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Exploring the applicability of configuration information in construction projects

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ABSTRACT

The architecture, engineering and construction industry focus on the project rather than on the product management. However, the development of digital and automated techniques requires more product based processes. Configuration information is an essential part of product management to ensure high performance. This study aims to explore if systematic configuration information, used in product development, can be applied in construction projects. An international guideline and an extensive literature study identified five key areas of configuration information applicable to construction projects. This knowledge was synthesised into a conceptual model for managing configuration information. A survey investigated the application of configuration information in construction projects. In comparison with the model, the results from the literature review and the survey show that configuration information was insufficient and not managed systematically. However, the findings also indicate that systematic configuration information can be used to improve control over the product and solve several problems encountered by construction projects. This study fills a knowledge gap regarding the management of configuration information in the context of construction projects. The ongoing development of new technologies in the architecture, engineering and construction industry will make the subject of configuration information increasingly important.

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configuration information; information management; construction project; building performance; healthcare facilities

Introduction

Processes that define and maintain the configuration throughout a project can ensure delivery of a product with the intended performance. Industries involved in product development often practice configuration management (Zhang 2014). An important part of this management is the configuration information, which includes function, design, realisation, audits and change control (ISO 2017). The architecture, engineering and construction (AEC) industry is often focused on processes associated with project management (Shen et al. 2010). The shifts towards digital building information and automated production techniques in the AEC industry requires processes similar to those used in product development industries (Bock 2015). Traceable and available information about the configuration will be an essential part of managing the product from planning to delivery in construction projects (Froese 2010).

Through a building lifecycle, accurate configuration information ensures that the property owner's intentions regarding performance are fulfilled (Pärn, Edwards, and Sing 2017). Even after the

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demolition of a building, the configuration information can continue to add knowledge to future designs and construction projects (Eleftheriadis, Duffour, and Mumovic 2018). Reliable information about the configuration (as built) flows from property owners to construction projects and back, as shown in Figure 1. Increased focus on optimising product configurations can prolong the lifecycle of buildings and consequently reduce the environmental impact of the AEC industry (UNEP 2018). There are general performance requirements on buildings, such as standards for constructions and sustainability. Healthcare facilities have additional requirements to ensure end-user functionality for diagnosis, treatment and care for patients, which makes the construction technically complex and the end-product does not always fulfil the intended performance (Van Hoof et al. 2015).

Configuration management is not extensively practiced the AEC industry, but has been applied by other industries for at least two to three decades (Zhang 2014). The present study aims to fill this gap by proposing a model for managing configuration information in construction projects. The availability of information in accordance with the proposed model was studied in healthcare construction projects through a survey addressed to project managers.

Background

Configuration management aims to describe and control the product from the planning to the realisation (Zhang 2014). In addition, the configuration information retrieved in one project can transfer knowledge to improve products and management in the future (Whyte, Stasis, and Lindkvist 2016). Construction projects manage a great amount of information about the building configuration in construction projects. This information needs to be processed and managed by the project managers (CEN 2016). Methods used to ensure products with high performance often emphasise the importance of configuration information, as within concurrent engineering (Monticolo et al. 2015), value management (Luo et al. 2011) and quality function deployment (Merschbrock and Munkvold 2015).

Several issues encountered by construction projects are related to the management of building configuration. There are problems with collecting functional requirements in the planning phase (Kim, Cha, and Kim 2016). The designers should fulfil the requirement of functions by providing technical solutions. However, their specifications defining the configuration are often insufficient or inaccurate, which cause problems with inefficiency and delays in the production phase (Aljohani, Ahiaga-Dagbui, and Moore 2017). Feasibility is often not considered in the design phase (Parvan, Rahmandad, and Haghani 2015). Including contractor knowledge of production methods in the development of design solutions can ensure an effective realisation (Porwal and Hewage 2013). Information about verification methods should describe how the decided functions should be measured from the determination of the baseline configuration to the delivery (ISO 2017). The verification of performance mainly consists of inspections when the construction work is completed in construction projects (Ding et al. 2017). Clear definition and verification of functional requirements throughout all the construction phases can reduce the risk of inadequate performance of the end-product (Kamara, Anumba, and Evbuomwan 2001). After the client has approved the baseline

