by conducting a content analysis the literature review addresses some of the criticisms related to lacking critical assessment, rigour, relevance, and thoroughness (Tranfield, Denyer, and Smart 2003). We followed the four main steps of the process model of qualitative content analysis by Mayring (2000) (Seuring and Gold 2012):

1. Material collection: the material to be collected and analyzed is identified, delimitated, and the unit of analysis is defined.
2. Descriptive analysis: the formal characteristics of the material are assessed including the number of publications per year and region of publication. This provides the background for the content analysis that follows.
3. Category selection: the structural dimensions and related analytic categories are selected; these will be used to analyze the material.
4. Material evaluation: the material is analyzed according to the category selection process outcomes.

3.1. Material collection

Delimitation: It is important to define clear boundaries of the research in a literature review. Here we define three important notes about the delimitations of this research:

1. Papers focussing on innovation in project management in general are not included. By their very nature, megaprojects encounter different innovation processes and outcomes compared to traditional standard projects. Using the matrix of product and process innovation in projects by Davies, Gann, and Douglas (2009) projects differ according to the degree of standardization. In projects that are routine, the product and processes are highly standardized and replicable, providing a different setting for innovation compared to megaprojects, which have unique outcomes and non-routine processes.
2. Papers focussing on innovation industries outside of construction are not included. As Eveleens (2010) revealed in their paper, the industry matters when considering innovation, hence we decided to focus on one industry. We selected the construction industry because of its reputation of often falling back on standardized proven methods and techniques (van Marrewijk et al. 2008; Maghsoudi, Duffield, and Wilson 2016).
3. The analysis is aimed at peer-reviewed papers in English journals with a focus on management and construction.[1] We have not restricted the literature search to top tier journals due to the relatively new research area and the risk of missing relevant papers in other journals (Seuring and Gold 2012). Academic conference papers, book chapters, business articles, editorials, reviews and books are excluded from the search to ensure quality outcomes (Gunasekaran et al. 2015).

Our literature sample comprises English-speaking peer-reviewed papers on innovation in megaprojects covering a period from 1989 to 2019. We did not restrict our initial search to a specific time period and after evaluating the results, we decided that the number of papers was manageable and the time period did not have to be restricted.

In literature reviews by content analysis, the manifest content of communication is mainly represented by peer-reviewed journal articles (Gold, Seuring, and Beske 2010, Seuring and Gold 2012). Peer-reviewed journal articles therefore form the unit of analysis in this research.

A structured keyword search was conducted using both the databases SCOPUS and Web of Science (WoS). These two search databases were selected as they are the most comprehensive and commonly used databases of peer-reviewed journals in the social sciences and specifically management. Moreover, the use of these citation databases ensures a wider range of studies being identified as it indexes several journals and vendor databases in a central location (Thomé, Scavarda, and Scavarda 2016). The two main concepts in this research are innovation and megaprojects. Based on an initial screening of the literature we identified different ways in which these two concepts are commonly referred to in the literature. While the term megaproject is often used, alternatives that are being used are mega project, mega-project, major project, or large scale project. Hence, we used the term megaproject and the four alternatives as keywords in the literature search and combined them with the keyword innovation and its derivatives using the asterisk within the search. Considering the variety of ways in which researchers may have used the term innovation, and in line with other studies on innovation (e.g. Crossan and Apaydin 2010) we employed this general keyword to maximize the inclusion of potentially relevant studies in the initial sample. The specific search string that was used in title, keywords or abstract is: *innovat* AND* 'large scale project' *OR* 'mega project' *OR megaproject OR mega-project OR* 'major project'.

In addition, we used complex project as a synonym for megaproject and combined this with the innovation keyword in a search. The second search string that was used in title, keywords, or abstract is: *innovat* AND* 'complex project'.[2]

This initial search resulted in 254 articles from Scopus and 274 articles from WoS. We removed any duplications (a total of 49 articles), after which 479 articles remained in the initial sample. To select the relevant papers for this research the specific content was analyzed using formal inclusion and exclusion criteria.

3.1.1. Inclusion criteria

Papers that address the different innovation process or innovation outcomes in megaprojects in the construction industry are included.

Table 1. Inclusion and exclusion criteria.

No	Criteria	Reason
1	Innovation focus	Exclude articles that do not address innovation (256), or in which innovation was not the main focus (65), or does not relate to innovation in megaprojects (8) because they do not fit the objectives of this research.
2	Scope	Exclude articles that do not address innovation in construction or transport infrastructure projects (98) because they do not fit the objectives of this research.
3	Document type	Exclude articles that are not peer-reviewed (8), not English (3), or for which no full copy was available (5).

3.1.2. Exclusion criteria

In line with Centobelli, Cerchione, and Esposito (2017) and Demartini (2013), papers belonging to subject areas out of topic were excluded. Table 1) shows the exclusion criteria (with the number of articles that were excluded between brackets).

To increase the reliability of the research, a two-stage process was adopted. If the title and abstract did not give a clear indication on whether to include or exclude the paper, the full paper was read to make this decision. This stage of the systematic literature review reduced the sample to 36 articles. It is common for literature reviews to have a steep decrease of number of papers from initial literature search to the selected sample after analysis of the content against inclusion and exclusion criteria (Bakker 2010; Ardito, Messeni Petruzzelli, and Albino 2015).

However, in order to ensure all relevant papers have been identified, we extended the selection of papers by adopting a snowballing procedure (backward search and forward search of retrieved papers) as a complementary search (Wohlin 2014; Jalali and Wohlin 2012). By using this method of triangulation in material collection, using Scopus, Web of Science, and snowballing, we dealt with some of the challenges with database searches, including the selection of databases, search limitations, and use of synonyms of terms, that risk missing important literature (Wohlin 2014).

The backward snowballing approach identifies new papers by using the reference lists of the 36 retrieved articles from the initial search. A total of 1651 references were identified and 190 duplicates were removed from this sample. For the remaining articles, the title and abstract were reviewed using the same exclusion criteria, innovation focus (839), scope (37) and document type (578).

The forward snowballing approach identifies new papers based on the papers citing the paper being examined. Citations were identified using the same databases as were used in the initial database search (i.e. Scopus and Web of Science) and in addition Google Scholar was used because of its citation function. A total of 536 papers were identified and duplications were removed, also removing duplications with the initial sample following the database search and sample of papers following the backward snowballing approach. A total of 90 duplicates were removed, and for the remaining articles, the title and abstract were reviewed using the same exclusion criteria, innovation focus (405), scope (16) and document type (20).

It is worthwhile to note that the large number of papers being excluded is not surprising considering the references could relate to any aspects in the paper, for example the methodological approach taken, which were not relevant for our study on innovation in megaprojects. As a result of the backward and forward snowballing approach an additional 12 relevant papers were identified leading to a final sample of 48 papers.

The selected articles were read carefully and classified into papers to be utilized for the subsequent analysis and papers to be excluded. This process was conducted independently by each research team member. In order to assure inter-rater reliability, a quantitative measure reporting the number of disagreements (defined as cases in which the judgement about the inclusion or not of a paper had not been unanimous) over the total number of papers to be classified was developed. The process resulted in a very low number of disagreements, which were all discussed individually in order to reach a final consensus. A similar procedure was followed for the classification process.

Figure 1 shows the process that was followed to search and review the literature.

3.2. Descriptive analysis

The descriptive analysis was carried out to obtain some first insights into the formal aspects of the material. This included (1) Distribution of articles across a time period, (2) Distribution of articles across the journals in which they were published, (3) Distribution of articles by their geographical focus, and (4) Categorization of articles according to the research methods used in the publications.

3.3. Category selection

The structural dimensions and related analytic categories used to analyze the material were derived both deductively and inductively. For example, some of the dimensions and categories related to innovation were selected before the material was reviewed (in this case the dimension of the organizational innovation framework) whereas others were derived inductively while conducting the literature review. This approach ensures that both established categories and potential new emerging categories were included in the review process (Yawar and Seuring 2017).

3.4. Material evaluation

The articles were analyzed according to the selected categories whereby articles were coded against one or multiple categories depending on the focus of the paper. Using frequency counts and descriptive analysis, the current view on innovation in megaprojects is discussed. A detailed content analysis is conducted to identify the key issues in innovation in megaprojects and to propose a conceptual framework showing the relation between the constructs.

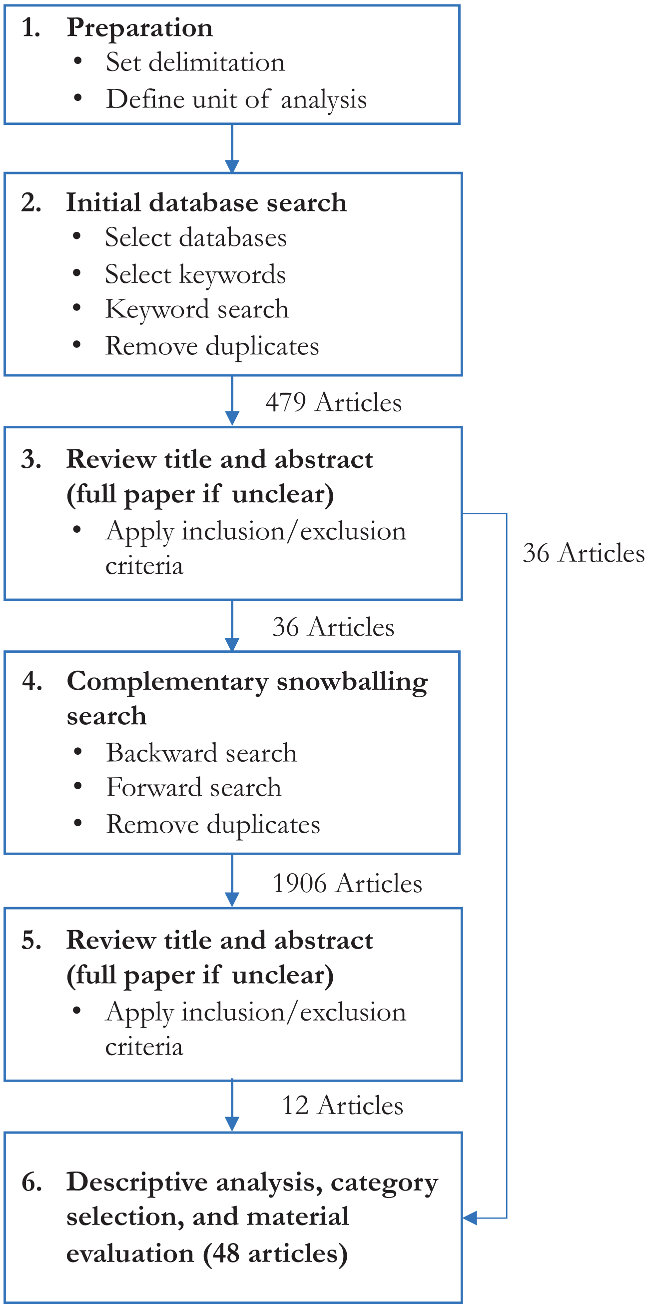

Figure 1. Flowchart systematic literature review process.

