Construction Management and Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

Industrialized construction in the Swedish infrastructure sector: core elements and barriers

Johan Larsson, Per Erik Eriksson, Thomas Olofsson & Peter Simonsson

To cite this article: Johan Larsson, Per Erik Eriksson, Thomas Olofsson & Peter Simonsson (2014) Industrialized construction in the Swedish infrastructure sector: core elements and barriers, Construction Management and Economics, 32:1-2, 83-96, DOI: 10.1080/01446193.2013.833666

To link to this article: https://doi.org/10.1080/01446193.2013.833666

Published online: 08 Oct 2013.

Construction Management and Economics, 2014
Vol. 32, Nos. 1–2, 83–96, http://dx.doi.org/10.1080/01446193.2013.833666

Routledge
Taylor & Francis Group

Industrialized construction in the Swedish infrastructure sector: core elements and barriers

JOHAN LARSSON[1]*, PER ERIK ERIKSSON[2], THOMAS OLOFSSON[1] and PETER SIMONSSON[3]

[1]*Department of Civil, Environmental and Natural Resources Engineering,* [2]*Department of Business Administration, Technology and Social Sciences, Luleå University of Technology, Luleå, Sweden*
[3]*Swedish Transport Administration, Luleå, Sweden*

Received 6 November 2012; accepted 6 August 2013

Improving productivity and innovation is a central challenge in all industries, but particularly in construction where improvements have been slow. To meet this challenge, a recent investigation into the actions of Swedish government clients has recognized needs to improve planning during project procurement phases, increase numbers of turnkey contracts and raise industrialization of the sector. In response, the Swedish Transportation Administration has launched a research and innovation programme to foster an industrial approach and identify ways to increase the standardization of products and processes. However, increasing industrialization has been difficult to achieve in the project-based construction industry except in the process-based housing sector. Further, there has been little research on the concept of industrialized infrastructure construction and barriers to its implementation. Opinions and attitudes of clients, consultants and contractors in the infrastructure sector were investigated in relation to the core elements of industrialized construction, and the barriers hindering its development. Opportunities and obstacles related to both product and process standardization for continuous improvements and the relationships between clients and contractors are revealed. Hence, the implementation of industrialized construction requires tightly focused governance at the outset of projects and profound changes to established attitudes, norms and regulations.

Keywords: Barriers, industrialization, infrastructure, prefabrication, standardization.

Introduction

A problem highlighted in numerous studies from many countries, including the UK and the US (Egan, 1998; Teicholz, 2001; Huang *et al.*, 2009), is that productivity increases slowly in the construction industry. In Sweden, recognition of an urgent need to improve productivity and client satisfaction in the industry has prompted a number of government investigations (Building Commission, 2002; Ministry of Finance, 2009; Productivity Committee, 2012). Several productivity studies (e.g. Horman and Kenley, 2005; Josephson and Saukkoriipi, 2005; Mossman, 2009) have also shown that large amounts of material, time and other resources are wasted in traditional onsite construction projects. Such waste is clearly detrimental to productivity. In other industries, waste is reduced and productivity improved by gradual, continuous improvements of industrialized processes (Winch, 2003). Accordingly, researchers and practitioners argue that the construction industry could improve productivity by adopting procedures applied in manufacturing industries, such as the automobile industry (Gann, 1996), to increase the industrialization of design and production processes.

Koskela (2000) identified three distinctive features of construction projects (one-of-a-kind production, site production, and temporary teams) that may explain the inefficiency and complexity that are often discussed in construction management literature. However, the construction industry is far from homogeneous in this respect. In the housing sector, production companies have used industrialized processes and offsite manufacturing for decades, resulting in continuous productivity improvements (Höök and Stehn, 2008; Segerstedt and Olofsson,

*Author for correspondence. E-mail: johan.p.larsson@ltu.se

2010). In contrast, increased industrialization has been difficult to achieve in other construction sectors, such as infrastructure and complex industrial and commercial buildings (Winch, 2003).

Previous research has found that efficiency and productivity are key challenges in the infrastructure sector and that many infrastructure projects suffer from cost and schedule overruns (Flyvbjerg *et al.*, 2004; Minchin *et al.*, 2011; Cantarelli *et al.*, 2012). The Swedish Transport Administration (STA), the major public procurer of infrastructure in Sweden, has been assigned by the government the task of creating conditions to improve productivity in the infrastructure sector. The STA is responsible for creating local norms and regulations for designing and constructing infrastructure in Sweden, apart from the Euro code. These norms are subsequently used by all other infrastructure clients, e.g. municipalities. The exceptional market position of the STA provides a unique opportunity for the STA to influence the infrastructure sector, both by creating an innovative environment and by setting rules and norms.

The client often initiates an infrastructure project by procuring a designer at an early stage in order to specify the product, while the contractor is procured late in the project, to construct the product on site, often based on detailed specifications in design-bid-build contracts. This approach has several negative consequences. Notably, customer-led location-specific design results in little or no repetition, and thus little (if any) post-order design certainty (Fox *et al.*, 2002). It also complicates the link between contractor productivity and client productivity since the client often procures work based on detailed specifications (Bröchner and Olofsson, 2012). Thus, the product design is often excluded from production control (Winch, 2003). In addition, this use of design-bid-build contracts, with late involvement of contractors, reduces opportunities for innovative approaches during construction. Furthermore, the STA hinders the implementation of innovations by failing to consider alternative solutions or allowing contractors to propose potentially better solutions (technically or financially) for a specific product in a specific location.

The Productivity Committee, which is supported by the Swedish Ministry of Enterprise, Energy, and Communications, has recently examined how the STA is handling the assigned task. The Committee concluded that the STA should increase the degree of industrialization, procure more projects based on design-build contracts, and improve its long-term planning during project initiation and procurement phases in order to increase innovation and productivity in infrastructure projects (Productivity Committee, 2012). In response, the STA has launched a long-term research and innovation programme to increase industrialization throughout the value chain and standardization of products. The STA is also reconsidering its tendering specification procedures and criteria. In the future, the organization will strive to avoid specifying more details than the minimum required for a specific project to increase the freedom for contractors to formulate solutions.

Measures to increase the productivity of infrastructure projects are particularly important from a societal perspective since public money is spent on investments that are crucial for national development and economic growth (Caerteling *et al.*, 2011). However, although the largest infrastructure client in Sweden (the STA) is keen to increase industrialization, this approach to improve productivity in the infrastructure sector is not widely used in practice as yet and has been poorly researched.

