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Managing short-term efficiency and long-term development through industrialized construction

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There is a strong need for a productive and innovative infrastructure sector because of its monetary value and importance for the development of a sustainable society. An increased level of industrialization is often proposed as a way to improve efficiency and productivity in construction projects. In prior literature on industrialized construction, there are however neither many studies addressing more long-term aspects of innovation and sustainability nor studies within the infrastructure context. Organizational theory suggests that firms need to be ambidextrous and focus on both long-term exploration of new knowledge and technologies and short-term exploitation of current knowledge and technologies, in order to achieve sustainable development. Therefore, an investigation of how both short-term exploitative performance objectives and long-term explorative development can be addressed when implementing industrialized construction in infrastructure projects was conducted. A case study consisting of four infrastructure projects shows that the main drivers for increased industrialization are of an exploitative nature, focusing on cost savings and increased productivity through more efficient processes. The main barriers to increased industrialization are however related to both explorative and exploitative activities. Hence, by managing the identified barriers and explicitly addressing both exploitation and exploration, industrialized construction can improve both short-term efficiency and long-term innovation and sustainability.

Keywords: Ambidexterity, efficiency, industrialization, infrastructure, sustainability.

Introduction

Increased industrialization of construction processes is often suggested by both researchers and practitioners to be a promising approach to improve construction project performance (Abdul Kadir *et al.*, 2006; Höök and Stehn, 2008; Girmscheid and Rinas, 2012). The basic argument is that the construction industry has much to learn from manufacturing industries in terms of product development, production processes and supply chain management (Gann, 1996). Yet others warn that management practices that are successful in manufacturing contexts cannot be readily transferred to the construction industry without major adaptations to fit the project-based context (Bresnen and Marshall, 2001; Riley and Clare-Brown, 2001). Nevertheless, prior findings highlight many different benefits that drive the interest in implementing industrialized construction, such as time savings, improved cost efficiency, improved safety, and better quality (Abdul Kadir *et al.*, 2006; Alinaitwe *et al.*, 2006; Girmscheid and Rinas, 2012).

Most of the earlier studies on industrialized construction highlight productivity improvements achieved in production processes in the housing sector (e.g. Gann, 1996; Abdul Kadir *et al.*, 2006; Höök and Stehn, 2008), whereas the concept is less actively considered and is also more difficult to transfer successfully to, and implement in, the infrastructure sector (Winch, 2003). The inherently one-off nature

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of the infrastructure sector means that each project is different, making it difficult to achieve the degree of repetition and routinization necessary to make the most of this kind of manufacturing concept (Bresnen and Marshall, 2001). Having said that, improved productivity in the infrastructure sector is especially urgent from a societal perspective since the efficiency of large public spending in infrastructure investments is crucial for development and economic growth in many countries (Caerteling *et al.*, 2011). This is because an efficient infrastructure system can reduce transaction costs and enhance opportunities for access and exchange in a society (Rose and Manley, 2012). The rationale for the application of industrialized construction in the infrastructure sector is yet to be investigated. In order to study how the concept of industrialized construction might be applied within the context of the infrastructure sector, it seems relevant to investigate the drivers for and barriers to increased industrialization in infrastructure projects.

Prior studies have found that efficient and productive performance in infrastructure projects is a challenge and that many projects suffer from cost and schedule overruns (Flyvbjerg *et al.*, 2003; Minchin *et al.*, 2011; Cantarelli *et al.*, 2012). Other authors note that innovation is central both for improving efficiency and for achieving high quality, added value and sustainable development in infrastructure projects (Eriksson and Westerberg, 2011; Gil *et al.*, 2012; Rose and Manley, 2012). Although previous studies in the infrastructure sector have highlighted the urgency of addressing either short-term efficiency or long-term innovation they have not acknowledged their mutual importance and the tension between them.

In organizational learning literature, this tension is pinpointed in research on exploration and exploitation (March, 1991). The challenge of achieving both short-term efficiency based on exploitation of existing knowledge and technologies and long-term adaptation and innovation based on exploration of new knowledge and technologies is central in both theory and practice (Gupta *et al.*, 2006). Tiwana (2008) argues that project-level investigations, in which exploration and exploitation and their effects on performance are studied within projects, are very few. This gap may be due to the fact that prior studies on this topic mainly have focused on manufacturing industries (Adler *et al.*, 1999; Katila and Ahuja, 2002) rather than project-based industries such as construction (Eriksson and Westerberg, 2011). Owing to decentralization and short-term project focus, the difficulty of achieving both exploration and exploitation is, however, especially evident in project-based industries (Eriksson, 2013).