4. Descriptive analysis and findings

This section describes the findings of the descriptive analysis covering the distribution of papers across time period, the distribution of articles by journal in which articles were published, the geographical focus of the articles, and methodological approach that was applied.

4.1. Distribution across time period

Figure 2 shows the distribution of publications per year for the 48 papers that were retrieved. While the first paper on the topic was published in 1989, it isn't until 2009 that the research on this topic starts to take off. In fact, with 71% of the papers published in the last 10 years, it shows this is an emerging field of research.

4.2. Distribution by academic journal

The 48 articles on innovation in megaprojects have been published in 32 different journals. Figure 3 shows the journals that published at least two articles on innovation in megaprojects. The top contributors are Research Policy and International Journal of Project Management (4 papers), Project Management Journal, Journal of Construction Engineering and Management, Internal Journal of Managing Projects in Business, and Construction Management and Economics (all 3 papers). We use the rankings by SCImago to measure the scientific influence of journals and conclude they have a large impact. All journals in Figure 3 are in Quartile 1 (Q1) group of the SCImago rankings, except for Construction Management and Economics and Public Works Management & Policy (Q2).

4.3. Geographical distribution

For each of the 48 selected articles the country of study was identified, for example the country in which the case study project was implemented. Figure 4 shows the distribution of articles by their geographical focus. Based on this review of geographical focus, it can be concluded that innovation in megaprojects is predominantly studied in the United Kingdom. In fact, 33% of all studies originated from the UK (16 articles), followed by the United States of America (8% of all studies). A large number of papers (77%) focussed on one specific country. About 17% of all studies (8 articles) did not indicate a specific country as geographical unit of analysis, these are mainly conceptual papers.

4.4. Methodological approach used

The research methods and instruments used for data collection were also reviewed. Figure 5 provides an overview of the research methodologies. Four categories of research methods were identified:

- *Qualitative research (69%):* by far the majority of articles used a qualitative research method, the articles in this category used a case study research method or interviews for data collection. For example, Gil, Miozzo, and Massini (2012) and Davies, Gann, and Douglas (2009) used an in-depth case study (Heathrow Terminal 5) combined with interviews. Crossrail, a 73-mile railway line under development in London, has been used as a case by Dodgson et al. (2015), Davies et al. (2014), and Worsnop, Miraglia, and Davies (2016) with each study also conducting interviews.
- *Quantitative research (8%):* papers in this category used surveys or modelling (e.g. system dynamics). For example Hosseini et al. (2018) developed a model of sustainable delivery of megaprojects. They adopted a questionnaire survey approach and utilized structural equation

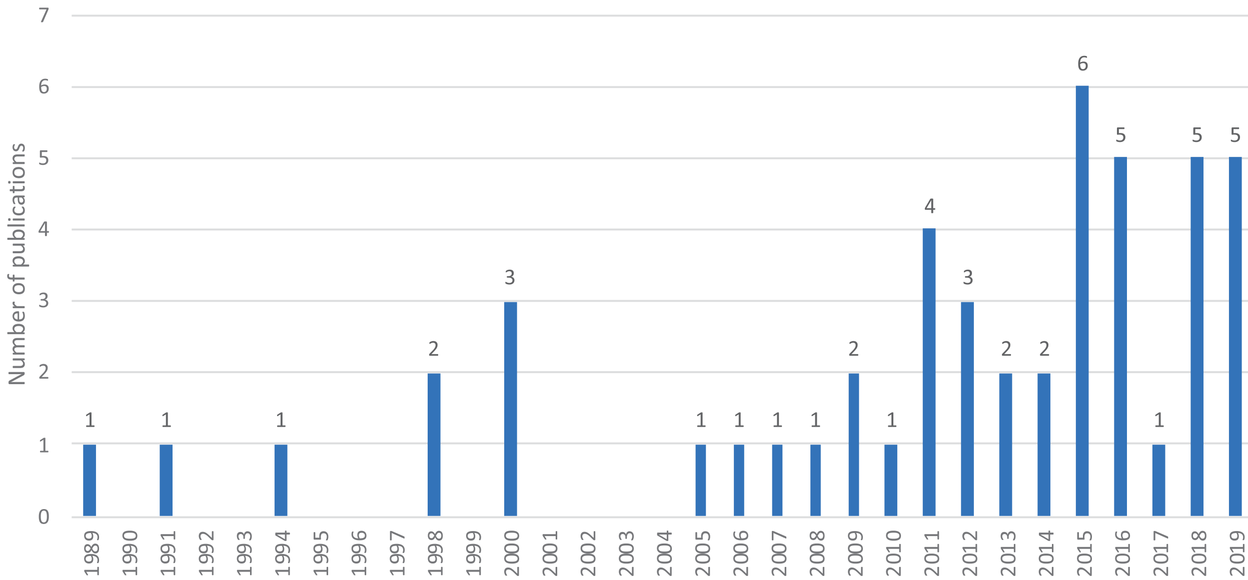

Figure 2. Distribution of articles over studied period.

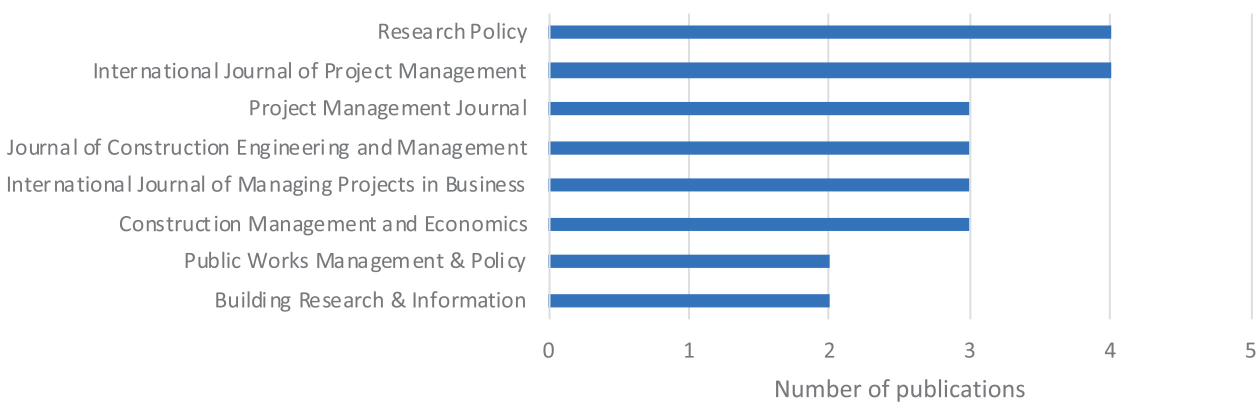

Figure 3. Distribution of articles by journal.

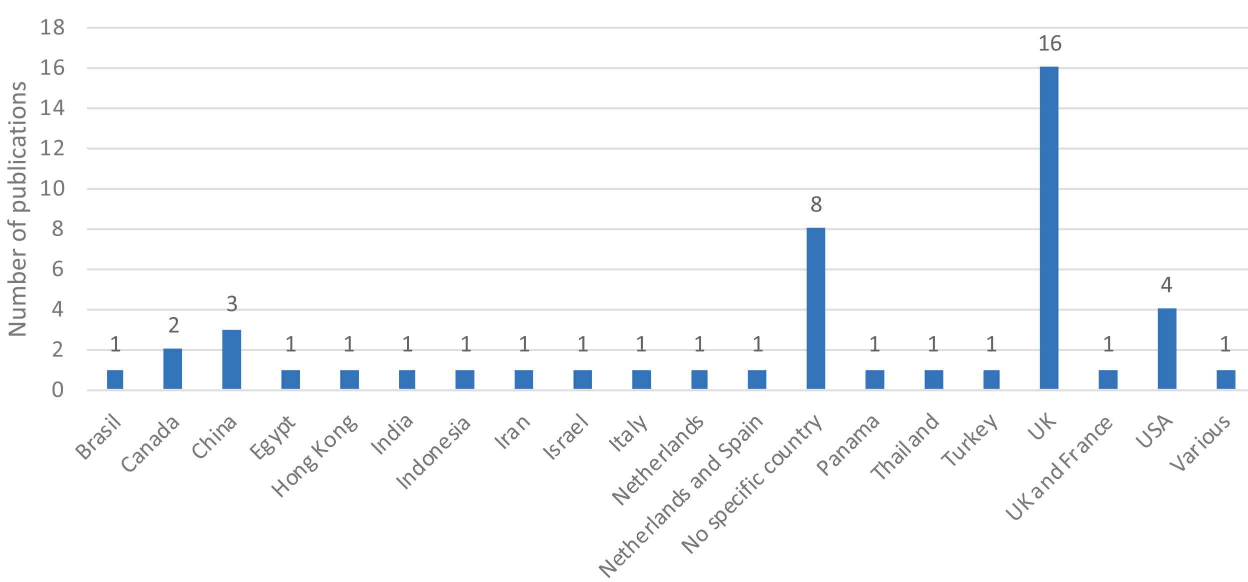

Figure 4. Distribution of articles by geographical focus.

modelling as a data analysis method. Husin et al. (2015) use a Systems Dynamics simulation model to compare financial feasibility of projects involving innovation.