In order to enhance theoretical understanding of industrialized construction in the infrastructure sector and its practical implications, investigations of the key features of the concept and barriers to its implementation are needed. Thus, the knowledge of, and attitudes to, industrialized construction among practitioners operating in the sector were investigated. The primary focus is on the core elements of the concept (what industrial construction means in this particular context) and perceived barriers to its implementation (the factors hindering increased industrialization in it). The empirical data were acquired from two surveys and a workshop; the second of the surveys was undertaken as part of research commissioned by the Swedish Ministry of Enterprise, Energy, and Communications and reported by the Productivity Committee (2012). However, the paper starts by presenting two relevant industrialization strategies used in construction. Results of the empirical study are then presented and discussed in relation to these strategies, to increase understanding of the complexities in this previously neglected sector. The final section presents conclusions and recommendations for future research.

Industrialization strategies

Models for industrialization taken from the manufacturing industry are often seen as solutions to the lack of productivity improvements in construction (Winch, 2003). For example, the Swedish and Japanese housing industries show significant similarities to manufacturing processes (Gann, 1996; Höök and Stehn, 2008). Perhaps most importantly, the focus is on maximizing the efficiency of the whole production system rather than individual projects. Industrialized construction normally involves two strategies to decrease the complexity of construction: standardization of products and standardization of processes, both underpinned by continuous improvements (Bertelsen, 2004). The former involves producing many required components in a factory for assembly at the construction site (Höök and Stehn, 2008), while the latter involves developing processes to address unique aspects of specific products in specific locations. However, standardization of both kinds has proved difficult to achieve in the project-oriented infrastructure sector (Winch, 2003), where clients manage projects from initiation to completion and very rarely exploit contractors' knowledge, experience or innovative ideas during early design phases, when most decisions affecting the outcome are taken. Hence, organizational and cultural aspects are also discussed in this section.

Product innovation

Standardization of products is not a new concept, despite its slow implementation. It has long been recognized as essential for maximizing predictability and efficiency in construction projects (Gibb, 2001). Applying a multi-method approach (interviews, workshops and case studies) as part of the CIRIA (Construction Industry Research and Information Association) project the cited author identified four suitable categories of construction activities and products for industrialization: (1) component manufacture and pre-assembly; (2) non-volumetric pre-assembly; (3) volumetric pre-assembly; and (4) modular building. Infrastructure (e.g. bridges) is categorized among non-volumetric pre-assembly products. The reported findings show that allocating time during planning is essential for efficient industrialized production, especially in infrastructure. Further, both Gibb (2001) and Blismas *et al.* (2006) found that only financial costs are considered in traditional evaluations, while value is neglected, leading to low uptake of innovative products that primarily provide time and quality benefits rather than initial cost savings. These barriers were also confirmed by Blismas *et al.* (2005) during multiple workshops in which 22 constraints identified in previous research were discussed. The discussions highlighted three major categories of constraints for industrialized production: (1) processes related to early design decisions; (2) prioritization of lowest bid prices rather than best value; and (3) supply chain issues including long lead times and scarcity of suppliers.

Various researchers have attempted to identify and discuss the major drivers of industrialized products in the construction industry. In a large interview-based survey of clients' views of the benefits of standardized and pre-assembled products, Gibb and Isack (2003) found that the main advantages are improvements in quality and reductions in time, cost and the complexity of onsite construction, since fewer people are engaged and the onsite activities become more straightforward. Blismas and Wakefield (2009) reported similar findings in a qualitative survey of drivers and constraints for off-site manufacturing in Australia. They also found an additional driver: an increasing shortage of skilled workers, which is also a problem in the Swedish construction industry. However, although benefits and constraints are well documented by researchers, standardized and pre-assembled products and their benefits are poorly understood by many practitioners, leading to a widespread reluctance to use them (Pasquire and Gibb, 2002).

In a study of Japanese housing construction, Gann (1996) found that standardization and prefabrication are the main industrialization principles, but balancing standardization and flexibility is believed to be a key for success. One way of optimizing the balance is through modularization, defined by Gibb (2001) as decomposition of a product into modules with specific interfaces, each fulfilling a specific function in the end product. Development of standardized interfaces between modules is also essential, to ensure interchangeability of module variants.

Various kinds of product specification processes can also be identified, which are closely related to the modularity of the product, the design entry point for the client and the contractual relationships between the client, principal designer and main contractor (Winch, 2003; Hvam *et al.*, 2008). The trade-off between predefined specifications and specifications created in the project depends on the upstream point where the client enters the design process. Hvam *et al.* (2008) define several kinds of product specification processes, depending on how much of the product is standardized. In traditional engineer-to-order design processes, like in infrastructure, component-level standardization can be utilized, but more predefined subsystem-level specifications are used in modify-to-order and configure-to-order design processes. In product-level standardization the client can only select variants. However, in a study of the design process of a modularized multi-storey building, Jensen *et al.* (2012) found that closer integration between design and construction requires complementation of the downstream flow of design information to production with an upstream flow of constraints from production to design.

Process innovation

Standardization is important not only in product innovation but also in both innovative design and production processes, where attention focuses on technical solutions and planning/execution, respectively. Production information refers to the specification of processes, operations, operational sequences and related resources (Ballard, 2000). Thus, it is only in the production stage that actual product costs, lead times and quality can be determined (Jiao and Tseng, 2004).

It should be noted that product modularization has some negative effects on production, particularly an increased number of process variants. However, the customized components and product structure introduce similarity in the associated production processes (Simpson *et al.*, 2005). Concepts like process platforms have been explored, for example by Jiao *et al.* (2003), that can facilitate coordination of product and process variety management, thus forming a coherent framework for both product and process structure. While most concepts discussed in literature about innovative processes are derived from manufacturing, they are now starting to gain some acceptance in construction literature. For instance, Gibb (2001) noted that construction companies have always struggled to solve the conflict between uniformity and variation. However, according to Sawney (1998) it is possible to manage the conflict between high volume and high flexibility by allocating products to appropriate process platforms and reduce development risks by exploiting similarities between processes to use proven elements in multiple projects. These industrialization concepts have been proposed by several authors, e.g. Vrijhoef and Koskela (2005) and Voordijk *et al.* (2006), as possible solutions to the problems connected to the previously mentioned distinctive features (one-of-a-kind production, site production, and temporary teams) associated with construction.

While product and process design can be standardized for standard products, Ballard and Howell (1998) argued that for non-standard products it is necessary to standardize procedures for planning and managing the design and installation of unique facilities. Hence, another approach to process innovation is the TVF (transformation, flow and value) theory developed by Koskela (2000), which provided foundations for the lean production strategy adapted to the project-based construction industry. Approaches such as the Last Planner system, which focuses on reducing variability (Ballard and Howell, 1998) and value stream mapping of work flows (Simonsson, 2011) are examples of lean tools that have been applied to improve the efficiency of onsite construction processes.