Prior research on exploration/exploitation has found that process management models (e.g. Six Sigma and total quality management), which have been widely diffused in many manufacturing industries, are efficiency oriented while their variance-reducing focus hampers exploratory innovation (Benner and Tushman, 2003). As industrialized construction is based on a process-focused perspective transferred from manufacturing industries, it may drive the infrastructure sector towards improved exploitation and efficiency but further away from exploratory innovation. In addition, infrastructure clients' common focus on lowest cost in competitive bidding pushes suppliers towards cost orientation based on short-term exploitation, rather than on explorative innovation (Caerteling *et al.*, 2011). Hence, industrialized construction inflicts a major risk that an already strong focus on exploitation becomes even stronger at the expense of even weaker focus on innovation. It therefore seems urgent to improve our understanding of the concept of industrialized construction in the infrastructure sector and how it is related to exploration and exploitation.

This research addresses the abovementioned shortcomings in prior research by explicitly analysing both explorative and exploitative aspects of industrialized construction in the infrastructure sector. The research was initiated by a Swedish parliamentary investigation with the purpose of investigating how the infrastructure sector could achieve greater efficiency. One area that was identified as important was a higher degree of industrialization. The Ministry of Enterprise, Energy and Communications assigned two research teams the task of investigating how industrialized construction could be implemented in the infrastructure sector. When comparing the teams' research results it became apparent that there were many interesting and relevant reflections to be made from the two studies. This paper combines the two studies with the aim of improving the understanding of how project actors can balance the sometimes contradictory short-term exploitative performance objectives with long-term explorative development when implementing industrialized construction. The studies focused on investigating how explorative and exploitative aspects of drivers for, and barriers to, increased industrialization affect the implementation of industrialized construction in infrastructure projects.

Organizational ambidexterity

Exploration and exploitation

Exploration includes concepts captured by the terms diversity, adaptability, risk taking, experimentation, flexibility, innovation and long-term orientation, whereas exploitation involves refinement, alignment, control, constraints, efficiency and short-term orientation

Table 1 Aspects related to exploration and exploitation

Aspects related to exploration	Aspects related to exploitation
Heterogeneity and diversity	Homogeneity and alignment
Adaptability and flexibility	Formalization and constraints
Experimentation and risk taking	Control and risk avoidance
Creation and change	Refinement and reuse
Innovation and development	Efficiency and productivity
Long-term orientation	Short-term orientation

(March, 1991; Gibson and Birkinshaw, 2004; Andriopoulos and Lewis, 2010); see Table 1. The organizational capability of simultaneously achieving both exploration and exploitation is sometimes termed organizational ambidexterity (Duncan, 1976). Accordingly, ambidexterity involves the capability both to exploit existing knowledge and technologies for short-term profits and to explore new knowledge and technologies to enhance long-term development (O'Reilly and Tushman, 2008).

In his pioneering article on organizational learning, March (1991) argues that firms focusing on exploitation may obtain short-term efficiency gains based on current competences, leading to success and thereby more exploitation. As a result of the direct benefits of exploiting current competences, firms may get stuck in a competence trap. In a quantitative study of 279 US companies, Uotila *et al.* (2009) found that most organizations focus more on exploitation than on exploration. This is because of exploration's greater uncertainty and distance in time and space between the locus of learning and the locus of realization of returns (Uotila *et al.*, 2009). This may result in short-term success but long-term stagnation and failure (O'Reilly and Tushman, 2008). Finding a suitable solution to the ambidexterity dilemma is therefore crucial for a firm's sustainable competitive advantage (Gupta *et al.*, 2006).

Different solutions to organizational ambidexterity

There are three main types of ambidexterity solutions:

(1) Structural ambidexterity separates exploration and exploitation activities in different business units (Duncan, 1976; Tushman and O'Reilly, 1996; Benner and Tushman, 2003).
(2) Sequential ambidexterity separates the exploration and exploitation through focusing on first one type of activity and then the other (Duncan, 1976; Adler *et al.*, 1999; Gupta *et al.*, 2006).
(3) Contextual ambidexterity is based on a capability to simultaneously and synchronously pursue exploration and exploitation within a business unit or work group (Gibson and Birkinshaw, 2004; Gupta *et al.*, 2006).

Most prior studies focus on one or another of these three solution types, but recent research has found that a combination of different solutions may be the most practicable (Raisch *et al.*, 2009; Andriopoulos and Lewis, 2010).