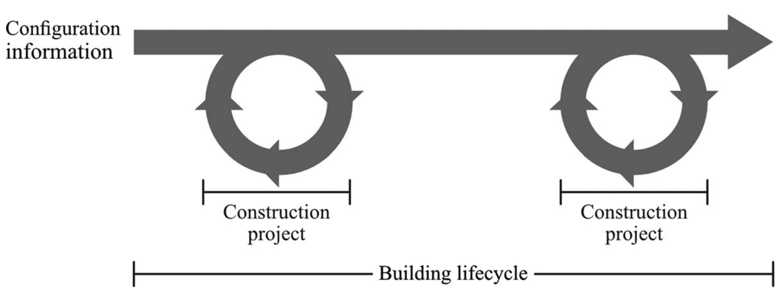

Figure 1. Configuration information flow between building owner and construction projects.

configuration, all changes to the configuration should be managed systematically (Whyte, Stasis, and Lindkvist 2016). The subject of changes in construction projects is well studied regarding the impact on cost and time (Sun and Meng 2009; Aljohani, Ahiaga-Dagbui, and Moore 2017), but the consequences to building configurations and in the extension their performance are less studied. During the whole construction process, BIM provides detailed information about components and systems that enables control of the configuration (Ding et al. 2019). The increasing accessibility to digital information enables automated analysis that can improve the management of configurations (Smith 2014). Detailed digital information about the configuration becomes imperative as automated production techniques are implemented in the AEC industry (Bock 2015; Oesterreich and Teuteberg 2016). Hence, the management of information about the product configuration will become increasingly important for the AEC industry.

A functional requirement on healthcare facilities can comprise of complex systems, which together ensure adequate performance. For example, medical imaging equipment can be both heavy and vibration-sensitive, which requires a concrete slab that is configured to withstand the load and reduce vibrations (Avci et al. 2019). The supply chain within healthcare facilities requires configuration of transport routes that will not interfere with the flow of patients, clinicians or visitors (Hicks et al. 2015).

Research design and methods

The design of this study consists of two parts. First, an international guideline and a literature review provided knowledge about configuration information in construction projects. Second, a survey investigated the availability of configuration information in projects managing complex facilities, where Swedish healthcare constructions served as an example in this study. The results from the two parts were synthesised in the proposed model. Figure 2 shows the overall design of this study. This study focuses on configuration information in construction projects, since delivery of insufficient information to or from these can affect the overall configuration management of buildings (see Figure 1).

Literature review

The aim of the literature review was to propose a conceptual model for configuration information and identify any knowledge gaps. First, the ISO 10007:2017 guidelines were analysed to find key areas of configuration information applicable to construction projects. These guidelines describe configuration management during the lifecycle of a product and have developed since the first edition in 1995 (ISO 2017). Five key areas of configuration information applicable in construction

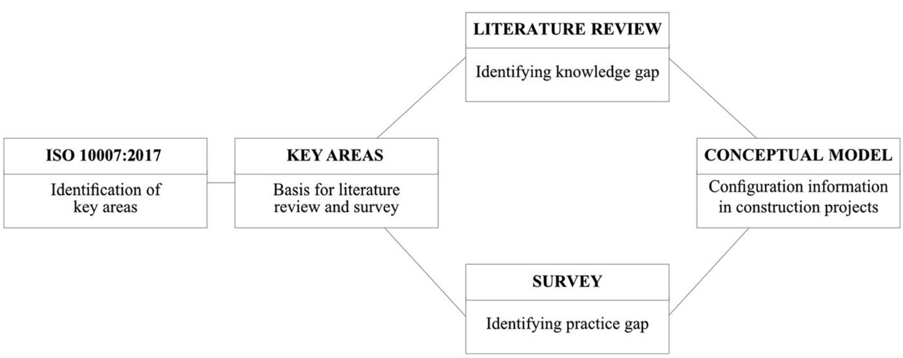

Figure 2. Overall research design.