Infrastructure projects, especially in Sweden, are often carried out merely by traditional onsite production methods, with very little prefabrication. According to an STA database (BaTMan), only about 1300 out of over 21 000 bridges administrated by the STA include prefabrication in some way. However, in full-scale tests and case studies, Simonsson (2011) showed there is huge potential for applying more innovative processes and products in Swedish bridge construction. During the studies, the contractors were involved early in the projects to increase the buildability of the product by sharing knowledge about innovative construction methods for all of the building components. Further, the US Federal Highway Administration has recently promoted, and developed a manual for, use of a concept called accelerated bridge construction (ABC), which incorporates innovative solutions for design, planning, materials and construction methods to reduce onsite construction time through prefabrication. ABC also emphasizes the importance of early cooperation between participants, focusing on innovative solutions (Culmo, 2011).

Organizational and cultural aspects

When addressing industrialization (e.g. product and process innovations) in construction, another issue has to be considered. After studying procedures used by Toyota for over two decades, Liker (2008) concluded that industrialization involves not only the implementation of product and process innovations, but also cultural and attitudinal changes. Similar conclusions have been reached in construction research, e.g. Courtney and Winch (2003) found that some constraints are more strongly related to organizational and behavioural obstacles than to technological obstacles. Survey and workshop findings they presented also show that the construction industries in many countries face the same major challenges and advocate cross-border cooperation in order to increase productivity.

The way business is organized can also hamper industrialization. Because of the focus on site production and one-off production, construction is often undertaken by temporary teams formed to execute a specific project. This does not support long-term thinking and knowledge transfer from an improvement perspective. Further, Kadefors (1995) found that the construction industry is subject to strong institutionalization owing to the need for coordination and communication in complex project organizations, explaining why innovations in individual projects seldom bring about long-term changes. Institutional here refers to the cultural rules that provide foundations for the way people act and think about the world.

Build-operate/own-transfer contracts including responsibilities to meet end users' performance requirements dominate in the single-house market, while design-bid-build contracts between the contractor(s) involved in the project and the client are common in infrastructural projects. This strongly affects the scope for introducing innovations in the market. In the single-house market the manufacturer is at the focal point of the supply/demand chain, whereas in design-bid-build projects, such as typical infrastructure projects, the client acts as a systems integrator in the supply chain (Segerstedt and Olofsson, 2010). A systems integrator is an organization that brings together component subsystems into a whole and ensures that those subsystems function together.

Research design

A mixed method design was applied in the presented study, including both qualitative and quantitative approaches to increase the reliability of the empirical results (Creswell, 2003). Two surveys and a workshop (all involving clients, consultants and contractors) were undertaken, then the responses in the surveys and discussion in the workshop were analysed. Surveys are frequently used to collect rich descriptive data about focal phenomena, for instance Gibb (2001) and Blismas *et al.* (2006) used them to map both advantages and disadvantages of offsite production perceived by practitioners in the UK. Further, Blismas *et al.* (2005) used a survey to quantify the constraints for implementation of offsite production identified in previous literature. These examples show that the chosen approach is suitable both for collecting rich descriptive data regarding phenomena within a construction context and for quantifying their significance. However, the outcome of a survey depends on how the questions are asked; in this case both open-ended (Survey 1) and structured questions (Survey 2) were used. The workshop involved in-depth discussions that further enrich the empirical data.

In Survey 1 a qualitative approach was adopted, the main objective being to gain a deeper understanding of practitioners' attitudes and opinions about the infrastructure sector in general and industrialization in particular. For this purpose, a questionnaire was developed that included both structured and open-ended questions by the authors in cooperation with three experienced contractors. It was discussed and debated with several people, both practitioners and academics, in order to minimize misunderstandings and leading questions, which can greatly influence the answers. It was then distributed, during the autumn of 2010, to a sample of practitioners selected on both corporate and individual levels after discussions with major firms operating in the infrastructure sector. Each major contractor and consultancy firm selected was asked to contribute suitable respondents with experience of infrastructure construction to participate in the survey. In addition, the STA was asked to contribute respondents from various departments of its organization. The questionnaire was sent out by mail to 159 staff of the companies and the STA, and responses were received from 21 STA staff members, 13 designers from six major consultancy firms and 27 contractors from two of the four largest firms working in infrastructure construction (61 in total), giving a response rate of approximately 40%. For a summary of the types of respondents and their work experience, see Table 1.

Four of the questions in the questionnaire (25 in total) were selected for the analysis presented in this paper, namely:

(1) Do you think that the infrastructure sector will become more industrialized in the future, and if so how?
(2) What are the major reasons for the often stated inefficiency in the infrastructure sector?
(3) Are there any specific parts or components of a concrete bridge that are suitable for prefabrication?
(4) Are there any specific parts or components of a concrete bridge that are suitable for standardization?

These open-ended questions were selected because of their relevance to both industrialized construction and the objectives of the study. Standardization and prefabrication have been identified as important elements of industrialized construction in previous surveys (e.g. Gibb, 2001; Blismas *et al.*, 2005), while concrete bridges are complex infrastructure products and were thus selected as illustrative focal objects. Some of the other questions are also relevant to industrialization, but less relevant to the specific objectives of the study.

To complement some of the results from Survey 1, a workshop was organized with five contractors from two large firms, four clients (STA staff), two consultants from different firms and three suppliers of prefabricated components. These 14 participants were selected because they had wide experience, showed high interest in the focal subject and had substantial opportunity to influence the infrastructure sector in Sweden. Five out of the 14 were Survey 1 respondents. The topics discussed were based on interesting

Table 1 Summary of respondents (questionnaire survey 1)

Resp. category	Client			Consultant			Contractor		
No.	21			13			27		
Exp. (years)	0–5	5–10	>10	0–5	5–10	>10	0–5	5–10	>10
Construction	0%	0%	100%	0%	0%	100%	0%	7%	93%
Onsite	10%	10%	80%	0%	0%	100%	4%	11%	85%
Offsite	29%	23%	48%	24%	38%	38%	30%	27%	43%

aspects of industrialization identified in Survey 1. Three groups were formed to discuss five specific aspects for one hour of the workshop, three of which are addressed here: core elements of industrialization, uniqueness of the infrastructure sector, and reluctance to change. Results from the group discussions were subsequently compiled and discussed jointly during the last hour of the workshop.