Sequential separation can be achieved by focusing more on exploration in the early stages of a project and on exploitation at the end of the project during production/implementation (Raisch *et al.*, 2009; Andriopoulos and Lewis, 2010). However, previous investigations in the construction industry suggest that the structural and sequential separation of design and construction results in a prolonged project duration (Elfving *et al.*, 2005), poor buildability since construction planning cannot affect design, and poor innovation and poor implementation of explorative solutions during the construction stage due to lack of joint problem-solving (Korczynski, 1996). Accordingly, Eriksson (2013) argues that structural and sequential ambidexterity solutions are not sufficient in the project-based construction industry. Because of interdependences between different actors and their explorative and exploitative activities, distinct separation of exploration and exploitation may be unsuitable. Instead contextual ambidexterity within projects is required in order to obtain sufficient focus on both exploration and exploitation (Eriksson, 2013).

Exploration and exploitation in infrastructure projects

In a quantitative study of 258 transport infrastructure projects in 20 countries it was found that nine out of 10 projects suffer from cost overruns and that the average project in the sample had a cost overrun of 28% (Flyvbjerg *et al.*, 2003, 2004). Another similar study of 78 Dutch transport infrastructure projects found that new infrastructure projects on average had a 21% cost overrun whereas projects involving extensions of existing infrastructure suffered from 9% cost overrun (Cantarelli *et al.*, 2012). In light of these studies it is not surprising that much prior research into the infrastructure sector has investigated causes of design changes and cost and time overruns (Flyvbjerg *et al.*, 2004; Wu *et al.*, 2005; Han *et al.*, 2009) and means for improving productivity and efficiency (Minchin *et al.*, 2011;

Giezen, 2012). In a Dutch case study of a metro extension project, Giezen (2012) describes how project management succeeded in maintaining the budget and the schedule in this mega project by keeping it simple, that is, by exploiting old and proven technologies and by avoiding building underground constructions. This is an illustrative example of how a public infrastructure client discourages exploration in order to achieve exploitative project objectives.

The abovementioned studies are of an exploitative nature, pinpointing the need for more efficient project management and control. The opposite aspect (i.e. exploration) is often downplayed. Because infrastructures are public spaces that require durability and safety, public clients often discourage innovation and prefer staying with familiar technologies with predictable quality levels in order to avoid taxpayer and media scrutiny (Keegan and Turner, 2001; Caerteling *et al.*, 2011; Rose and Manley, 2012). In addition, the project-based nature of the infrastructure sector discourages investment in research and development that cannot be earned back on single projects (Caerteling *et al.*, 2011). Nevertheless, innovation in infrastructure projects cannot be neglected since it is central to improving both efficiency and quality (Tawiah and Russell, 2008; Gil *et al.*, 2012). Hence, it seems urgent to investigate how industrialized construction might affect both short-term project performance and long-term sustainable development, in order to obtain a more balanced perspective on exploitation and exploration in infrastructure projects.

Research methods

The Swedish Ministry of Enterprise, Energy and Communications initiated the research presented in this paper by assigning two teams to investigate industrialized construction in the infrastructure sector. Both empirical studies focused on how industrialized construction was implemented, on identifying and discussing the drivers and barriers that affected the implementation, and *how* and *why* these drivers and barriers interplayed. The empirical data collection was performed as a case study investigating four ongoing infrastructure projects. In line with arguments put forward by Yin (2003), a case study approach was deemed appropriate to develop deep and detailed knowledge related to how and why the phenomena under study occurred and affected each other. In addition, case studies are especially suitable when collecting and analysing data from processes (Pratt, 2009), such as the implementation of industrialization in infrastructure projects.

One research team carried out a multiple case study (Cases 1 to 3) in which the construction projects were selected through theoretical sampling in order to enhance external validity and analytical generalization (Eisenhardt, 1989). The other research team chose to study one other construction project in more detail (Case 4). All four projects were procured by different regional organizations of the Swedish Transport Administration (STA), the main client in the Swedish infrastructure sector. An advantage of the chosen approach is that observed differences related to industrialization can be more clearly associated with differences in how projects were procured, managed and governed on a local level rather than with contextual and organizational differences on a national or international level. The four cases represented a variety in terms of different contractors and contract forms, which enhances analytical generalization. Cases 1 and 2 were performed as design-bid-build projects, with the exception of bridges that were separately procured as design-build contracts. Case 3 was based on early involvement of contractors in a design-build contract. Case 4 was a design-build-operate contract where the contractor was responsible for operating and maintaining the facility for 20 years. In addition, Case 4 had the specific aim of promoting new and innovative methods of production. Hence, the chosen projects illustrate both traditional and more innovative approaches when contracting and carrying out infrastructure projects. This selection of cases made it possible to compare the effects of different contract forms on the implementation of industrialized construction as well as supporting the analysis of short- and long-term aspects from a number of perspectives.