- *Conceptual or descriptive papers (17%):* papers in this category do not rely on empirical data but discuss some key innovations or their characteristics in megaprojects. Several papers in this category propose new frameworks

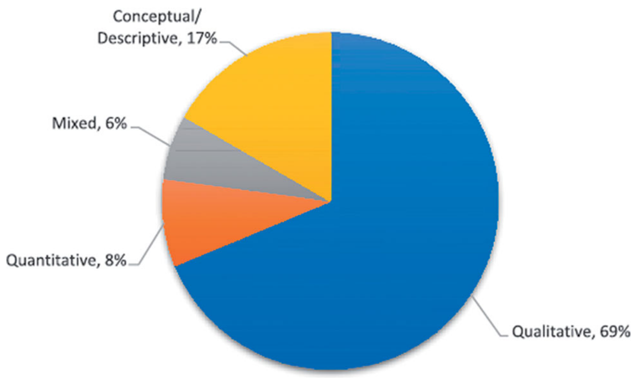

Figure 5. Distribution of articles by methods adopted.

to manage innovation based on open systems (Davidson and Huot 1991) or the two levels of the firm and the institution (Winch 1998). Others propose frameworks to analyze innovation concepts such as Tinoco, Sato, and Hasan (2016) who propose a framework of responsible innovation, and Chung, Kumaraswamy, and Palaneeswaran (2009) who develop a collaborative briefing framework to extend stakeholder engagement in megaprojects.

- *Mixed method research (6%):* this category includes papers that use both quantitative and qualitative research methods in one study. For example, Boateng, Chen, and Ogunlana (2015) combined survey with an Analytical Network Process model and Slaughter and Shimizu (2000) combined a survey with interviews.

Figure 6 shows the instruments that were adopted in the various studies. The two main instruments used in research on innovation in megaprojects are case study (62%) and interviews (46%) methods. Of the 30 papers that use a case study approach, 20 combined this with the interview method (67%). The single case study is most common (63%) in the study of innovation in megaprojects.

5. Content analysis and findings

Each of the 48 papers that were selected from the systematic literature review was read and reviewed in full, and coded according to the ten dimensions of organizational innovation by Crossan and Apaydin (2010). Dimensions are not mutually exclusive; thus each paper should be assigned to at least one category but could be assigned to more than one. In fact, dimensions are often linked, for example incremental or radical innovations (magnitude dimension) can apply to either product, process or business model innovations (form dimension). We did not find clear evidence of papers addressing the nature dimension directly, so this analysis focuses on the remaining nine determinants.

Besides this deductive approach, categories were derived inductively while conducting the literature review, which were then used to code papers against one or multiple of these categories. This inductive approach resulted in four new categories: (1) timing, (2) barriers and enablers, (3) diffusion of innovation, and (4) impact of innovation.

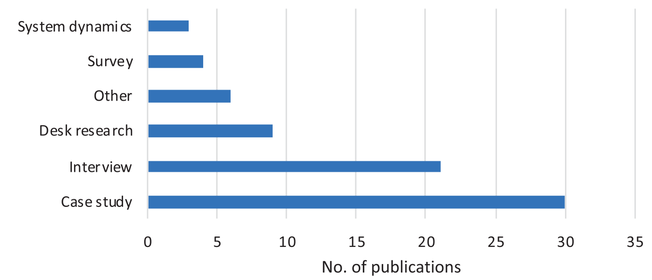

Figure 6. Distribution of articles by instruments adopted.

The full classification of the papers can be found in the Appendix Table A1 of this paper. Below we will evaluate and discuss the key issues that emerged.

5.1. Innovation as a process

Innovation as a process refers to 'how' innovation comes about. Table 2 gives a brief description of the five dimensions that are part of innovation as a process. 'Driver' is addressed most often by papers on innovation as a process in megaprojects, closely followed by source, then view, locus, and level.

5.1.1. Driver

The literature on megaprojects has identified various key drivers including technical challenges (Procter and Kozak-Holland 2019), failure with past projects (Davies et al. 2014; Whyte 2019), better solutions and improving performance (Worsnop, Miraglia, and Davies 2016; He et al. 2019; Sergeeva and Zanello 2018), and gaining economic and social value (Parrado and Reynaers 2020). For example, frequent failures in megaprojects when transferring from implementation to operations led to innovations in the organizational design of Crossrail (Davies et al. 2014) and to innovative ways of working in Heathrow terminal 5 (Whyte 2019).

Internal drivers of innovation also include knowledge and resources in the form of capital and human resources (Gui et al. 2018). Different parties often collaborate to bring knowledge and resources together such as in exchanges with Universities (Han et al. 2018), Communities of Practice (Veenswijk, Van Marrewijk, and Boersma 2010) and public-private partnerships (PPPs). PPPs can be seen as a formalized collaboration approach whereby resources and knowledge such as funding and expertise from private parties are pooled together with public sector resources (Kwak et al. 2014). Governments worldwide have shown an increased interest to deliver large capital infrastructures via PPPs (e.g. Little 2011; Himmel and Siemiatycki 2017). One of the reasons for the surge in PPP adoption was the belief that PPPs would allow for more innovation, particularly risk allocation would stimulate innovation (Badi and Pryke 2016). However, while PPPs act as a driver of innovation, Parrado and Reynaers (2020) and Barlow and Köberle-Gaiser (2008) found that the realization of innovation remains limited.

Besides these internal drivers, *external drivers* for innovation exist. For example, the use of public procurement is a

Table 2. Description dimensions pertaining to innovation as a process (adapted from Crossan and Apaydin 2010).

Dimension	Explanation	Dimension usage (%)
Driver	Available knowledge and resources (internal) or a market opportunity or imposed regulations (external)	42
Locus	The extent of the innovation process	17
Source	Ideation (internal) or adoption of innovation invented elsewhere (external)	33
Level	Whether it concerns individual, group or firm processes	9
View	How the innovation starts and develops	19

force to promote innovation because it allows opportunities for public authorities to specify innovative solutions through functional performance requirements (Barlow and Köberle-Gaiser 2008). The output specification of a contract can provide market opportunities for the private partners acting as an external driver for innovation. If consortia are free to choose their methods, materials, and techniques, it motivates them to develop innovative solutions if this has an economic value (Parrado and Reynaers 2020; Davies et al. 2014). Targets set by the Government, changes in regulations or the political environment (Sergeeva and Zanello 2018), and globalization of markets and economic conditions (Gann and Salter 2000) are also key drivers for innovation in megaprojects. Besides, job creation was an economic motivation on the French side to make process improving innovations in the Channel tunnel (Winch 2000). Societal challenges such as the need for mass housing in Israel gave rise to innovative risk sharing approaches and construction methods (Rosenfeld 1994), whereas socio-environmental risk has been a driver for companies to adopt sustainability innovations (Spitzeck, Boechat, and Leão 2013; Tinoco, Sato, and Hasan 2016).

5.1.2. Locus

Davidson and Huot (1991) consider innovation within organizations (closed innovation) and call for an open system approach in managing large-scale projects to deal with the hindrance traditional closed systems put on innovation by freezing the design scope early on to avoid costly design changes. Likewise, Gann and Salter (2000) review innovations within organizations and particularly difficulties of managing innovation in project-based firms. However, in megaprojects innovation often unfolds beyond individual organizations (Worsnop, Miraglia, and Davies 2016) and the innovation process is not isolated to one firm but is a 'multidisciplinary activity spanning multiple organizations' (Badi and Pryke 2015, 412). It involves temporary and permanent organizations working together in the process of innovation (Worsnop, Miraglia, and Davies 2016; Hobday 1998; Han et al. 2018). Similarly, Davies et al. (2014) and Dodgson et al. (2015) argue that such an open approach, spanning outside the boundaries of the organization and supply chain, is necessary for successful innovation. The innovation strategy that was utilized in Crossrail shows how in-house expertise and resources were combined with new ideas, practices, and external capabilities of other stakeholders (Davies et al. 2014) and that the innovation strategy should encourage open innovation in the supply chain (Dodgson et al. 2015).

5.1.3. Source

Several studies discussed how projects discovered and introduced original innovations or 'independent innovations' (Gui et al. 2018) such as new concrete technology and construction methods (Kwak et al. 2014; Rosenfeld 1994). Stakeholders within the project organization who promote and support innovation initiatives can also be an *internal source of innovation*. These are also referred to as innovation champions and their role is to enable innovative ideas and to communicate and support colleagues in bringing forward innovative ideas (Worsnop, Miraglia, and Davies 2016; Sergeeva and Zanello 2018). Different groups can promote an innovation such as top executives, the bid team, the project manager and team, any of the workers on the project (Brockmann, Brezinski, and Erbe 2016; Worsnop, Miraglia, and Davies 2016), contractors (Boland, Lyytinen, and Yoo 2007), the public sector (Veenswijk, Van Marrewijk, and Boersma 2010), the solution provider (Roehrich and Caldwell 2012; Worsnop, Miraglia, and Davies 2016) or system integrator (Davies, Gann, and Douglas 2009; Brady 2011). Examples of innovation champions are the CEOs in Crossrail, Thames Tideway Tunnel (TTT) and High Speed Two (HS2), the Head of Innovation in TTT and HS2, (Sergeeva and Zanello 2018), and the system integrator BAA in Heathrow Terminal 5 project (Davies, Gann, and Douglas 2009; Brady 2011).