Responses in the 62 returned questionnaires and transcripts of discussions during the workshop were analysed mostly using a qualitative approach. Open-ended questions typically provide no predetermined alternative answers for the respondents, hence the responses were analysed by content analysis using VISIO software to categorize answers and make the data more manageable and meaningful (Gibbs, 2002). Coding into categories is essential in qualitative research because it greatly facilitates interpretation of the acquired data. Answers referring to different categories of barriers, or standardization and prefabrication of various parts, were counted to obtain indications of their importance, as perceived by the participants. A primary purpose of these first two studies was to identify categories and patterns to facilitate the planning and design of the second survey, which was intended to quantify the importance of core elements of industrialization and barriers hindering its implementation, as expressed by practitioners with explicit interest in, and to some extent experience of, industrialized construction in the infrastructure sector. Fifty-two questionnaires were sent to people who had been invited and/or registered to attend a special seminar about industrialized infrastructure construction on 11 October 2011, hosted by the Productivity Committee of the Ministry of Enterprise, Energy and Communications. The survey was part of a research project about industrialized construction within the infrastructure sector commissioned by the Productivity Committee. Thirty-three responses were received from four clients (STA), 14 consultants and 15 contractors, giving a response rate of 63%. This sample included no respondents to the first questionnaire or workshop participants.

The design of the questionnaire, including the selection of response alternatives, was based on categories identified in the analysis of responses in Survey 1, the workshop discussions and a previous multiple case study of three infrastructure projects undertaken as part of the research project commissioned for the Ministry of Enterprise, Energy, and Communications (Productivity Committee, 2012).

The first question addressed practitioners' attitudes to core elements by asking: How important are the following elements of industrialized infrastructure construction? (1) Repetition and standardization; (2) Automation; (3) Prefabrication; (4) Planning for efficient production; (5) Experience feedback; and (6) Integrated design and construction. Five-point Likert scale options were provided for the responses, where 1 = not important, 2 = quite important, 3 = important, 4 = very important, 5 = extremely important.

The second question addressed barriers by asking: How large are the following barriers to increased industrialization of infrastructure construction? (1) Lack of large-scale and repetition possibilities; (2) Norms and rules of the Swedish Transport Administration (STA); (3) Design-bid-build contracts; (4) Impaired aesthetics and monotonous architecture; (5) Severe environmental impact due to long transportation distances; (6) Conservative industry culture; (7) New solutions and methods increase risks; (8) Strong focus on lowest bid price; and (9) Government rules regarding plans. Again, five-point Likert scale options were provided for the responses, where 1 = not large, 2 = quite large, 3 = large, 4 = very large, 5 = extremely large.

The third question addressed the suitability for standardization and prefabrication (S&P) of building products and components in infrastructure construction. The respondents were asked to answer the following question: How suitable are the following 11 products and components for standardization and prefabrication? (The reply alternatives were identified in the multiple case study undertaken for the Productivity Committee.) (1) Tunnel lining; (2) Steel bridges; (3) Noise barriers; (4) Retaining walls; (5) Barrier walls; (6) Prefabricated reinforcement; (7)

Edge beams of concrete bridges; (8) Cut and cover concrete tunnels; (9) Prefabricated concrete bridges; (10) Foundations for bridges and tunnels; and (11) Permanent concrete casting moulds. Again, five-point Likert scale options were provided for the responses, where 1 = not suitable, 2 = quite suitable, 3 = suitable, 4 = very suitable, 5 = extremely suitable.

Statistical analyses of the quantitative survey data were very simple: mainly mean values and standard deviations of the Likert scores were calculated to map the respondents' opinions. In addition, a comparison of means test (ANOVA) was applied to determine whether there were any significant differences in mean values of the scores for the three groups of respondents (clients, contractors, and consultants).

Empirical results

The empirical results are divided into four sections: (1) Interest in and drivers for industrialized infrastructure construction; (2) Core elements of industrialized infrastructure construction; (3) Barriers to industrialized infrastructure; and (4) Standardized and prefabricated products and components.

Interest in and drivers for industrialized infrastructure construction

According to the responses in Survey 1 nearly all (92%) of the respondents (clients, consultants, and contractors) believe that the degree of industrialization will increase in the future. The main drivers of this increase suggested by the responses are increasing demands for cost and time reductions and increased competition from foreign contractors. To date the large contractors in Sweden have been immune to foreign competition, but new rules and legislation have made it easier for foreign firms to compete for large infrastructure projects. The respondents argue that this is forcing the contractors to adopt both product and process innovations (including increased industrialization of the infrastructure sector) in order to survive in the more global market.

Core elements of industrialized infrastructure construction

In the analysis of transcripts from the workshop the following seven categorical themes (core elements of industrialized infrastructure construction) were identified:

(1) Process
(2) Standardization
(3) Repetitiveness
(4) Cooperation
(5) Prefabrication
(6) Continuous improvement
(7) Experience feedback

A brief summary of discussions from the workshop is presented below to increase the understanding for the reader. According to all the group discussions, striving to achieve *continuous improvements* in long-term *processes* is a key aspect of industrialized infrastructure construction. One contractor stated that, 'We strongly believe in standardization of work tasks, and that when you have enough (standardized tasks) you put them together in products. Then one can continuously improve the processes linked to the standard products'. In fact, it can be argued that such improvements span many of the other elements. *Experience feedback* was frequently mentioned as an important tool for obtaining *continuous improvements*, and *Cooperation* between involved actors and the creation of clear communication channels as necessary for increased industrialization. One consultant summarized the latter by saying, '... the unique problems (characteristics) of projects makes it particularly important for the contractor to enter early in the process. These problems [technical and architectural issues related to the specific location and structure to be constructed in the project] may be eliminated more easily and earlier by better cooperation.'

The workshop participants agreed that *standardization* is a major requirement for industrialization of infrastructure in general, and that standardized processes are required to make and use standardized products efficiently, through recognizing similarities among projects and exploiting the scope they provide for *repetitiveness*. Discussions of comparable aspects of different projects mostly concerned the similarity of the processes, which would benefit from standardization, but some participants claimed that all types of aspects are comparable among projects. One client summarized this by saying 'It is all very similar, the cross-section of the road is the same, the bridge often has a fixed width, depending on the location, and then you have railings and coatings on top of the bridge.' Every infrastructure project might have unique characteristics, but the process of constructing a specific structure, e.g. a concrete bridge, always follows the same stages, which facilitates repetition.

Survey 2 was designed to investigate practitioners' views about six core elements identified from the workshop and the previous multiple case study. Standardization and repetition were identified as core elements in both the workshop and case study, but they are closely associated so they were merged into a single element. Cooperation was also identified (by the clients, consultants and contractors in both the workshop and case study), as a very important but also problematic element, especially during the design stages and thus was re-labelled integration of design and construction. It is crucial because of the importance of actors exchanging knowledge to facilitate the design of better, more buildable products. Prefabrication and experience feedback were also identified as core elements in the workshop, and were not modified in any way. Automation and planning for efficient production were also identified in the case study and included in Survey 2. Planning for efficient production means using available planning tools to create a continuous flow through the whole process in order to minimize wastes associated with (for instance) delays and shortages of materials. The general elements of *process* and *continuous improvement*, identified in the workshop, overlap with many of the other core elements of industrialization and hence were not included in the quantitative study. The final six core elements addressed in Survey 2 were: (1) automation; (2) experience feedback; (3) integrated design and production; (4) planning for efficient production; (5) prefabrication; and (6) repetition and standardization.