projects were identified from the guidelines; function, design, production method, verification and change. The key areas in combination with construction project and configuration information were the search criteria in the databases of Primo and Google Scholar™. Relevance to the subject was established by analysing abstract, discussion and conclusion of the 177 papers found. Thereafter, the complete text of the remaining 67 studies was analysed. Finally, 24 papers were included that applied to configuration information, as shown in Table 1.

Survey

Construction projects often manage information manually and use implicit knowledge. Therefore, a survey identified the opinions of project managers regarding the availability of configuration information in practice. The purpose was to investigate if projects managing complex configurations apply configuration information as described in the proposed model, using Swedish healthcare constructions as examples. Property management organisations in twenty tax-financed Regions (previous County Councils) own and manage most of the healthcare facilities in Sweden. All Regions received an invitation to participate in the survey, half of them accepted. At the time of the survey, the ten participating organisations together managed 72% of the total area of Swedish public healthcare facilities and accounted for 79% of the total investments (KOLADA 2019). The selection of respondents was information oriented and they had similar backgrounds. Most respondents (90%) had the professional title of 'project manager' or 'production project manager'. Two to ten years of experience of healthcare construction projects was most common among the respondents (63%) and second most common was ten years or more (22%). The Regions provided the e-mail addresses to 148 project managers and there were 59 respondents, which give a completion rate of 40%. In a UK study, the completion rate of 27% for samples of construction professionals was considered to be good (Idrus and Newman 2002). The participating respondents gave their informed consent to participate in the study and to the processing of personal information (i.e. e-mail address). Recording the results from the survey separate from personal or organisational information further ensured the respondents' privacy. Table 2 presents the survey questions and their response options.

Table 1. Literature assessed relevant to the key areas of configuration information in construction projects.

Reference	Function	Design	Production method	Verification	Change
(Aljohani, Ahiaga-Dagbui, and Moore 2017)			X		X
(Bock 2015)			X		X
(Chen and Luo 2014)		X			
(Chun and Cho 2015)					X
(Cox et al. 1999)					X
(Ding et al. 2017)			X	X	
(Ding et al. 2019)	X			X	
(Fernandes et al. 2015)				X	
(Hallerstede, Jastram, and Ladenberger 2014)		X			
(Huovila et al. 2004)	X	X			
(ISO 2017)	X	X	X	X	X
(Joseph et al. 2014)	X				
(Kamara, Anumba, and Evbuomwan 2001)	X				
(Kim, Cha, and Kim 2016)	X				
(Kiviniemi 2005)		X			
(Minato 2003)	X				
(Parvan, Rahmandad, and Haghani 2015)			X		
(Porwal and Hewage 2013)		X			
(Shipton, Hughes, and Tutt 2014)					X
(Stasis, Whyte, and Dentten 2013)	X				
(Sun and Meng 2009)					X
(Toor and Ogunlana 2010)	X				
(Ullah et al. 2018)					X
(Whyte, Stasis, and Lindkvist 2016)					X
Total	9	6	5	4	9

Table 2. Presentation of the survey questions including response alternatives.