External sources of innovation can either refer to *adoption* or *adaptation*. Innovations invented elsewhere are *adopted innovations*. They can be innovations acquired from other projects (Davies et al. 2014; Procter and Kozak-Holland 2019; Roehrich and Caldwell 2012; Sergeeva and Zanello 2018; Worsnop, Miraglia, and Davies 2016; Rosenfeld 1994), other industries (Davies et al. 2014; Sergeeva and Zanello 2018; Winch 1998), or other countries (Winch 1998; Gui et al. 2018 ; Rosenfeld 1994; Mann and Banerjee 2011). Adoption is also referred to as *replication* (Davies, Gann, and Douglas 2009; Brady 2011; Worsnop, Miraglia, and Davies 2016), 'pinching' (Worsnop, Miraglia, and Davies 2016), or trait-taking (Mann and Banerjee 2011 drawing on Hirschman 1967). Case studies that use adopted innovations are for example Florence Duomo project (Kozak-Holland and Procter 2014) and Delhi Metro (Mann and Banerjee 2011).

Innovations that integrate or recombine existing technologies, and innovations that transfer and apply mature technologies (Gui et al. 2018; Barlow and Köberle-Gaiser 2008) can be considered *adaptations* (or trait-making innovations). Similarly, technology innovations that involve substantial improvements on previous innovations but with no past experience are adapted innovations (Rosenfeld 1994). When considering the adaptation of innovations in megaprojects system recombination is recommended, whereby ideas, practices and technologies from other industries are taken over and combined in a single breakthrough project (Davies et al. 2014). While similar to adoption, inspiration is taken from outside the project, with adaptation the combination of processes is new.

5.1.4. Level

Several studies consider innovation at the firm level (Barlow and Köberle-Gaise 2008; Brady 2011; Davies, Gann, and Douglas 2009). In their study on project-based firms, Gann and Salter (2000) conclude that the management of innovation is often confined to specific groups within the firm, for example the R&D unit, senior management team, or engineering staff. Winch (1998) considers construction innovation at both the institutional and firm levels.

5.1.5. View

From the literature review the bottom-up approach seems most common in megaprojects. In Crossrail, any member of the project supply chain could submit a new idea, which was then discussed and evaluated with an innovation coordinator and representatives of the Innovation Programme team (Dodgson et al. 2015; Worsnop, Miraglia, and Davies 2016). Several studies illustrated bottom-up innovation through collaboration (Han et al. 2018; Hobday 1998; Spitzeck, Boechat, and Leão 2013; Veenswijk, Van Marrewijk, and Boersma 2010). Winch (1998) identifies two innovation dynamics, the top-down adoption/implementation dynamic and the bottom up problem-solving/learning dynamic. Similarly, Davies, Gann, and Douglas (2009) showed that both dynamics were present in Heathrow Terminal 5 whereby BAA's innovative efforts started at the highest levels, whereas for the contractor LOR it mostly started at the lowest level with innovations created in individual operational and project processes. Furthermore, Slaughter and Shimizu (2000) consider the interactions between innovations and conclude that innovations often appear to cluster together rather than to emerge in isolation.

5.2. Innovation as an outcome

Innovation as an outcome refers to 'what kind' of innovation. Table 3 gives a brief description of the four dimensions that are part of innovation as an outcome . It shows that 'form' is by far the most often addressed dimension by papers on innovation as an outcome in megaprojects.

5.2.1. Form

The form of innovation is often differentiated by product, process, and business model innovations.

Product innovations are products or services that are new to the market, and could relate to the design and development of an unique product. Innovations in megaprojects often concern the design and development of a unique one-off solution (Davies, Gann, and Douglas 2009). Design innovations include future proof designs (Roehrich and Caldwell 2012) such as the physical adaptability of hospital buildings to accommodate future changing requirements (Barlow and Köberle-Gaiser 2008), bridge designs (Granell 2019) such as the BangNa Expressway design for which the superstructure is entirely composed of precast concrete segments (Brockmann, Brezinski, and Erbe 2016), the designs of the Bilbao museum (Siemiatycki 2013) or the Denver International Airport Terminal roof (Johnston 2011). Often design innovations lead to construction technology innovations to produce innovative designs, such as the technologies to implement the structures or megaprojects (e.g. Brockmann, Brezinski, and Erbe 2016; Granell 2019; Gui et al. 2019; Procter and Kozak-Holland 2019) or information technologies to support the megaprojects, such as the innovative IT system to support collaboration between stakeholders (Chung, Kumaraswamy, and Palaneeswaran 2009), 2D and 3D computer aided designs (CAD) (Harty 2005) and single model environment (SME), a precursor to Building Information Modelling (BIM).

Process innovation is the 'introduction of new production methods, new management approaches, and new technology that can be used to improve production and management processes' (Wang and Ahmed 2004, 305). For example, process innovations used to *improve production processes* include the assembly line process in the mass production outbreak of China's HSR technologies (Gui et al. 2018), the use of new material and equipment to produce and assemble different bridge components (Slaughter and Shimizu 2000), innovative construction methods such as concrete-filled polystyrene blocks in the large-scale housing project (Rosenfeld 1994), the use of automated systems in the manufacturing and handling of segments of the Channel tunnel (Winch 2000), processes to receive digital information from the project supply chain to support the delivery of megaprojects as with London 2012 Olympics (Whyte 2019), innovative programme training approaches educating the local population rather than bringing in workers to complete the construction work (Spitzeck, Boechat, and Leão 2013), and more efficient processes to transform resources to the end product such as the integration of design and construction into a single contract in the BangNa Expressway (Brockmann, Brezinski, and Erbe 2016). Process innovations by introducing *new management approaches* can be seen in the form of new protocols and procedures for ethical supply chains in construction (Worsnop, Miraglia, and Davies 2016), the introduction of new approaches of responsible innovation

Table 3. Description dimensions pertaining to innovation as an outcome (adapted from Crossan and Apaydin 2010).

Dimension	Explanation	Dimension usage (%)
Form	Differentiates product or service, process, and business model innovations	71
Magnitude	The degree of newness of the innovation outcome with respect to the referent	28
Type	Distinguishes between social structure (administrative innovations such as organizational structure) and technology	42
Referent	Benchmark which defines the newness of the innovation as an outcome	15

(Tinoco, Sato, and Hasan 2016) and sustainable innovation (Badi and Pryke 2015, 2016; Hosseini et al. 2018), the use of new collaboration software (Davies, Gann, and Douglas 2009) such as the collaborative briefing framework proposed by Chung, Kumaraswamy, and Palaneeswaran (2009) providing a virtual organization through a shared digital workspace.

Business model innovation is related to creating new value for customers, transforming the delivery of the value, or delivering the value to new customers (Davila, Epstein, and Shelton 2006). An organization's innovation strategy includes the processes that create and capture value by combining and coordinating resources (Davies et al. 2014; Dodgson et al. 2015). Other innovations related to creating value to customers are value engineering methods (Husin et al. 2015), innovative financing (Johnston 2011) and risk (sharing) approaches (Mukherjee and Chatterjee 2015; Boateng, Chen, and Ogunlana 2015; Rosenfeld 1994), new appraisal frameworks for financing instruments (Henn et al. 2016) to support decision-makers in financing large public infrastructure projects and ensuring value for money.

However, most literature related to business model innovations is concerned with transforming the delivery of the value such as the bundling of different entities for design and construction (Johnston 2011), innovative tendering (Veenswijk, Van Marrewijk, and Boersma 2010), and new procurement approaches such as Early Contractor Involvement (ECI) in London 2012 Olympics (Sergeeva and Zanello 2018). A new partnership model was used for the delivery of the Hoover Dam project which was 'one of the first examples of a partnership between public and private sectors where a link between government funding and private-sector expertise was formed' (Kwak et al. 2014, 259). Moreover this was the first project in which a joint venture was employed involving more than three firms (Kwak et al. 2014). A new contractual partnering model was also created for the delivery of Heathrow Terminal 5 project discussed above (Davies et al. 2014). Particularly delivery through PPP has been a major business model innovation in megaprojects (Kwak et al. 2014; Little 2011; Himmel and Siemiatycki 2017; Siemiatycki 2006).

5.2.1.1. Magnitude.

The most well-known distinction of the newness of the innovation outcome is probably between radical and incremental innovations (Brockmann, Brezinski, and Erbe 2016; Dodgson et al. 2015; Rosenfeld 1994), which is also recognized in the megaproject management literature.

Incremental innovations reinforce existing products or processes using current knowledge (Slaughter 1998). Most studies on PPPs conclude they only bring incremental innovations (Badi and Pryke 2016; Himmel and Siemiatycki 2017; Roehrich and Caldwell 2012). According to Badi and Pryke (2016) this can be explained by the way in which risks are allocated, often forcing private sectors to opt for tried and tested technologies rather than adopting more revolutionary innovations.

There have been various case studies on innovations in megaprojects which revealed incremental innovations such as the BangNa Expressway in Thailand (Brockmann, Brezinski, and Erbe 2016), the London 2012 Olympics (Sergeeva and Zanello 2018), Crossrail (Worsnop, Miraglia, and Davies 2016), and the Channel Tunnel (Winch 2000). Indeed Worsnop, Miraglia, and Davies (2016) argue that success of innovations in megaprojects can be ensured by encouraging contractors to search for incremental innovations.

Radical innovations typically produce disruptive changes or a clear departure from existing methods and techniques (Slaughter 1998). Megaprojects implementing radical innovations are relatively rare (Brockmann, Brezinski, and Erbe 2016). Examples are the engineering breakthroughs (such as the internal spiral ramps) in the Giza Pyramid (Procter and Kozak-Holland 2019) or the hyperwing of Canadair's Challenger aircraft (Davidson and Huot 1991). More recently, Building Information Modelling (BIM) has been widely acknowledged as one of the most radical innovations in the construction industry (Koseoglu, Keskin, and Ozorhon 2019). And perhaps the partnership between public and private sectors is a radical organizational innovation that has transformed the delivery of major projects.

The magnitude dimension has close links with the source of innovation, with internal sources often having a greater extent of innovation, while external sources such as adaptation and adoption innovations are often more incremental.