The results show that all six identified core elements of industrialized infrastructure are considered very important, with mean Likert scores ranging from 3.8 to 4.5, see below.

(1) Automation (3.9)
(2) Experience feedback (4.2)
(3) Integrated design and production (4.2)
(4) Planning for efficient production (4.5)
(5) Prefabrication (3.8)
(6) Repetition and standardization (4.1)

Planning for efficient production was considered most important (4.5) and prefabrication least important (3.8). However, since 3.8 is very close to 4, which is labelled 'very important', all six can be considered core elements of industrialization. Furthermore, the standard deviations are quite low, ranging between 0.6 and 0.9. Thus, the responses do not vary considerably and the respondents have similar opinions. In addition, the ANOVA results indicate that there are no statistically significant differences in opinions between the three types of respondents (clients, consultants and contractors) about these elements. This supports the conclusion that the respondents agree that all six are core elements of industrialized infrastructure construction.

Barriers to industrialized infrastructure

Both surveys also addressed the practitioners' opinions about barriers to industrialization. In Survey 1, the respondents' opinions were sought by including an open-ended question, allowing them to suggest more than one barrier, which was answered by 54 of the 61 respondents. The following eight categories of barriers were identified during the analysis of the qualitative data obtained from Survey 1:

(1) Conservative industry culture
(2) Lack of large-scale and repetition possibilities
(3) STA norms and rules
(4) Design-bid-build contracts
(5) Impaired aesthetics and quality
(6) Strong focus on lowest bid price
(7) Lack of competition
(8) Negative STA reviews

Three out of the eight barriers (conservative industry culture; lack of large-scale and repetition possibilities; and STA norms and rules) were mentioned more frequently (10 times or more) than the others. However, the other five (design-bid-build contracts; impaired aesthetics and quality; strong focus on lowest bid price; lack of competition; and negative STA reviews) were mentioned sufficiently often (5 to 10 times) to be recognized as significant, distinct categories of industrialization barriers. One client summarized this by saying 'A market with relatively low competition and perhaps a bit conservative approach in terms of everything from the rules and norms to execution of projects.' One contractor also highlighted the barriers by saying 'Very governed by laws, standards and requirements. Late project involvement of contractors means that the risk (time, cost, and acceptance) becomes too great to step outside the frame.' No relevant differences in answers between respondent types (clients, contractors and consultants) were detected during the analysis.

Six of the eight categories identified in Survey 1 were directly addressed in Survey 2, while the last two (lack of competition and negative STA reviews) were excluded. Lack of competition was excluded because it was assumed to be closely connected to norms and rules set by the STA (which have previously hindered competition from foreign actors for contracts in Sweden). Negative review was excluded because it was assumed to be closely connected to conservatism in the client organization. Both norms and rules and conservatism are included in the response options in Survey 2, hence the two excluded items are indirect components of the other barriers. Based on the results from the case study, three additional barriers (governmental rules regarding plans; new solutions and methods increase risks; and severe environmental impact due to long transport distances) were added to the list from the first survey. Thus, in total nine categories of barriers were addressed in Survey 2.

The empirical results show that the respondents considered the nine identified barriers to be of varying importance:

(1) Conservative industry culture (3.5)
(2) Design-bid-build contracts (3.5)
(3) Governmental rules regarding plans (3.1)
(4) Impaired aesthetics and monotonous architecture (2.2)
(5) Lack of large-scale and repetition possibilities (3.0)
(6) New solutions and methods increase risks (1.5)
(7) Severe environmental impact due to long transportation distances (1.3)
(8) STA norms and rules (3.1)
(9) Strong focus on lowest bid price (3.5)

Mean Likert scores for two barriers (new solutions and methods increase risks; and severe environmental impact due to long transportation distances) are low and have standard deviations below 1.0, indicating that the respondents agree that these barriers are not large. For the other barriers, standard deviations vary between 1.1 and 1.4, indicating that respondents' opinions regarding their importance vary substantially. These differences in opinions are corroborated by the ANOVA, which indicates that opinions regarding two barriers are statistically significant. Design-bid-build contracts are considered to comprise a very large barrier by contractors and clients, while consultants view it to be of less importance (mean Likert scores: 4.1, 3.8 and 2.9, respectively). Contractors also view governmental rules regarding plans to be a very large barrier, while it is considered to be of less importance by consultants and clients (mean Likert scores: 3.9, 2.3 and 3.3, respectively). Non-significant differences in opinions are also evident for the barrier 'strong focus on lowest bid price' (mean Likert scores: 3.8, 3.4 and 2.3, respectively).

Standardized and prefabricated products and components

In prior construction management literature on industrialized construction, standardization and prefabrication of products and components have often been highlighted as the two most central aspects of industrialization. Therefore, specific parts of the questionnaires used in both surveys focused explicitly on standardization and prefabrication of infrastructure (generally in Survey 2, and in construction of concrete bridges, as examples of complex products, in Survey 1). In Survey 2, only 24 of the respondents expressed opinions about this issue, because nine felt that they did not have sufficient knowledge and experience of these more technological aspects. This supports our notion of a claimed knowledge gap of industrialization among practitioners in infrastructure. Respondents who did express opinions considered almost all of the 11 listed parts and components to be appropriate or even very suitable for standardization and prefabrication, see below:

(1) Tunnel lining (3.8)
(2) Steel bridge (4.2)
(3) Noise barrier (4.4)
(4) Retaining wall (3.4)
(5) Barrier wall (4.7)
(6) Reinforcement (4.2)
(7) Edge beam at concrete bridge (3.3)
(8) Cut and cover concrete tunnel (2.7)
(9) Concrete bridge (3.6)
(10) Foundations in bridge and tunnel (3.3)
(11) Permanent concrete casting mould (3.5)

Cut and cover concrete tunnels were the only listed component that received a mean Likert score below 3.0 (suitable). Three (barrier walls, noise barriers and