ID	Question	Type of response options	Response alternatives
Q1	Rank what you think is important for a high quality of the end-product configuration in healthcare facilities construction projects? (drag and drop the options in the order you want them) 1 = most important, 2 = second most important etc.	Fixed	– Documentation of all functions – Complete description of the product configuration – Control of changes to the product – Structured management of functional requirements on the product
Q2	Based on your experience of construction projects, what information about the healthcare facility configuration is documented at the end of the planning phase?	Fixed	– Functional requirements – Design solutions – Production methods – Verification methods
Q3	The planning phase includes all information about functional requirements needed to select technical solutions in the design phase.	Likert scale	1 = 'fully agree' 2 = 'agree' 3 = 'disagree' 4 = 'do not agree at all' Do not know
Q4	It is common that new requirements on the healthcare facility configuration are added in the design phase.	Likert scale	See Q3
Q5	Based on your experience of construction projects, what information about the healthcare facility configuration is documented at the end of the design phase?	Fixed	– Functional requirements – Design solutions – Production methods – Verification methods – All configuration changes
Q6	The design construction documents include all information about functional requirements and the related technical solution needed to select adequate production methods.	Likert scale	See Q3
Q7	It is common that new requirements on the healthcare facility configuration are added in the production phase.	Likert scale	See Q3
Q8	In the production phase, the healthcare facility functional requirements are documented together with the associated technical solution and production method.	Likert scale	See Q3
Q9	In the production phase, healthcare facility functions are continuously verified against measurable requirements.	Likert scale	See Q3
Q10	Based on your experience of construction projects, what information about the healthcare facility configuration is documented at the handover?	Fixed	See Q5

Using a four-point scale reduces the risk of a systematic tendency to respond in a certain way (i.e. response set) (Chang 1994). To prevent misinterpretation and response errors due to incorrect respondent perception (i.e. halo error), both laypeople and project managers of healthcare construction projects evaluated the survey questions regarding wording, content and relevance. This resulted in minor word adjustments. The external reliability of this survey was relatively low, since the result would probably not be the same with another population or another time point. The survey data was analysed using descriptive statistics in MATLAB (MathWorks 2018).

Results

In both research and practice, the key areas of configuration information applied were similar. The literature mostly addressed configuration information in the context of function and change, while studies from the three other key areas were less frequent, as shown in Table 1. According to respondents, the key areas of function and design information was the most complete, followed by change. The results regarding available information from the survey are provided in Figures 3–5.

Conceptual model for configuration information

The management of configuration information is a continuous process aimed at ensuring that the description of the product is always updated and accurate (Monticolo et al. 2015). Therefore, the information must be available and flow between all stakeholders through the construction phases (Kamara, Anumba, and Evbuomwan 2001). Figure 6 presents the proposed conceptual model with the five key areas of configuration information and their interrelationships, based on the ISO 10007:2017 guidelines and the literature review. The following sections present a more detailed description of the results from the literature review and the survey.

Function

The information about required functions is essential for the end-product performance as well as the lifecycle management (ISO 2017). The product should be unambiguously defined in the planning or early design phase of construction projects (Chun and Cho 2015). Otherwise, the consequences can be low efficiency in the production phase (Minato 2003) and insufficient end-product performance (Stasis, Whyte, and Dentten 2013). Evaluation of functions in operational use can help clients to develop, refine and standardise their functional requirements (Joseph et al. 2014; Ding et al. 2019). The functions should be measurable with acceptance criteria (Toor and Ogunlana 2010). In the survey, almost all respondents considered information on functions to be present in all construction phases (see Figure 3). Most respondents also agreed that the information on functional requirements at the end of the planning phase was sufficient to select design solutions (see Figure 4). However, 85% of the respondents considered new requirements common in the design phase, which implies that the information was insufficient. Ensuring that functions have feasible design solutions and construction techniques are essential to prevent unnecessary configuration changes after the planning phase (Bock 2015). The respondents ranked structured management of functional requirements as the most important for a high quality of the end-product, followed by documentation of functional requirements (see Figure 5). The information about functions is the controlling basis for all other key areas of configuration information and should be available throughout the project process (ISO 2017).