In order to enhance construct validity, a variety of data collection methods and information sources was utilized (Yin, 2003; Gibbert *et al.*, 2008). Empirical data were collected mainly through 14 semi-structured interviews with the client's project manager (in Case 4 there were two project managers), the contractor's project manager and the design manager (in cases in which this person was not the same as the project manager). Furthermore in Case 4, the contract manager and the dispute resolution manager were interviewed. Of the 14 respondents one was female and two were hired consultants, whereas the others were employed directly by the client or contractor organizations (see Table 2).

In addition, contracts and documents describing project organizations were studied before or after interviews. Study visits were also conducted in order to develop a deeper understanding of the case study projects. These two data collection methods

Table 2 Case study projects and respondents

Case	Object (size)	Contract	Contractor	Respondents
1.	Roads and bridges in a dense urban area (~ €90 million)	Design-bid-build	Medium sized, focused on civil engineering	1. Client, project manager 2. Contractor, project manager 3. Consultant, design manager
2.	Roads and bridges in suburban area (~ €50 million)	Design-bid-build, but design-build for bridges	Large, comprising both civil engineering and other areas	1. Consultant, client's project manager 2. Contractor, project manager 3. Contractor, design manager for bridges
3.	Highway and connection roads in the countryside (~ €50 million)	Design-bid-build, but design-build for bridges	Large, comprising both civil engineering and other areas	1. Client, project manager and design manager 2. Contractor, project manager
4.	Roads and bridges in the countryside (~ €180 million)	Design-build-operate	Large, comprising both civil engineering and other areas. The same contractor firm as in Case 3	1. Contractor, contracts manager 2. Contractor, project manager 3. Contractor, manager of dispute resolutions 4. Contractor, design manager 5. Client, 1st level project manager 6. Client, 2nd level project manager

complemented the interviews and provided opportunities to triangulate the interview data (Denzin, 1978).

An analysis was conducted for each case. To enhance transparency and future replication, case study protocols were constructed together with case study databases, containing case notes, documents, and the narratives collected during the study, all with the aim of facilitating retrieval for future studies (Yin, 2003). The qualitative process data formed empirical data patterns, describing drivers for and barriers to increased industrialization in the case study projects. These empirical patterns were first analysed within each case and subsequently compared among cases in cross-case analysis in order to improve external validity (Eisenhardt, 1989). From the analysis of each case it was apparent that the overarching reason for problems concerning industrialization and innovation was the difficulty of balancing short-term project goals with long-term objectives on a company or sector level. The next step of the analysis was then to combine the results of each case in order to obtain explanations for sources of these barriers and, further, to analyse the respondents' views of how to enhance the drivers for a more long-term perspective.

Empirical results

Case-specific results

Case 1

The client's project manager took an early initiative for industrialized construction. The main idea was to seek repetition effects and predictability so that it would be easy and convenient for the contractor. The client's project manager stated that 'industrialized construction involves a specific template or model that is consistently used; we should do it like this in order to proceed'. Although the client was the driving force, the implementation of industrialized construction was undertaken in collaboration. Thanks to this, the project's actors came quite far with their industrial thinking and were satisfied with this approach, although further improvement was possible. Many methods and technologies were developed by the client and the consultant before the contractor was appointed but some technical solutions and methods were developed and implemented during the construction phase by contractor initiatives, so all three parties made significant contributions to industrialized construction.

Efficient and rational production was achieved through careful planning by the contractor, the client and the client's consultants. The cable trenches were not blasted separately after the tunnel section which is the conventional way. Instead, the contractor made the whole tunnel section a bit larger to make room for cable trenches directly in the section. This saved time and made possible more efficient production without duplication of work. Automation was also utilized in terms of a new efficient curb casting machine purchased from abroad specifically for this project. It was an expensive investment (€40 000) but it paid off thanks to the extensive length of curb in the project (> 4km).

The project's actors also achieved standardization and repetition in several ways. They used predetermined and standardized options for rock reinforcement and grouting by a limited number of predefined reinforcement and grouting classes. This reduced the number of approaches and work methods, and the contractor knew in advance what methods to use. Tunnelling work was standardized by making the tunnel section the same size throughout. This enhanced robustness at the expense of oversizing some parts of the tunnel. They also made use of one type of well with three chambers instead of three different types of well.

Prefabrication has been used to quite a large extent, mostly thanks to initiatives taken by the contractor. Standardization and prefabrication of the extractor fan foundations were undertaken instead of casting them *in situ*. Inside, the wall linings consisted of prefabricated concrete elements. The design manager described this approach as: 'we build a tunnel inside the tunnel'. Thus, the inner walls and ceiling in the tunnel constitute a standardized and uniform shell that protects the tunnel road from leakage, instead of working with rock drainage. The downside is that water may drip a little without drainage. In addition, pre-processed reinforcement was bought and transported from abroad. The reinforcement was ready to use upon arrival, and in some cases also assembled into prefabricated reinforcement cages, which saved time at the construction site.