5.2.1.2. Referent.

The referent dimension defines the basis to what the newness is referred to such as the firm, the industry, or even the world (Brockmann, Brezinski, and Erbe 2016). Innovations which explicitly used the *firm* as referent include management innovations such as the use of an integrated project team and chaperoning (Smits and van Marrewijk 2012). Moreover, innovations that are adopted or adapted from other firms use the firm as the referent (e.g. Davies, Gann, and Douglas 2009; Rosenfeld 1994) to assess the newness of the innovation. On a wider scale, using the industry as the *referent*, is the new type of cost-plus contract in Heathrow Terminal 5, the first time used in the UK construction industry (Davies, Gann, and Douglas 2009). Sustainability (Hosseini et al. 2018) and frameworks to model complexity and risk (Mukherjee and Chatterjee 2015) are said to be potential transformative innovations for megaprojects in the construction industry.

5.2.1.3. Type.

The type of innovation distinguishes between technical and administrative innovation.

Technical innovations deliver products or services directly related to the core activities of an organization and might include products, processes, and technologies (Crossan and Apaydin 2010). Technical innovations have been widely acknowledged in the literature (e.g. Brockmann, Brezinski, and Erbe 2016; Gann and Salter 2000; Koseoglu, Keskin, and Ozorhon 2019; Kozak-Holland and Procter 2014; Johnston 2011; Kwak et al. 2014; Procter and Kozak-Holland 2019; Roehrich and Caldwell 2012; Worsnop, Miraglia, and Davies 2016. Examples include BIM (Koseoglu, Keskin, and Ozorhon 2019), digital 3D models (Boland, Lyytinen, and Yoo 2007), and new material and equipment (Kozak-Holland and Procter

2014; Procter and Kozak-Holland 2019; Roehrich and Caldwell 2012; Worsnop, Miraglia, and Davies 2016; Slaughter and Shimizu 2000). For example, various technological innovations such as radar systems and ground movement technology were introduced in Denver International Airport (DIA) (Johnston 2011) and the Hoover Dam megaproject is known for its new material delivery system (Kwak et al. 2014).

Administrative innovations relate directly to the managerial aspects of the organizations' core activities and include the organizational structure, administrative processes and human resources (Crossan and Apaydin 2010; Brockmann, Brezinski, and Erbe 2016). In the front-end phase of projects, an innovative project process, organization, and governance structure can be created (Davies et al. 2014; Dodgson et al. 2015). Examples are the new governance regime in Heathrow Terminal 5 (T5) (Davies, Gann, and Douglas 2009) and the formation of a new organizational form in Crossrail project that involved an Integrated Project Team (IPT) (Davies, Gann, and Douglas 2009; Davies et al. 2014). The knowledge and expertise of different organizations in the partnering structure are brought together in a cross-functional team. Other innovations related to the organizational structure include the adoption of a mobilization team – a team consisting of people from different project phases (Roehrich and Caldwell 2012), the use of a construction services consultant changing the role and responsibilities of line and project managers (Rutherford 1989), the use of chaperoning – a type of collaboration by giving training on the job (Smits and van Marrewijk 2012), or even the establishment of new institutions in case of the Delhi Metro Rail (Mann and Banerjee 2011).

Besides changes in the organizational structure, new ways of working have emerged within the work force (Kozak-Holland and Procter 2014) or between public and private members of a project-based organization (Community of Practice (Veenswijk, Van Marrewijk, and Boersma 2010). Novel collaboration agreements between different agencies or levels of government (Johnston 2011) or with contractors (Davies et al. 2014; Han et al. 2018) have been drawn up and new practices, processes and structures related to the day-to-day operations as well as the organizational and project strategies have been introduced (Boland, Lyytinen, and Yoo 2007).

5.3. Barriers and enablers

While there is a substantive amount of literature on barriers and enablers of innovation in the construction industry, this section deals with the barriers and enablers identified for megaprojects specifically.

5.3.1. Barriers

The characteristics of megaprojects may create barriers to innovation, such as their project size, the separation of design and construction, the fragmented supply chain (Brockmann, Brezinski, and Erbe 2016), the large uncertainty and risk involved (Dodgson et al. 2015; Barlow and Köberle-Gaiser 2008), and the transitory nature of project activities (Davies et al. 2014). Other barriers identified include the design of the organization (Winch 2000), the complexity and lack of coordination between the infrastructure delivery and operation (Barlow and Köberle-Gaiser 2008), the lack of resources which may constrain the organization's ability to innovate (Gann and Salter 2000), risk aversity (Barlow and Köberle-Gaiser 2008), the lack of independent innovation capabilities in temporary organizations (Worsnop, Miraglia, and Davies 2016), and regulations and standards (Brockmann, Brezinski, and Erbe 2016; Badi and Pryke 2015). In his case study of the Channel Tunnel, Winch (2000) suggests that innovations could be hampered by procedures and narrow role specifications, whereby workers tend to fall back upon what they already know.

Moreover, PFI/PPP projects are confronted with additional barriers to innovation. First of all, ineffective *communication and collaboration* in the project organization (Badi and Pryke 2015; Barlow and Köberle-Gaiser 2008) due to the rigid structure of the PPP model, can stifle the opportunity for innovation (Himmel and Siemiatycki 2017). It may undermine trust amongst stakeholders further hampering innovation (Himmel and Siemiatycki 2017; Parrado and Reynaers 2020). Secondly, the *misalignment* of public sector and private sector objectives with sometimes competing interests (Badi and Pryke 2015; Himmel and Siemiatycki 2017; Barlow and Köberle-Gaiser 2008) can discourage innovation efforts. The contractual or agency-like relation between procurers and consortia causes short-term self-interested goals to prevail over long-term goals, hampering achievement of innovation and value creation (Parrado and Reynaers 2020). Thirdly, the excessive perceived *innovation-related risks* (particularly capital cost risks) (Badi and Pryke 2016) lessens the perceived reward of proposing innovations (Himmel and Siemiatycki 2017). Moreover, risks and rewards from innovation are unevenly distributed (Barlow and Köberle-Gaiser 2008). Fourthly, the *governance model* inhibits innovation in large-scale infrastructure projects because they are typically initiated by national/provincial governmental agencies, whereas key constituencies who are particularly able to identify innovations beneficial to the local community have limited involvement (Himmel and Siemiatycki 2017).

5.3.2. Enablers

While the nature of megaprojects can restrict innovation, the large network of parties can also encourage new products, processes, and modes of organizing (Brockmann, Brezinski, and Erbe 2016; Worsnop, Miraglia, and Davies 2016). The design of the organization, with many megaprojects delivered through project-based organizations, is often said to bypass barriers to innovation (Winch 2000; Sydow, Lindkvist, and DeFillippi 2004).

Collaboration is a key factor in facilitating innovation. Davies, Gann, and Douglas (2009) argue that the potential of innovations can only be fulfilled with collaborative behaviour between parties. A tendering and contracting approach based on early and structured collaboration can allow for identification of innovation opportunities as well as generate innovative solutions to deal with risk and uncertainty (Davies et al. 2014). Other enablers for innovations include the social responsibility (He et al. 2019), internal environment, competencies, resources, and the reputation of external partners (Spitzeck, Boechat, and Leão 2013).

PPP projects, as a specific form of project organizing, are widely believed to allow for more innovation and efficiency in projects, but only if collaborative relationships and incentives to work together to identify innovations can be established (Himmel and Siemiatycki 2017). For example, performance-based output specifications can provide flexibility that allow innovation, and the financial incentives and risk sharing arrangement built into the PPP model can encourage innovation (Davies et al. 2014; Himmel and Siemiatycki 2017). The innovation potential of PPP projects also depends on the extent to which parties can generate economic and social value through innovation (Parrado and Reynaers 2020), and the degree to which risks are allocated appropriately to parties that can manage the risk (Badi and Pryke 2016).

5.3.3. Capabilities and skills

Appropriate skills and capabilities are needed to facilitate innovations. The skills of the project team and project manager are critical factors of innovation (Kozak-Holland and Procter 2014; Winch 2000; Kwak et al. 2014). The success in the Hoover Dam project was partly ascribed to the superior skills of the project manager (Kwak et al. 2014). Sergeeva and Zanello (2018) refer to the need for innovation champions to have good 'storytelling capabilities' as it increases their chances of getting innovations approved and it stimulates others to present innovative ideas.

Furthermore, projects may require technical, managerial, communication, and leadership skills (Kwak et al. 2014) to identify and support technological innovations. The technological innovation capacity is often affected by two main determinants, i.e. stakeholders' assessment of the expected profitability and stakeholder's development of absorptive capacity (Gil, Miozzo, and Massini 2012). Stakeholders evaluate different aspects of technology adoption and these assessments may differ between stakeholders. Absorptive capacity refers to stakeholders' in-house capabilities and willingness to develop their capacity further. For PPP projects, additional skills required include contractual, relational, negotiation, and commercial skills (Roehrich and Caldwell 2012; Sergeeva and Zanello 2018)

Besides, megaprojects organized as temporary project-based organizations rely on the configuration of external skills and technologies (Dodgson et al. 2015) including financial management, coordination skills (Gann and Salter 2000) as well as the ability to model, measure, and monitor megaproject dynamic risk characterizations (Mukherjee and Chatterjee 2015). Acquiring such external capability can be realized by forming joint ventures and bringing together a pool of capabilities necessary to manage projects. This was for example the case in Crossrail where a coordinated mobilization of innovative capabilities across the project supply chain was the key in the project's successful innovation (Davies et al. 2014). Indeed, in megaprojects, a wide range of skills or 'capability bundles of skills' are needed (Dodgson et al. 2015).

5.4. Timing

Innovations can be identified and introduced during different phases of the project. Davies et al. (2014) developed a framework that identifies four windows of opportunity to promote innovation in a megaproject: (1) the bridging window: innovations are generated during the preparation and front-end planning; (2) the engaging window: innovations emerge during the design of the tendering and contracting process when new ways of working are sought; (3) the levering window: innovations are proposed after contracts have been awarded and the core supply chain has been formed; and (4) the exchanging window: innovations are introduced during and/or after the project has been executed. Examples are the innovative approaches in the front-end in High-Speed Two (HS2) and Thame Tideway Tunnel (TTT), novel cost management strategies in Hoover dam in the bridging window (Kwak et al. 2014), and the innovative procurement approaches ICE used in Bank Station Capacity Upgrade (BSCU) project in the engaging window (Sergeeva and Zanello 2018). Innovations initiated at the exchanging window of opportunity are often related to the transfer of knowledge that emerged out of innovation processes.