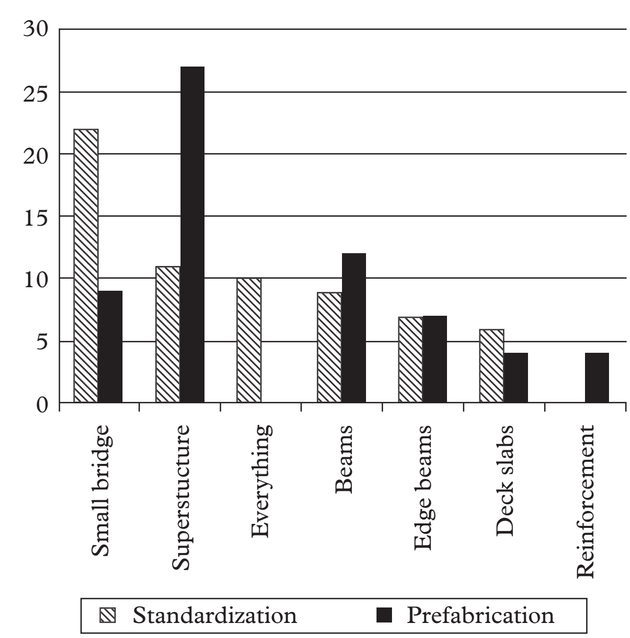

Figure 1 Numbers of respondents (of 52 who expressed opinions in Survey 1) who felt that the indicated parts of concrete bridges could be standardized and prefabricated

reinforcements) of the four most suitable parts and components for industrialization are considered to be standard products.

In Survey 1, small to medium-sized concrete bridges were chosen to identify subsystems, parts and components of complex products perceived to have the greatest potential for standardization and prefabrication. Nearly all (94%) of the respondents thought that it is possible to standardize concrete bridges, or at least some parts of them. Fifty-two respondents chose to comment on standardized parts, see Figure 1. Further, 42% thought that small bridges should be standardized, and that their superstructure, or parts of it (beams, edge beams and deck slabs), is the most suitable part of medium-sized bridges to standardize. Thus, results from Survey 1 show that similar structures are seen as suitable for both standardization and prefabrication.

Analysis and discussion

The findings from Survey 1 support prior indications that increasing industrialized construction is an appropriate approach to improve productivity and reduce both costs and time (e.g. Pasquire and Gibb, 2002; Blismas and Wakefield, 2009). Further, respondents in Survey 1 agreed that increased industrialization could be suitable for solving efficiency and productivity issues associated with the infrastructure sector.

An interesting aspect of the empirical results from the surveys and workshop is the multi-faceted views of practitioners and industry experts about industrialized construction in infrastructure projects, a concept that involves much more than merely prefabrication strategies. Many of the identified core elements of industrialization are related to processes (long-term) rather than projects (short-term). The core elements identified from the workshop with selected industry professionals were processes, standardization, repetitiveness, cooperation, prefabrication, continuous improvement and experience feedback. The importance of these elements was subsequently confirmed by the second survey, which added automation, planning for efficient production and integrated design and construction to the list of core elements of industrialized infrastructure construction. Many of these elements are incorporated in industrialization strategies described in the literature regarding the industrialization of products and processes. Standardization is regarded as a major component of an industrialization strategy since it facilitates implementation of many of the other core elements, such as prefabrication, experience feedback and continuous improvement of products and processes. The findings show that it is important to switch the project focus to include processes, as suggested by Höök and Stehn (2008). Both the literature and findings from the workshop highlight the need for flexibility to counter possible causes of reluctance to standardize. One strategy to maintain flexibility within standardization is by modularization, as concluded (for instance) by Gibb (2001). In infrastructure projects, where the client serves as the systems integrator, it is important for the client to permit the development of these innovations, both by allowing early involvement of contractors and by being more open to innovations. As the workshop highlights, many similarities between projects need to be explored in order to see how they can be standardized. Integrating all of the standards into a product or process platform is a possibility highlighted in both the workshop and previous literature (Sawney, 1998). Hence, identifying similarities among projects instead of merely their uniqueness is a first step towards increased industrialization.

Product standardization is one of two strategies for decreasing production complexity proposed by Bertelsen (2004). Possible candidates for standardization and prefabrication (S&P) in infrastructure projects on various product architecture levels, ranging from complete products to subsystems and components, were suggested and are illustrated in Figure 2.

The results from Survey 2 show that three of the four most suitable parts and components for industrialization (barrier walls, noise barriers and reinforcement) are considered to be standard products. The suggestions for parts of concrete bridges that are suitable for both standardization and prefabrication (Figure 1) indicate that the most difficult structures to construct by traditional onsite construction methods should be selected, although this does not imply that they are difficult to construct with innovative methods. For instance, the construction of bridge superstructure, identified as suitable for both prefabrication and standardization, requires complex formwork and reinforcement activities on site. Hence, a clear driver for standardization of parts is complex and time-consuming onsite construction (Blismas *et al.*, 2006). According to Gann (1996), flexibility is important and the superstructure is probably the subsystem least affected by unpredictable geotechnical conditions; hence, it is a suitable subsystem for standardization and possibly prefabrication.

Gibb (2001) noted that concrete bridges are generally non-volumetric products, but their individual components (e.g. deck slabs and beams) can be seen as component sub-assemblies, which increases the scope for standardization. These components are both components within a subsystem (superstructure) and can be easily compared to hollow cores (for example),

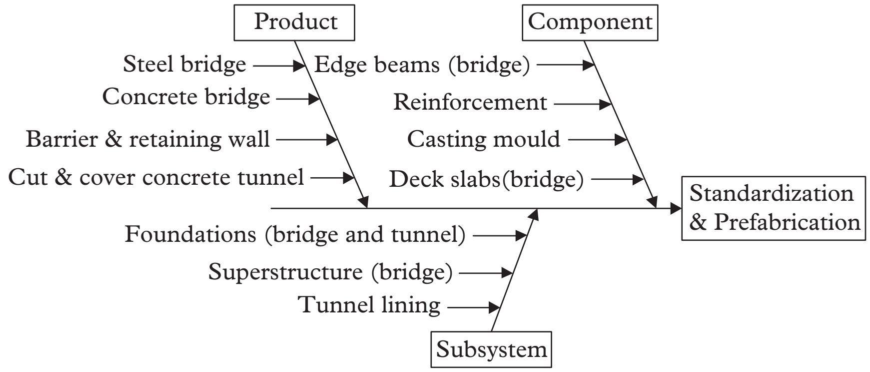

Figure 2 Products, subsystems and components of infrastructure (e.g. bridges) identified as being suitable for standardization and prefabrication

which are standard components of industrialized housing. The identified subsystems (superstructure and foundation) can also be treated as modules, as they have clear functions and interfaces in bridges. Since every bridge is seen as unique, especially in Sweden, it is important to identify modules and subsequently components of the modules that can be standardized. Hence, the development of standardized products, subsystems and components in the infrastructure sector should exploit recent advances in product platforms, modularization and configuration strategies for building systems (Hvam *et al.*, 2008; Jensen *et al.*, 2012).