Case 2

In this project, industrialized construction was not implemented as explicitly and systematically as in Case 1. The client's project manager, who came quite late into the project, has not worked actively with industrialized construction: 'We have not deliberately pushed this issue, but we use common sense and strive to obtain repetition of work methods'. Although the respondents did not think they had much industrialized construction, at least some practices and solutions related to industrial construction have been implemented.

Rational production has been achieved, for example by reusing the shuttering on a bridge (superstructure on the existing road bridge), and using foam instead of lightweight aggregate to minimize tongue. In terms of prefabrication, noise barriers and retaining walls were prefabricated instead of being cast *in situ*. The contractor pushed this issue because it was possible to save money and time while maintaining quality. The client agreed to the change. The client and the consultant also designed and planned for an opportunity to roll out lengthy reinforcement, but they later decided to adopt the traditional way. They have tried to create opportunities for economies of scale and repetition of tasks. One example is the use of the same shuttering beneath edge beams for several bridges, but time constraints interfered with its implementation so that complete repetition was not possible.

In regard to contracts and procurement forms, the client's project manager did not think it had any impact: 'we have not introduced any industrialized construction so it has not affected anything'. The contractor's project manager is of a different opinion and said that 'if it had been a turnkey contract, we would have felt a greater opportunity to find our own solutions'. Design-bid-build contracts may also work if the client drives the issue more from the start of pre-planning, but it takes longer to implement any changes proposed in retrospect by the contractor.

Case 3

In this project there was not an explicit focus on industrialized construction, although rational production and prefabrication were still significant aspects of the project. The industrialization work was mainly driven by the client and the consultant at the design stage. At the time of the interviews, the construction stage had not progressed very far so the contractor's achievements in the implementation of industrialized construction were rather limited.

Rational production was stimulated in a number of ways. Owing to the large surplus of clay, much effort was devoted to finding suitable landfills and minimizing transportation. More shift work was encouraged to achieve better utilization of machines and equipment. They also used mastic asphalt joints instead of milling with a cutter close to the edge beams before coating. An intentional repetition effect was achieved by having only two types of edge beam on a total of 16 bridges.

There were several examples of prefabrication. Four bridges for the passage of wildlife were based upon prefabricated drums instead of cast *in situ* structures. These did not however lead to any significant savings. Noise barriers were designed in the form of modules consisting of 3m sections from a factory that could easily be hooked on to a site-built steel structure. The same noise barriers were used for a long stretch of road. A prefabricated bridge from Germany was suggested by the contractor. The aim was to reduce production costs and share the savings with the client. Economic reasons and curiosity drove the contractor to test this new solution. However, after analysing the suggested solution and its consequences, the client decided not to agree to this change, since the economic benefits were considered too small. Reinforcement was prefabricated abroad into three sizes of cage for assembly in a temporary factory enclosure at the site.

The client's project manager did not think that contract and procurement forms affected the opportunity to implement industrial construction: 'it did not affect anything: all the examples of prefabrication and standardization we conducted were part of the contract; that is, they were designed and planned before the contractor was procured'. The contractor's project manager had the opposite opinion, and felt that 'design-bid-build contracts were useless from an innovation perspective'.

Case 4

In line with the client's choice of procuring the project as a design-build-operate contract, there was the ambition of seeking a long-term relationship with the contractor. Since the contract concerning operation and maintenance lasts for 20 years the risk of implementing new methods and products that may prove to be inferior mainly lies with the contractor. Client representatives saw this as 'an opportunity to approve alternative and new methods within the project'. One example of this was a new method of stabilizing the soil, which made the excavation works more effective in some areas of the project. The long-term nature of the contract also fostered a culture within the project that was focused on collaboration rather than confrontation. Both client and contractor respondents expressed the view that the limit for more industrialized efforts rested on a higher organizational level, mainly the client. However, client representatives expressed the need 'to maintain a level of control'.

The respondents, both client and contractors, mentioned prefabrication of bridges as the most applicable form of industrialization, at least on a short-term basis. Although the contract did not prohibit prefabricated bridges, just two out of 39 bridges were prefabricated. The contractor argued that 'barriers, foremost the early specifications and the norms and regulations of STA, prevent the use of prefabrication to a large extent'. Other examples of industrialized methods were GPS controlled excavation machines where the work was carried out with the help of 3D visualization and planning tools connected to 3D models that enabled the project manager to obtain an overview of the whole project and, thus, a more efficient production process.

In conclusion, although the contract took the form of design-build-operate it should have enabled a higher degree of flexibility, resulting in the adoption and use innovative methods for the production process and the end-product. This was not the case. From the contractor's point of view, the reason was that the project specification was, to a large extent, decided at an earlier stage of the project by the client. From the client perspective, there was the difficulty of finding the right balance between control and flexibility, which often resulted in a higher degree of control than was felt necessary.