Depending on the phase of origin, innovations can be said to be planned up front or emergent as a response to problems during implementation (Dodgson et al. 2015). For example, for the Transportation Expansion Project in Denver, already delayed, the decision to opt for an innovative financing strategy emerging over the course of the project resulted in time savings (Johnston 2011).

5.5. Diffusion

Successful innovations can be diffused and adopted by other megaprojects (Mann and Banerjee 2011; Siemiatycki 2013). An example is the BIM implementation in large-scale projects (Koseoglu, Keskin, and Ozorhon 2019). Siemiatycki (2013) suggests that innovation happens in cycles, whereby successful megaprojects act as examples to promote megaprojects elsewhere. This is related to the innovation adoption theory Hosseini et al. (2018) use to investigate the process of sustainability adoption in construction projects in developing countries. They refer to the two main mechanisms for spreading innovation across the construction industry identified by Kale and Arditi (2010). The first mechanism concerns the internal influence which refers to imitative behaviour, and the second mechanism concerns the external influence which originates from the market. Winch (1998) supports this later mechanism and argues that new ideas which are diffused and implemented are external to the innovating firm, regardless of whether these are transferred from other countries/sectors or copied from other innovators within the sector.

Similar to Siemiatycki (2013), Boland, Lyytinen, and Yoo (2007) consider patterns in innovation diffusion. They refer to wakes of innovation whereby firms within a network would each produce multiple and distinct innovations that would become a wake of innovation resulting in a system of innovations stimulating other innovations.

5.6. Impact

While most of the classifications of innovations focus on the nature of the innovation itself, Harty (2005) considers the effects and consequences of innovations and distinguishes two modes of innovation, bounded and unbounded innovation. Innovations that have relatively contained effects and consequences within a single organization are considered bounded innovations and innovations that have widely felt inter-organizational impacts are unbounded innovations. Major projects typically involve these later types of innovation. An example of an unbounded innovation was the use of 3D CAD in Heathrow Terminal 5 project (Harty 2005) as it required coordination across different systems, people, and technologies.

Several studies have shown successful realization of innovation in megaprojects such as the BangNa Expressway in Bangkok (Brockmann, Brezinski, and Erbe 1996), London Heathrow Terminal 5 (Davies, Gann, and Douglas 2009; Gil, Miozzo, and Massini 2012), London Crossrail (Davies et al. 2014; Dodgson et al. 2015; Sergeeva and Zanello 2018; Worsnop, Miraglia, and Davies 2016), LBJ Express Highway project (Granell 2019), China's HSR (Gui et al. 2018), Hoover Dam project (Kwak et al. 2014), the UK government's Building Schools for the Future (BSF) PFI school projects (Badi and Pryke 2015, 2016), Delhi Metro Rail (Mann and Banerjee 2011), Channel Tunnel (Winch 2000), and the Transportation Expansion Project (T-Rex project) in the US (Johnston 2011).

Despite these successes, Davidson and Huot (1991) warn against the adoption of a large number of major innovations in one project due to the potential adverse compounded impacts. This may explain the failure of the Denver International Airport which adopted several innovations in construction technology such as innovations related to ground movement technology, communications, and radar systems (Johnston 2011).

While PPPs were expected to allow for more innovation, Parrado and Reynaers (2020) and Barlow and Köberle-Gaiser (2008) found limited levels of innovation and realization of anticipated benefits. Moreover, PPPs were expected to provide incentives to introduce innovative technologies during the design phases. However, evidence of this effect is scarce and inconclusive. For example, Roehrich and Caldwell (2012) showed for two PPP case studies that innovations were largely non-technological and mainly emerged in the operations phase. Similarly, based on a sample of 50 PPP projects in Ontario, Canada, Himmel and Siemiatycki (2017) maintained that innovations brought forward through PPPs tend towards incremental innovations in design, construction method, or material selection choices rather than more radical technological innovations.

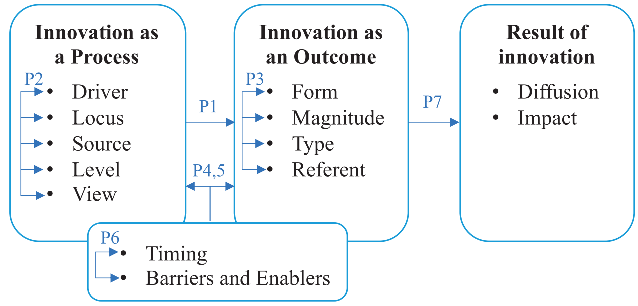

Figure 7. Framework innovation adoption in megaprojects.

6. Theoretical framework and discussion

Based on the systematic literature review we have developed a theoretical framework of innovation in megaprojects (Figure 7). The framework consists of the dimensions of innovation (as a process and as an outcome) from Crossan and Apaydin (2010), as well as the new dimensions: timing, barriers and enablers, diffusion and impact. Following the analysis of the literature we identified associations between dimensions which are represented by the seven propositions below.

The first relationship is between the two roles of innovation as a process and innovation as an outcome, the first preceding the second role of innovation (Crossan and Apaydin 2010). Considering innovation as a process in megaprojects, driver and source are predominantly associated with dimensions pertaining to innovation as an outcome. *Drivers* determine whether innovations in product, process, or business models are made (form) and they influence the degree of innovation (magnitude). Particularly internal drivers and business model innovations seem connected (Himmel and Siemiatycki 2017; Kwak et al. 2014; Siemiatycki 2006; Veenswijk, Van Marrewijk, and Boersma 2010). We found that the *source* of innovation mainly influences form and type. Project promotors as *internal sources* and particularly engineers and politicians are most likely to propose form and type of innovations (e.g. Worsnop, Miraglia, and Davies 2016; Sergeeva and Zanello 2018). The *external sources* are also associated with form and type innovations (e.g. Davies, Gann, and Douglas 2009; Procter and Kozak-Holland 2019; Roehrich and Caldwell 2012), but there is no clear indication on whether adoption or adaptation is more common for certain types or forms of innovation over others. Moreover, there is an association with *magnitude*; contractors are more likely to propose incremental innovations (Worsnop, Miraglia, and Davies 2016), whereas radical innovations are more likely to be proposed by project promotors.

We also found a relation between *locus* and *type*. Open innovation is often more suitable for process, business model, and administrative innovations (Badi and Pryke 2015; Worsnop, Miraglia, and Davies 2016; Davies et al. 2014; Dodgson et al. 2015; Han et al. 2018), which require a high level of collaboration between parties involved.

Proposition 1: Dimensions pertaining to innovation as a process influence dimensions pertaining to innovation as an outcome, with source, driver, and (to a lesser extent) locus having the largest impact on type and form of innovation.

We also uncovered interactions between dimensions within each of the two roles of innovation.

Considering interactions *between dimensions of innovation as a process*, prominent relations which were revealed from the literature review are between internal drivers and both internal and external sources. Several studies discussed knowledge and capabilities driving innovations, and the invention of innovations either through their own development and initiations or through adaptation and adoption (Gui et al. 2018; Kwak et al. 2014; Sergeeva and Zanello 2018; Veenswijk, Van Marrewijk, and Boersma 2010; Worsnop, Miraglia, and Davies 2016).

There is some indication of an association between a bottom-up innovation process (view dimension) and (internal) drivers, sources, and an open approach (locus dimension) but so far only few studies have touched on this. For example, for the association between a bottom-up and open innovation approach, innovation in megaprojects unfolds beyond the boundaries of the firm and the supply chain (Dodgson, Gann, and Salter 2008; Worsnop, Miraglia, and Davies 2016; Davies et al. 2014), in a collaborative network (Han et al. 2018) where new ideas are encouraged and attracted from multiple sources within the network. This also provides a link with the source dimension (the actor in the network proposed the new idea or innovation) as well as with the driver dimension (the network of parties bring together knowledge and resources to realize the innovation). These interactions reveal a combination of innovations that are necessary to realize other innovation dimensions also known as actualizing interactions (Slaughter and Shimizu 2000).

Proposition 2: For innovation as a process, interactions between (internal) drivers, sources, and views are the most common. The interactions are typically of an actualizing nature.

Considering the interactions *between dimensions of innovation as an outcome,* we found clear actualizing interactions between the *form* and *type* of innovation, particularly for product innovations. For example, new products can be of a technical nature (Johnston 2011; Procter and Kozak-Holland 2019; Roehrich and Caldwell 2012), such as the new ground movement system in Denver International Airport (Johnston 2011). Product innovations may need to be organized in an integrated system (administrative innovation) (Roehrich and Caldwell 2012; Davies, Gann, and Douglas 2009) to be successful and beneficial to the overall completed project (Davies, Gann, and Douglas 2009). Davies et al. (2014) showed interdependencies between innovation types in Crossrail where technological innovations (technical) required changes in organizational structure, such as using integrated project teams (administrative). In addition, complementary innovations are likely when a project has multiple innovations of the same type or form.

The literature review also suggested interactions between magnitude and type, with radical innovations often referring to technical innovations (Koseoglu, Keskin, and Ozorhon 2019; Kwak et al. 2014; Procter and Kozak-Holland 2019), whereas incremental innovations could be both technical or administrative.

Proposition 3: For innovation as an outcome, interactions within and between type and form of innovation are the most common. They are often benchmarked against the extent of newness (magnitude) and can be characterized by actualizing interactions or complementary interactions.