However, the scope for innovation depends on how a project is organized (Kadefors, 1995), which is highlighted as a barrier in construction, both by Blismas *et al.* (2005) and here. Since standardization and prefabrication are often characterized by long lead times, the design must be completed early in the project, which is difficult to achieve today as the contractor and supplier are involved late in the project. Two reasons for the reluctance to standardize (industrialize) bridges were frequently mentioned by the respondents. First, architects want to put their unique mark on each bridge, and because they enter early in the project they set constraints on production. Secondly, clients are often conservative, i.e. reluctant to use new product options, as proved solutions decrease risks of failure. These factors are hindering the implementation of more predefined specifications mentioned by, for example, Winch (2003) and Hvam *et al.* (2008), as more time-efficient production methods. However, these specifications could all be incorporated in the design process in infrastructure construction, since the client entered the value chain in the specification phase of the project.

The main perceived barriers to increased industrialization of infrastructure construction, their relationships to the core elements, and the actors who could eliminate them are illustrated in Figure 3. Three out of five barriers (lack of repetition, norms and rules, and procurement strategies) are controlled by the main client in Sweden (the STA).

Removal of all six identified barriers is essential for introduction of the core elements of industrialized construction:

- Design-bid-build contracts split design and production. From an institutional perspective, the clients (STA and principal designer) act as systems integrators, making the contractor a supplier of construction services. In this system standardization of the design (at component, subsystem or product level) can only be implemented by the client. Both Simonsson (2011) and Culmo (2011) highlight the importance of early cooperation for innovation.
- Standardization of production processes can be encouraged by the client by using the same contractor (supply chain integration), but this can be difficult to accomplish using public procurement practices focusing on the lowest price for each new project. This barrier has been highlighted in previous literature, e.g. by Gibb (2001). Solely evaluating solutions in financial terms rather than value is very common in Sweden and is strongly connected to the conservatism barrier.
- Lack of repetition possibilities derived from clients' procurement and contracting practices hinder standardization, continuous improvement and investments in both automation and prefabrication facilities. One way for contractors to handle their late involvement is to explore the process innovation developed by, for instance, Koskela (2000). This approach can help tackle the onsite peculiarities, regardless of whether more industrialized products are implemented. Hence, planning can be improved by exploring process similarities between projects.

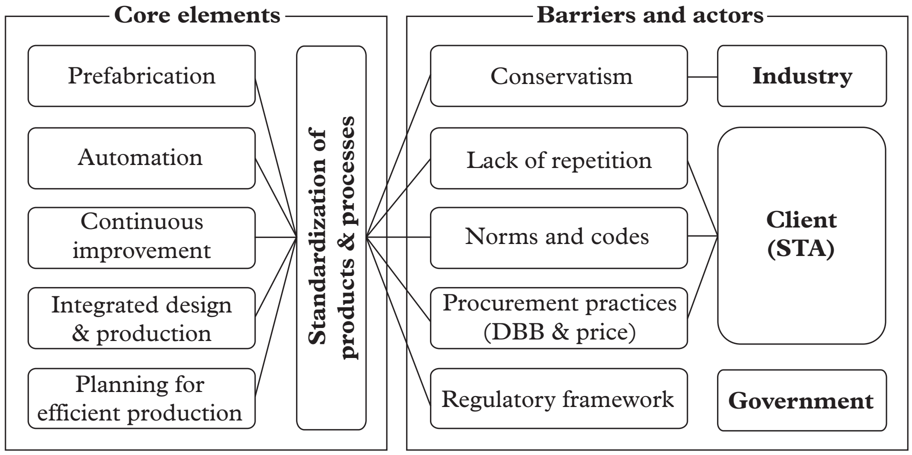

Figure 3 The main perceived barriers (process and product) to increased industrialization of infrastructure construction, their relationships to the core elements, and the actors who could eliminate them

- Norms and rules of the STA, governmental rules regarding plans and the conservative industry culture also affect the possibilities for standardization, automation and prefabrication. The conservative culture in the construction industry has also been identified as a barrier for innovation in previous literature, e.g. Kadefors (1995). These barriers that are strongly connected to culture are difficult to change and demand more radical counter-measures.

Conclusions

A better knowledge of core elements of, and barriers to, increasing the standardization of products and processes in a previously neglected context, the infrastructure sector, as perceived by professional clients, can help to foster broader awareness of possible ways to implement industrialized construction in infrastructure projects.

An important contribution to the literature on industrialized construction is the identified core elements of industrialized infrastructure construction. Four are primarily related to the process (planning for efficient production, integrated design and production, continuous improvement and automation) while only one (prefabrication) is primarily related to the product. Five elements contribute to standardization, the single most important element of industrialization, without which it is impossible to evaluate product and process innovations.

Interestingly, three of the five largest perceived barriers could be traced back to the client's role. Thus, the clients (i.e. the STA in Sweden) must address these barriers to increase industrialization. The long-term research and innovation programme launched by the STA to promote increased industrialization throughout the value chain and standardization of products is a first step toward breaking down the barriers and releasing the potential to increase productivity.

The standardization of products is shown to be a possible strategy for reducing the complexity of onsite construction, but it will not become more common as long as the chances for large-scale production and repetitiveness are small. Future research should focus on procurement strategies that support the standardization of products and processes, partly because they are strongly related to the identified core elements and partly because of the importance of shifting the focus from project to process in an industrialized infrastructure context.

Since the empirical results are based on data collected only from Swedish practitioners, international generalizations should be made with caution. Further research on practices in other countries is required to assess international differences and similarities of barriers to industrialized infrastructure construction. In addition, the samples of practitioners are not sufficiently large to draw generalized conclusions, but the main intention was to obtain indications of practitioners' knowledge and attitudes about industrialization in the infrastructure sector, which has been largely neglected in this type of research. In future research larger samples should be surveyed to enable hypotheses to be robustly tested.

References

Ballard, G. (2000) The Last Planner system of production control, Doctoral thesis, School of Civil Engineering, Faculty of Engineering, The University of Birmingham.

Ballard, G. and Howell, G. (1998) Shielding production: essential step in production control. *Journal of Construction Engineering and Management*, **124**(1), 11–7.

Bertelsen, S. (2004) Lean construction: where are we and how to proceed. *Lean Construction Journal*, **1**(1), 46–69.

Blismas, N.G. and Wakefield, R. (2009) Drivers, constraints and the future of offsite manufacture in Australia. *Construction Innovation: Information, Process, Management*, **9**(1), 72–83.

Blismas, N.G., Pendlebury, M., Gibb, A.G.F. and Pasquire, C. (2005) Constraints to the use of off-site production on construction projects. *Architectural Engineering and Design Management*, **1**(3), 153–62.