Results from the combined case analysis

The concept of industrialized construction

The respondents exhibited two fundamentally different views concerning their familiarity and knowledge of the concept of industrialized construction. Some respondents were unfamiliar with the concept and its content, while others were quite comfortable in both thinking about industrialized construction and discussing it from a professional viewpoint. The general view of industrialized construction was that it involves some sort of repetition in the use of production methods and production input. More specifically, three core elements were mentioned as defining the concept: (1) prefabrication; (2) efficient and rational production; and (3) standardization and repetition of products, processes and methods.

The concept of *prefabrication* was basically viewed as a means to transfer production hours from the construction site to a factory where prefabricated components are manufactured and then delivered to the construction site where work on site consists mainly of assembly. In general, there was an attitude among the respondents that it is more difficult for the infrastructure sector to adopt prefabricated methods than for the housing sector where prefabrication is more commonly used, because of a perceived view that infrastructure projects a more unique in nature. *Efficient and rational production* is a wide concept, exemplified by well-planned projects, improved predictability of the contractor's activities and a better flow of production activities in order to reduce waiting and idle time. It also includes automation, that is, an increased use of machinery and equipment in order to make the production process more efficient. *Standardization and repetition* were deemed relevant to processes and production methods as well as products and components. Another aspect of repetition is learning across projects, which makes it possible to apply lessons learned and best practices over a number of projects.

Drivers for implementing industrialized construction

The two most important reasons mentioned for increasing the level of industrialization in infrastructure projects were time and money, that is, the need to lower cost and shorten lead times in construction. Almost all respondents gave these as the major drivers and related them to efficiency and productivity. Another driver is increased predictability, arising from more standardized procedures, which may improve clarity of expected performance as well as achieve a lower level of uncertainty.

Some respondents mentioned drivers at an industry level although they were not considered as influential as the abovementioned project-level drivers. The potential lack of skilled construction labour in the future was mentioned by some respondents. More industrialized production of products and components, in terms of higher extent of automation and prefabrication, may reduce the need for construction labour on site. Furthermore, industrialized production might improve the working environment when hazardous working operations can be performed under more safe conditions in a factory. Another aspect that is believed by some respondents to drive development of industrialization is the need for change within the construction industry towards a better innovative climate for promoting the development and use of new products, processes and production methods. A reason for this was given in terms of improving the image and attractiveness of the sector so it could be viewed as forward-looking and innovative instead of conservative and problematic

Barriers to implementing industrialized construction

When it comes to barriers, the respondents were not in agreement to the same extent as they were in regard to drivers. Several different types of barrier were mentioned, most of which were firm-level barriers related to the client organization, STA. One of the main barriers cited by the respondents concerned the client organization's procedures when executing infrastructure projects. Especially among the contractors, the procurement procedure was seen as a major barrier since STA, together with its consultants, decides upon the design, whereas contractors have little or no ability to suggest alternative solutions to project design, production methods and materials in design-bid-build contracts. The incentive for contractors in this case is simply to focus on short-term project cost rather than a longer-term lifecycle perspective. When contractors are not involved in the design stage, consultants sometimes try to minimize the amount of material and components, which may lead to savings in material costs but increased costs for manpower due to low buildability.

The client's own norms, rules and regulations were found to be major obstacles to innovation in general and industrialized concepts in particular. The main argument was that STA is sceptical about new and untested solutions. Hence, even when it is possible for contractors to suggest alternative technical solutions these are often turned down. These firm-level norms and regulations thereby prohibit the contractor from adopting new and innovative processes, production methods and products. However, a change has been initiated in STA. A design manager stated 'thankfully, STA has now come out with a new edition of its regulatory framework, which provides the possibility to find alternative solutions'.

The main barrier at the project level was considered to be the lack of opportunity for standardization and repetition. Most respondents felt that investments in the development of new solutions have to pay off in the project at hand since the contractor cannot count on using the solution in the next project. Hence, each project must provide sufficient opportunity for standardization and repetition. However, two of the contractors' project managers felt that development might, on rare occasions, be allowed to increase costs for an individual project if there were an opportunity for increased profitability on a long-term basis. Prefabrication of bridges was a commonly mentioned example related to repetition. In the design phase there has to be an understanding of the conditions that need to be met in order to use prefabrication. A project manager on the client side felt, however, that 'architects and consultants can be negative regarding repetition of technical solutions. Consultants make money by developing new and unique solutions: that is the basis of their work'. Lack of repetition is also related to lack of learning across projects. One contractor stated that 'it is difficult to find a way to handle experience feedback. Each project is viewed as a separate and isolated case, instead of one stage in a long process'.