The literature suggested an association between *timing* and the *form* and *type* dimensions, but so far only few studies have addressed this directly. Innovation can take place in all phases and innovations need to be able to evolve over time (Dodgson et al. 2015) but some types and forms are more typical in the early phases, for example administrative and business model innovations (Davies et al. 2014; Dodgson et al. 2015; Sergeeva and Zanello 2018). Similarly, *drivers* of innovation can differ depending on the stage of the project life cycle. For example, previous project failures may spur innovation at the start (Davies et al. 2014; Sergeeva and Zanello 2018), whereas contract specifications may encourage innovation in the tendering phase (Davies et al. 2014)

Proposition 4: Timing measured by the project development phase, is associated with dimensions concerning both the roles of innovation as a process and innovation as an outcome and particularly source, form, and type.

Turning to *barriers and enablers*, there are interactions with drivers and sources of innovation. Considering *internal drivers*, parties may want to combine their skills and resources through collaboration to implement a particular innovation. The innovation is only enabled if the collaboration is characterized by a long-term perspective, goal alignment, trust (Parrado and Reynaers 2020), required skills (Kwak et al. 2014), and a coordinated mobilization of innovative capabilities (Davies et al. 2014), creating value that allows the realization of innovation. In contrast, a lack of perceived economic value (Parrado and Reynaers 2020) or excessive risk transfer (Badi and Pryke 2015; Himmel and Siemiatycki 2017) would hinder innovation despite collaboration driving innovations. The collaboration often requires some form of partnership, which can either act as a barrier or enabler to achieve the innovation. In partnerships such as PPPs, innovation can be stimulated by bundling of activities, using performance-based output specifications, creating collaborative relationships, and providing financial incentives (Himmel and Siemiatycki 2017; Davies et al. 2014; Parrado and Reynaers 2020). *External drivers* can also lead to innovation initiatives depending on capabilities (Davies et al. 2014; Sergeeva and Zanello 2018), competencies, resources and reputation of external partners (Winch 2000; Spitzeck, Boechat, and Leão 2013), and flexible output specifications of a contract (Davies et al. 2014; Parrado and Reynaers 2020). Lastly, sources of innovation, including initiators, adaptation, and adoption of innovation set requirements to the capabilities and skills of the project needed for the successful realization of the innovation (Sergeeva and Zanello 2018; Kozak-Holland and Procter 2014; Roehrich and Caldwell 2012).

Furthermore, relations were seen between *barriers and enablers* and the innovation dimensions form, type, and magnitude. Collaboration (Davies, Gann, and Douglas 2009), competencies (Spitzeck, Boechat, and Leão 2013; Gann and Salter 2000), as well as the innovativeness of the organization (Winch 2000) and the characteristics of megaprojects (Worsnop, Miraglia, and Davies 2016) can act as enablers and barriers, and determine the extent to which product, process, and administrative innovations can be realized.

Capabilities seem to play a predominant role in the interactions with the dimensions form and type of innovations. First of all, similar as with the dimensions of innovation as an outcome, a coordinated mobilization of innovative capabilities is needed to realize a project's innovation strategy, consisting of the various form and type of innovations (Davies et al. 2014; Dodgson et al. 2015). Secondly, both in-house capabilities and the ability to acquire capabilities from other stakeholders are required for technical innovations (Gil, Miozzo, and Massini 2012).

Regarding the magnitude of innovation, more extensive innovations require a wider set of capabilities and skills including absorptive capacity.

> Proposition 5: Megaprojects' characteristics and capabilities are important factors that can enable or restrict innovations. They influence whether and how drivers and sources of innovation realize innovations successfully.

Over the course of the project, different set of skills and capabilities are required. For example in the early stages advanced contractual, relational, negotiation, and commercial skills are required (Roehrich and Caldwell 2012; Sergeeva and Zanello 2018) while in the implementation phase governance capability, process and project management skills are needed (Roehrich and Caldwell 2012; Sergeeva and Zanello 2018). Moreover learning capabilities are needed to enhance innovation beyond implementation in the diffusion phase (Sergeeva and Zanello 2018).

> Proposition 6: Skills and capabilities are associated with the timing dimension. A dynamic approach is needed to appropriately assess these skills and capabilities during the different stages of project development.

Lastly, we will consider the association between different innovation dimensions and the result of innovation in terms of impact and diffusion. Agency theory argues that the relationship between the private and public sector could negatively impact the realization of this innovation if there is a (pure) contractual based relation without alignment of goals and incentives (see for example Parrado and Reynaers 2020). Thus, these innovations from PPPs can only be successful with sufficient level of governance capability to define and control an incentive structure to bring about these technological innovations as well as more radical innovations.

Sometimes projects are chosen or promoted due to their symbolic meaning and political legacy (Flyvbjerg 2014; Giezen 2012). As a result, innovations are not always adopted for the right reasons and therefore may not result in the desired efficiency gains, especially if the internal and external capabilities are insufficient.

> Proposition 7: Successful innovation relies on a good fit between innovation dimensions concerning the process and outcome, as well as the ability to develop absorptive capacity and to mobilize innovation capabilities externally.

7. Discussion and future research direction

While innovation is generally regarded as being critical for an organization's performance and competitive advantage (Dodgson, Gann, and Salter 2008), the literature reports diverging perspectives on innovation in construction infrastructure projects. On the one hand, the construction industry (in the UK) seems to lack innovation compared to other industries (Brady 2011; Brockmann, Brezinski, and Erbe 2016) and even if megaprojects may use some innovative elements, under conditions of risk and uncertainty they still rely on many standardized and repetitive processes, techniques, and technologies that are necessary for efficiency and productivity gains (Davies, Gann, and Douglas 2009; van Marrewijk et al. 2008; Maghsoudi, Duffield, and Wilson 2016). On the other hand, megaprojects appear to be larger in size, cost, and impact than ever before, with iconic designs and far advanced technologies (Flyvbjerg 2014) suggesting innovations are part of their nature.

Recently, there seems to be a drive towards increasing the levels of innovation in megaprojects (Holzmann et al. 2017) devising mechanisms to foster innovation (Worsnop, Miraglia, and Davies 2016) and making 'significant efforts to create a more innovative and flexible delivery model' (Davies and Gann 2017). Consequently, the more recent literature has identified various instances of innovations in megaprojects; however, currently, the dimensions of innovation in megaprojects are not sufficiently explored. Most studies focus on the drivers or sources of innovation, form and type of innovation, and the importance of collaboration to combine resources and knowledge. Some of these, such as innovation actor and collaboration, have also been highlighted in other projects such as for new product development projects (Song, Cao, and Zheng 2016) and globally distributed projects (Ollus et al. 2011). Our study has provided consolidated information on a wide range of dimensions of innovation in megaprojects, including dimensions which were so far underdeveloped (Brockmann, Brezinski, and Erbe 2016).

In line with the general innovation literature (Crossan and Apaydin 2010), studies on innovation in megaprojects have focussed more on innovation as an outcome (55% of the studies) compared to innovation as a process (45% of the studies). The lack of a balanced understanding of these two roles of innovation is concerning. In this respect, important research gaps that should be addressed in the future to understand innovation in megaprojects are the extent of the innovation process, the level of the innovation processes, and how innovation starts and develops within megaprojects (e.g. top-down, bottom-up). Another concern is the role of timing and its interactions with the various dimensions of innovation, and particularly the apparent lack of detail about what kind of innovation (form, type, magnitude, etc.) is most appropriate during the various project life cycle stages. Beside two seminal papers (Davies et al. 2014; Dodgson et al. 2015), few papers address this issue of timing. This issue is not specific to the management of megaprojects. Robert et al. (2019) found that literature on management innovation has a static approach to identify factors that enable or hinder implementation and a temporal perspective is lacking. More research is needed to understand what innovation processes and outcomes can be expected as the project evolves, and to take a dynamic approach to identify the respective capabilities over time.

While factors that influence innovation in projects have been discussed in previous literature, this is less understood for megaprojects specifically. Some of these factors may also apply for innovation in megaprojects, for example, the temporary nature of projects, unavailability of materials, lack of experience, and qualified staff (Ozorhon, Oral, and Demirkesen 2016) are factors that halt or discourage innovation, while collaboration and early contractor involvement are enablers for innovation (Blayse and Manley 2004; Ozorhon, Oral, and Demirkesen 2016). Our study has revealed additional barriers and enablers of innovation that are more specific for megaprojects. We have shown the result of innovation in terms of impact and diffusion. So far, diffusion has been addressed by few studies, and particular its interaction with barriers/enablers is an important area for further research. Except for Rosenfeld (1994) who identified capital intensiveness, legal responsibilities, and fragmentation as barriers in the diffusion process of innovative construction methods specifically, few studies have addressed this issue.

We have identified and discussed various dimensions of innovation in megaprojects and further research is recommended to test their significance on the successful realization of innovation. Little is known about the impact of different dimensions of innovation on the actual realization of innovation and the overall project success. For example, PPPs are often suggested to drive innovations, but literature has found limited evidence of the realization of innovation (e.g. Parrado and Reynaers 2020; Roumboutsos and Saussier 2014; Winch 2012).

Lastly, we have identified several actualizing and complementary interactions between dimensions of innovation and future research is recommended to test these interactions.

8. Conclusion

The interest in megaprojects is undisputed and there has been an increasing attention to the role of innovation in megaprojects. While there seems to be a drive towards increasing the levels of innovation in megaprojects, the literature often discusses specific innovation dimensions as distinct components. This paper provides a holistic view of what innovation entails and how this can emerge in megaprojects. It synthesizes the current literature in order to gain a more complete understanding of innovation dimensions and relations between them. The findings discover that the current focus has mostly been on tangible aspects of innovation (including drivers, sources, form and type of innovation) and innovation relations are present but largely implicit.

The main findings of this study are the identification of different dimensions of innovations and the clusters of innovations in megaprojects with both actualizing and complementary interactions. For example, a cluster of internal drivers, external sources, and an open approach can be described as follows. The nature of megaprojects implies that the innovation process spans across multiple organizations whereby organizations collaborate and knowledge and resources are pooled together to foster innovation opportunities. Recently, megaprojects had adopted innovation strategies allowing for innovation initiatives to be proposed at various levels of the organization.