Blismas, N.G., Pasquire, C. and Gibb, A.G.F. (2006) Benefits evaluation for off-site production in construction. *Construction Management and Economics*, **24**(2), 121–30.

Bröchner, J. and Olofsson, T. (2012) Construction productivity measures for innovation projects. *Journal of Construction Engineering and Management*, **138**(5), 670–7.

Building Commission (2002) *Skärpning gubbar! Om konkurrensen, kvaliteten, kostnaderna och kompetensen i byggsektorn* [About competition, quality, costs and competence in construction, in Swedish], SOU 2002:115, Stockholm, Sweden.

Caerteling, J., Di Benedetto, A., Dorée, A., Halman, J. and Song, M. (2011) Technology development projects in road infrastructure: the relevance of government championing behavior. *Technovation*, **31**(5–6), 270–83.

Cantarelli, C., van Wee, B., Molin, E.J.E. and Flyvbjerg, B. (2012) Different cost performance: different determinants? The case of cost overruns in Dutch transport infrastructure projects. *Transport Policy*, **22**(July), 88–95.

Courtney, R. and Winch, G. (2003) Re-engineering construction: the role of research and implementation. *Building Research & Information*, **31**(2), 172–8.

Creswell, J. (2003) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 2nd edn, Sage, Thousand Oaks, CA.

Culmo, M.P. (2011) *Accelerated Bridge Construction: Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems*, Federal Highway Administration Report No. FHWA-HIF-12-013, Alexandria, USA.

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

Flyvbjerg, B., Skamris Holm, M.K. and Buhl, S.L. (2004) What causes cost overrun in transport infrastructure projects? *Transport Review: A Transnational Transdisciplinary Journal*, **24**(1), 3–18.

Fox, S., Marsh, L. and Cockerham, G. (2002) How building design imperatives constrain construction productivity and quality. *Engineering Construction and Architectural Management*, **9**(5–6), 378–87.

Gann, D.M. (1996) Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. *Construction Management and Economics*, **14**(5), 437–50.

Gibb, A.G.F. (2001) Standardization and pre-assembly: distinguishing myth from reality using case study research. *Construction Management and Economics*, **19**(3), 307–15.

Gibb, A.G.F. and Isack, F. (2003) Re-engineering through pre-assembly: client expectations and drivers. *Building Research & Information*, **31**(2), 146–60.

Gibbs, G.R. (2002) *Qualitative Data Analysis*, Open University Press, Milton Keynes.

Höök, M. and Stehn, L. (2008) Applicability of lean principles and practices in industrialized housing production. *Construction Management and Economics*, **26**(10), 1091–100.

Horman, M.J. and Kenley, R. (2005) Quantifying levels of wasted time in construction with meta-analysis. *Journal of Construction Engineering and Management*, **131**(1), 52–61.

Huang, A.L., Chapman, R.E. and Butry, D.T. (2009) *Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations*, NIST Spec. Publ. 1101, National Institute of Standards and Technology, Gaithersburg, MD.

Hvam, L., Mortensen, N.H. and Riis, J. (2008) *Product Customization*, Springer, Berlin.

Jensen, P., Olofsson, T. and Johnsson, H. (2012) Configuration through the parameterization of building components. *Automation in Construction*, **23**, 1–8.

Jiao, J. and Tseng, M.M. (2004) Customizability analysis in design for mass customization. *Computer-Aided Design*, **36**(8), 745–57.

Jiao, J., Zhang, L. and Pokharel, S. (2003) Process platform planning for mass customization. Paper presented at the 2nd Interdisciplinary World Congress on Mass Customization and Personalization, Munich, Germany, 6-8 October.

Josephson, P.-E. and Saukkoriipi, L. (2005) Slöseri i byggprojekt – behov av förändrat synsätt [Waste in construction projects, in Swedish], FoU-Väst 0507, Göteborg, , Sweden.

Kadefors, A. (1995) Institutions in building projects: implications for flexibility and change. *Scandinavian Journal of Management*, **11**(4), 395–408.

Koskela, L. (2000) An exploration towards a production theory and its application to construction, Doctoral thesis, Helsinki University of Technology.

Liker, J.K. (2008) *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill, New York.

Minchin, E., Lewis, D. and McLeod, L. (2011) Improving productivity on a troubled bridge project. *Journal of Construction Engineering and Management*, **137**(5), 364–71.

Ministry of Finance (2009) *Återkrav inom välfärdssystemen: förslag till lagstiftning* [Repayment in welfare, proposals for legislation, in Swedish], SOU 2009:6, Stockholm, Sweden.

Mossman, A. (2009) Creating value: a sufficient way to eliminate waste in lean design and lean production. *Lean Construction Journal*, **2009**, 13–23.

Pasquire, C. and Gibb, A.G.F. (2002) Considerations of assessing the benefits of standardisation and pre-assembly in construction. *Journal of Financial Management of Property and Construction*, 7(3), 151–61.

Productivity Committee (2012) *Vägar till förbättrad produktivitet och innovationsgrad i anläggningsbranschen* [Ways to improve productivity and innovation in civil engineering, in Swedish], SOU 2012:39 for the Ministry of Enterprise, Energy, and Communications, Stockholm, Sweden.

Sawney, M.S. (1998) Leveraged high-variety strategies: from portfolio thinking to platform thinking. *Journal of the Academy of Marketing Science*, **26**(1), 54–61.

Segerstedt, A. and Olofsson, T. (2010) Supply chains in the construction industry. *Supply Chain Management*, **15**(5), 347–53.

Simonsson, P. (2011) Buildability of concrete structures: processes, methods and material, Doctoral thesis, Luleå University of Technology.

Simpson, T.W., Siddique, Z. and Jiao, R.J. (2005) *Product Platform and Product Family Design: Methods and Applications*, Springer, New York.

Teicholz, P., Goodrum, P. and Haas, C. (2001) Discussion: US construction labor productivity trends, 1970–1998. *Journal of Construction Engineering and Management*, **127** (5), 427–9. http://dx.doi.org/10.1061/(ASCE)0733-9364(2001)127:5(427)

Voordijk, H., Meijboom, B. and de Han, J. (2006) Modularity in supply chain: a multiple case study in the construction industry. *International Journal of Operations & Production Management*, **26**(6), 600–18.

Vrijhoef, R. and Koskela, L. (2005) Revisiting the three peculiarities of production in construction. Paper presented at the 13th International Group for Lean Construction, Sydney, Australia, 19-21 July.

Winch, G.M. (2003) Models of manufacturing and the construction process: the genesis of re-engineering construction. *Building Research & Information*, **31**(2), 107–18.