At the industry level, the perceived conservative industry culture was also put forward as a barrier to industrialized construction in particular and to innovation and change in general. Two respondents especially perceived that Swedish contractors are too traditional in their 'way of working' compared to some of their larger and international competitors, and thus less open-minded about new trends and developments, including industrialized construction.

Discussion

The case study projects investigated in this research achieved varying degrees of industrialization. Elements of industrialized construction that were implemented in the four projects are related to prefabrication of components and modules in factories instead of onsite construction, efficient and rational production (through careful planning and automation), and standardization and repetition of both processes and products. The degrees of industrialization that were achieved in the four projects are related to barriers to industrialized construction. Some barriers affect all projects in similar ways whereas others are more project-specific. Yet the drivers for increased industrialization seem to be similar across projects.

The empirical results show that opportunities for improved productivity and efficiency in terms of lower project costs and shorter duration are driving project actors' interest in implementing industrialized infrastructure construction. More long-term and macro-level drivers, such as an improved working environment and the need for change and innovation, were considered of less importance. From an ambidexterity perspective, the project actors' focus is thus on exploitation, whereas the interest in exploration is much slighter. This finding is in line with Benner and Tushman's (2003) argument that the implementation of process management may result in efficiency gains based on exploitation, while long-term innovation and exploration suffer. However, industrialized construction may in itself be regarded as a process innovation and, as such, it might spawn and/or require developments in other areas, such as product innovation or organizational/contractual innovations (Tawiah and Russell, 2008). In order to achieve a broad perspective on the possibilities and requirements for innovation, it is of utmost importance to explicitly relate the concept of industrialized construction to both exploration and exploitation, otherwise, there is a risk that the focus on exploitation will likely prevail.

In addition, the empirical results show that there are barriers to increased industrialization in infrastructure projects: traditional procurement methods and contract forms; the lack of possibilities for standardization and repetition; a conservative industry culture; and the client's norms and rules. These barriers inhibit not only short-term efficiency and exploitation but also long-term innovation and exploration. Hence, when dealing with these barriers, both exploration and exploitation can be addressed. The perceived conservative industry culture is a barrier not only to industrialized construction, but to change and innovation in general. Many previous studies have found similar results in Sweden (Kadefors, 1995; Eriksson *et al.*, 2008; Vennström and Eriksson, 2010) and other countries (Winch, 1998; Riley and Clare-Brown, 2001; Blayse and Manley, 2004), pinpointing the need for a long-term culture change at the industry level. The case study findings presented in this paper show that the degree to which industrialization was addressed was affected by key individuals whose views could not be characterized by conservative attitudes. In projects where the client's project manager explicitly drives an industrialization agenda (e.g. Case 1), a high degree of industrialization may be achieved through purposeful design work. However, in order to involve contractors as well and incentivize industrialization on a broader scale in the production phase, the other barriers must also be addressed.

In terms of the opportunities for standardization and repetition, Alinaitwe *et al.* (2006) and Tawiah and Russell (2008) argue that industrialized construction requires initial investment in technology and equipment. Large-scale projects and repetition possibilities are therefore crucial (Alinaitwe *et al.*, 2006; Tawiah and Russell, 2008) since investment in research and development has to be earned back on single projects (Caerteling *et al.*, 2011). Hence, in order to motivate suppliers to invest in explorative developments, the opportunity for exploitation of the investment must be put in place. The clients' common approach in dividing large projects into smaller parts in order to increase competition is counter-productive in terms of opportunities for combining exploration and exploitation.

Many infrastructure projects in Sweden are procured with design-bid-build contracts. There is a rational explanation for this based on STA's rules and regulations where control of the design process has to be maintained within the client organization. Some clients in the case projects did not perceive design-bid-build contracts as problematic from an innovation perspective. Clients and consultants worked together to develop the design and new technical solutions. However, the contractors perceived these contracts as a barrier to the development of the infrastructure sector, by inhibiting innovation in general and the use of industrialized concepts and processes in particular. This view is in line with that of Eriksson (2013), who argues that the structural and temporal separations of exploration and exploitation that occur in design-bid-build contracts are not working well, because of the interdependencies among different actors and their activities.

Empirical findings in this study suggest that the client should focus on developing its role in establishing the prerequisites for a good end-product and not concern itself with the contractor's choice of input components and production methods. Since inflexible product specifications hinder contractor innovation (Rose and Manley, 2012), clients should focus on what to do through functional requirements, not how to do it by detailed specification of methods and materials. Results from this study thereby support prior studies arguing that there is a need to develop and use new forms of procurement: see, for example, Pakkala (2012) and Han *et al.* (2009). Contextual ambidexterity can be facilitated through integration of design and construction by involving the contractor early in the design phase (Eriksson, 2013). This facilitates efficiency through improved constructability and enhances opportunities for joint innovation. Design-build-operate contracts, where contractors are responsible for the function of the facility over a number of years, may give them incentives to invest in exploring new processes, production methods and products that would ensure a good end-product from a lifecycle perspective rather than just pursuing the aim of cutting production costs.