Megaprojects may have several actualizing or complementary innovation interactions but the benefits need to be weighed against potential compounding risks, and innovation decisions need to be based on an appropriate assessment of the in-house and adaptive capabilities. Some interactions may be detrimental, for example interactions between internal sources, drivers, and technical innovations. There may be instances where project promotors may fall victim to the risk of 'technological sublime' (Frick 2008), an emphasis on using innovative technologies in megaproject delivery despite a higher level of uncertainty.

The study makes several significant contributions to theory and practice. First, the study expands the innovation framework by including four additional dimensions of barriers and enablers, timing, impact, and diffusion. Second, based on the identified gaps in literature, the paper proposes the following areas for future research: (i) a lack of a detailed understanding of the extent, level, and direction of the innovation process, (ii) a limited understanding of innovation dimension over the project life cycle, (iii) deficiency in capabilities related to dimensions of innovation, and (iv) the absence of specific actualizing and complementary interactions between innovation dimensions.

This research agenda aims to increase successful adoption of innovation in megaprojects by improving decisions on innovation through considering the clusters of innovations and the ability to mobilize and develop absorptive capacity. Secondly, the systematic literature review provides an overview of the current knowledge and understanding of innovation in megaprojects. Besides the academic relevance, it is relevant forpractitioners, as it will allow them to understand how multiple innovations can influence each other, and what external influences can facilitate or hinder the success of the innovations in their projects.

As the first systematic literature review on innovation in megaprojects, it reveals some interesting insights, however, there are a few limitations. First, the search method is focussed on management research and does not consider innovations in other domains. Second, the paper recognizes the limitations on generalizing the findings of the literature due to the relatively low number of papers focussing on innovation in megaprojects. However, considering the emerging field of research, the findings are useful to get a more comprehensive understanding of the complexity of innovation in megaprojects. Further empirical research into the innovation dimensions and their interactions is needed to enhance the framework and explore how innovation can be successfully implemented with a positive influence on the overall project performance.

Disclosure statement

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Notes

1. For the two databases that were used to search for literature, the subject areas included in Scopus are Business, Management and Accounting; Decision Sciences; Economics, Econometrics and Finance; Engineering; Multidisciplinary; Social Sciences. The subject areas included in Web of Science are: Business Economics; Construction Building Technology; Engineering; Transportation; Urban Studies.
2. The term 'megaproject' is not always consistently used in the literature and there is a variety of different spellings. Similarly, although megaprojects are defined as typically costing £1bn or more, the 'minimum cost' used to define a project as 'mega' project is not consistent. Therefore we used alternative wordings such as large-scale and complex (which are besides the size of the project in terms of cost) key characteristics for megaprojects.

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Appendix. Classification of papers

Table A1. Classification of reviewed papers on innovation in megaprojects.

Authors	Country	Methodology	Instrument	Innovation as a process	Innovation as an outcome	Other dimensions
Badi and Pryke (2015)	UK	Qualitative	Multiple case study, interviews	Locus: open	Form: process	Barriers; Impact
Badi and Pryke (2016)	UK	Qualitative	Multiple case study, interviews	Driver: internal	Form: process; Magnitude: incremental	Barriers; Enablers; Impact
Barlow and Köberle-Gaiser (2008)	UK	Qualitative	Multiple case study, interviews	Driver: internal, external; Source: external; Level: firm	Form: product; Referent: firm	Barriers; Enablers; Impact
Boateng, Chen, and Ogunlana (2015)	UK	Mixed	Survey, Analytical Network Process		Form: business model	
Boland, Lyytinen, and Yoo (2007)	No specific country	Qualitative	Single case study, interviews	Source: internal	Type: technical, administrative	Diffusion
Brady (2011)	UK	Qualitative	Single case study, interviews	Source: internal, external; Level: firm		
Brockmann, Brezinski, and Erbe (2016)	Thailand	Qualitative	Single case study, longitudinal action research	Source: internal	Form: product, process; Referent: firm, industry; Magnitude: incremental, radical; Type: technical, administrative	Barriers; Enablers; Impact
Chung, Kumaraswamy, and Palaneeswaran (2009)	Hong Kong	Conceptual paper	Conceptual		Form: product, process	
Davidson and Huot (1991)	No specific country	Descriptive	Descriptive	Locus: closed	Magnitude: radical	Impact
Davies, Gann, and Douglas (2009)	UK	Qualitative	Single case study, interviews	Source: internal, external; Level: firm; View: top-down, bottom-up	Form: product, process; Referent: firm, industry; Type: administrative	Enablers; Impact
Davies et al. (2014)	UK	Qualitative	Single case study, interviews	Driver: internal, external; Source: external; Locus: open	Form: business model; Type: administrative	Barriers; Enablers; Timing; Impact
Dodgson et al. (2015)	UK	Qualitative	Single case study, interviews	Locus: open; View: bottom-up	Form: business model; Magnitude: incremental; radical; Type: administrative	Barriers; Enablers; Timing
Gann and Salter (2000)	UK	Qualitative	Multiple case study, interviews	Driver: external; Locus: closed; Level: firm	Type: technical	Barriers; Enablers
Gil, Miozzo, and Massini (2012)	UK	Qualitative	Single case study, interviews		Form: product	Enablers
Granell (2019)	USA	Qualitative	Single case study		Form: product	Impact
Gui et al. (2018)	China	Mixed	Single case study, measurement model	Driver: internal; Source: internal, external	Form: product, process	Impact
Han et al. (2018)	China	Qualitative	Social Network Analysis	Driver: internal; Locus: open; View: bottom-up	Type: administrative	
Harty (2005)	UK	Qualitative	Single case study, interviews		Form: product	Impact
He et al. (2019)	China	Quantitative	Survey	Driver: internal		Enablers
Henn et al. (2016)	No specific country	Descriptive	Descriptive		Form: business model	
Himmel and Siemiatycki (2017)	Canada	Qualitative	Interview, documentation	Driver: internal	Form: business model; Magnitude: incremental	Barriers; Enablers; Impact
Hobday (1998)	No specific country	Descriptive	Descriptive	Locus: open; View: bottom-up		
Hosseini et al. (2018)	Iran	Quantitative	Survey		Form: process; Referent: industry	Diffusion
Husin et al. (2015)	Indonesia	Quantitative	System dynamics		Form: business model	
Johnston (2011)	USA	Qualitative	Multiple case study, interviews		Form: product, business model; Type: technical, administrative	Timing; Impact

(*continued*)

Appendix. Classification of papersTable A1. Continued.

Authors	Country	Methodology	Instrument	Innovation as a process	Innovation as an outcome	Other dimensions
Koseoglu, Keskin, and Ozorhon (2019)	Turkey	Qualitative	Single case study, interviews		Magnitude: radical; Type: technical	Diffusion
Kozak-Holland and Procter (2014)	Italy	Qualitative	Single case study, documentation	Source: external	Type: technical, administrative	Enablers
Kwak et al. (2014)	USA	Qualitative	Single case study	Driver: internal; Source: internal	Form: business model; Magnitude: radical; Type: technical	Enablers; Impact
Little (2011)	No specific country	Conceptual paper	Conceptual		Form: business model	
Mann and Banerjee (2011)	India	Qualitative	Single case study	Source: external	Type: administrative	Diffusion
Mukherjee and Chatterjee (2015)	No specific country	Quantitative	System dynamics		Form: business model; Referent: industry	Enablers
Parrado and Reynaers (2020)	Netherlands, Spain	Qualitative	Comparative case study, interviews	Driver: internal, external		Barriers; Enablers; Impact
Procter and Kozak-Holland (2019)	Egypt	Qualitative	Single case study, documentation	Driver: internal; Source: external	Form: product; Magnitude: radical; Type: technical	
Roehrich and Caldwell (2012)	UK	Qualitative	Longitudinal case study, interviews	Source: internal, external	Form: product; Magnitude: incremental; Type: technical, administrative	Enablers; Impact
Rosenfeld (1994)	Israel	Descriptive	Descriptive	Driver: external; Source: internal, external	Form: process, business model; Referent: firm; Magnitude: radical, incremental	Diffusion
Rutherford (1989)	USA	Qualitative	Comparative case study		Type: administrative	
Sergeeva and Zanello (2018)	UK	Qualitative	Interviews	Driver: internal, external; Source: internal, external	Form: business model; Magnitude: incremental	Enablers; Timing; Impact
Siemiatycki (2006)	No specific country	Qualitative	Single case study	Driver: internal	Form: business model	
Siemiatycki (2013)	Canada	Qualitative	Multiple case study, interviews		Form: product	Diffusion
Slaughter and Shimizu (2000)	Various	Mixed	Survey, interviews	View: interactions	Form: product, process; Type: technical	
Smits and van Marrewijk (2012)	Panama	Qualitative	Single case study, ethnographic fieldwork		Referent: firm; Type: administrative	
Spitzeck, Boechat, and Leão (2013)	Brazil	Qualitative	Comparative case study	Driver: external; View: bottom-up	Form: product, process	Enablers
Tinoco, Sato, and Hasan (2016)	No specific country	Conceptual paper	Conceptual	Driver: external	Form: process	
Veenswijk, Van Marrewijk, and Boersma (2010)	Netherlands	Qualitative	Ethnographic study, various	Driver: internal; Source: internal; View: bottom-up	Form: business model; Type: administrative	Enablers
Whyte (2019)	UK	Qualitative	Embedded case study, interviews	Driver: internal	Form: product, process	
Winch (2000)	UK and France	Qualitative	Single case study, interviews	Driver: external	Form: process; Magnitude: incremental	Barriers; Enablers; Impact
Winch (1998)	UK	Conceptual paper	Descriptive	Source: external; Level: firm; View: bottom-up		Diffusion
Worsnop, Miraglia, and Davies (2016)	UK	Qualitative	Single case study, interviews	Driver: internal; Source: internal, external; Locus: open; View: bottom-up	Form: process; Magnitude: incremental; Type: technical	Barriers; Enablers; Impact