The norms and rules of STA hinder the implementation of new solutions. This firm-level barrier hinders both industrialized construction and innovation in general. The reluctance to accept new technology and methods decreases the risk of implementing solutions that are not sustainable (Caerteling *et al.*, 2011), but it also hinders innovation and development (Rose and Manley, 2012). STA needs to find a balance between radical innovation and continuous development, which requires an attitudinal change and also new procurement methods. Present procurement methods focus on short-term efficiency and do not incentivize more radical supplier-led innovations. In addition, the client should be more open to alternative solutions and more trusting of the contractor's suggestions. However, this lays the responsibility on the contractor to develop new products and production methods that meet the demands of the client. In a quantitative study of 115 US suppliers in the infrastructure sector, it was found that government-championed behaviours enhanced performance in technology development projects (Caerteling *et al.*, 2011). This supports our argument that public clients, like STA, have to change their norms and rules in order to encourage suppliers to develop new exploratory innovations that are crucial for sustainable development of the infrastructure sector.

Conclusions

This study has identified several critical barriers to increased industrialization of the infrastructure sector (i.e. traditional procurement methods and contract forms, the lack of possibilities for standardization and repetition, a conservative industry culture, and clients' norms and rules). These barriers inhibit not only short-term efficiency and productivity (exploitation) but also long-term innovation and change (exploration). The main argument put forward in this paper is that when planning for implementation of the concept of industrialized construction an ambidextrous perspective should be considered. Prior literature on industrialized construction and project actors implementing the concept mainly focus on exploitative productivity gains by enhancing efficient use of existing technologies and resources. This one-sided focus carries the risk of increasing the already strong emphasis on exploitation at the expense of exploration and sustainable development.

Prior literature has focused on either explorative or exploitative aspects of construction management. Through the adoption of an ambidextrous frame of reference we have contributed to construction management literature by showing how industrialized construction can provide opportunities for both exploration and exploitation in the infrastructure sector. More specifically, we have elaborated on the interplay between exploration and exploitation when implementing industrialized construction. By developing exploitation of prior explorative investments on a larger scale by standardization and repetition, both exploration and exploitation can be enhanced. This requires repetitive production in large projects, procurement procedures that make it possible to incentivize project actors to adopt contextual ambidexterity when collaborating in integrated design and construction, and public clients that act as champions of innovation instead of opponents to new and untested technology. By systematically addressing the barriers to industrialized construction, project actors might actually improve their capabilities and possibilities for organizational ambidexterity, which is critical for sustainable development. The discussion on how to release the tension between exploration and exploitation and achieve both simultaneously at the project level is an important contribution to the literature on ambidexterity within organizational theory.

The main practical contribution of the paper is a suggestion that project actors need to adopt an explicit ambidextrous perspective in order to fully benefit from implementing increased industrialization. Clients can enhance suppliers' explorative investments and developments by facilitating repetition and large-scale exploitation of successful explorative solutions. Hence, by adopting an ambidextrous perspective and dealing with the barriers to industrialized construction project actors can achieve a focus on both short-term efficiency and long-term innovation. If actors fail to acknowledge the importance of combining short- and long-term perspectives they risk missing the opportunities for exploration since the perceived drivers for implementing industrialized construction are mainly related to short-term efficiency.

To achieve a balance between a long-sighted innovation process (exploration) and a more short-sighted efficiency perspective (exploitation), there is a need for an attitude change among both clients and contractors. The innovation process for an increased level of industrialization in the infrastructure sector is affected by the development and use of more innovative forms of procurement that promote a more long-sighted focus on cooperation between clients, designers and contactors in order to achieve an innovation process that is driven from both suppliers as well as clients.

A limitation of this study is its explorative and qualitative nature based on four cases. Generalizations regarding, for example, the identified barriers should be made cautiously. In spite of this, we believe that many of our general arguments hold for the infrastructure sector as a whole. However, large-scale quantitative studies in both the infrastructure sector as well as other sectors of the construction industry should be encouraged in order to investigate the drivers for and barriers to industrialized construction on a more general level. There is also a need for further studies on the balance between explorative and exploitative efforts when implementing industrialized construction. A practical as well as theoretical challenge is to improve our understanding of how we can encourage both improved exploitation and exploration through new forms of procurement and changes in attitudes and behaviours.

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