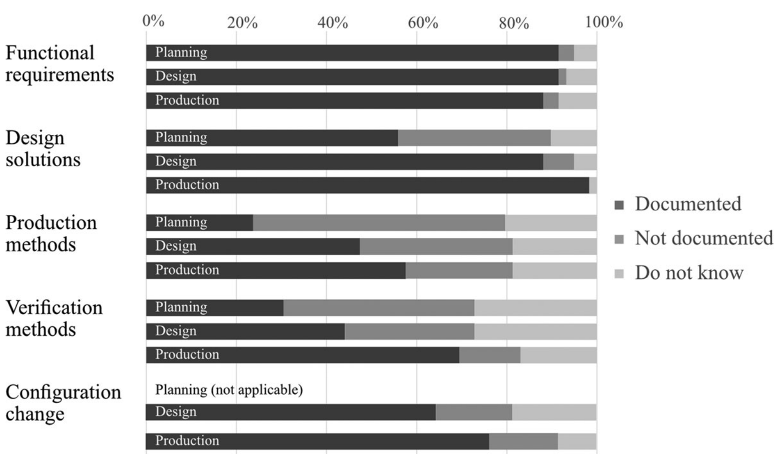

Figure 3. The respondents' opinion on which information is documented in each construction phase.

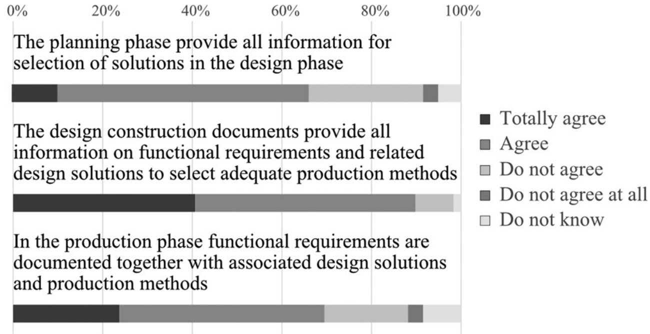

Figure 4. Completeness of the necessary configuration information flow between the construction phases, according to the respondents.

Verification

From the design phase to the handover, the fulfilment of the decided functions should be verified to ensure adequate performance of the end-product (Fernandes et al. 2015). Verification methods and acceptance values should be established together with the functions in the planning phase to enable a continuous confirmation of the product performance (ISO 2017). For example, an acceptance criterion that x number of people should be able to work in the same room for x hours should be converted to measurable values for acquired configurations, such as ventilation, size of the area and sound insulation. Verification methods were documented at the end of the planning phase according to 31% of the respondents. In fact, information on verification methods was not available to any great extent until the end of the production phase (see Figure 3). This is consistent with previous observations that verifications in construction projects are performed at the end of projects rather than continuously (Ding et al. 2017). Half of the respondents agreed that continuous verification was performed during the production phase. The model in Figure 6 shows that information about verification methods affects all the other key areas, directly or indirectly. Any change of verification methods requires assurance that the decided functions still are measured and that the acceptance values are valid (ISO 2017).

Design

The design process is complex since all functions must be included in the product specifications to provide complete information about the configuration (ISO 2017). Starting the design before all the

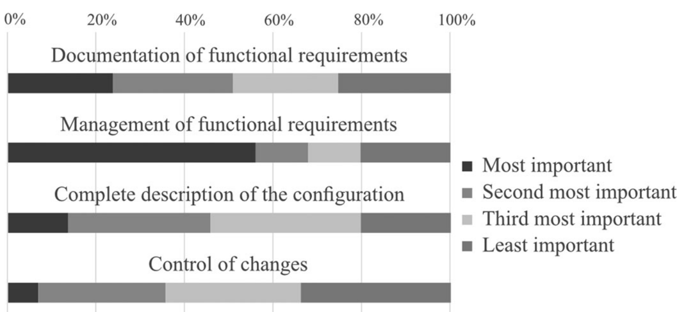

Figure 5. Respondents' ranking of what is most important for high end-product quality.

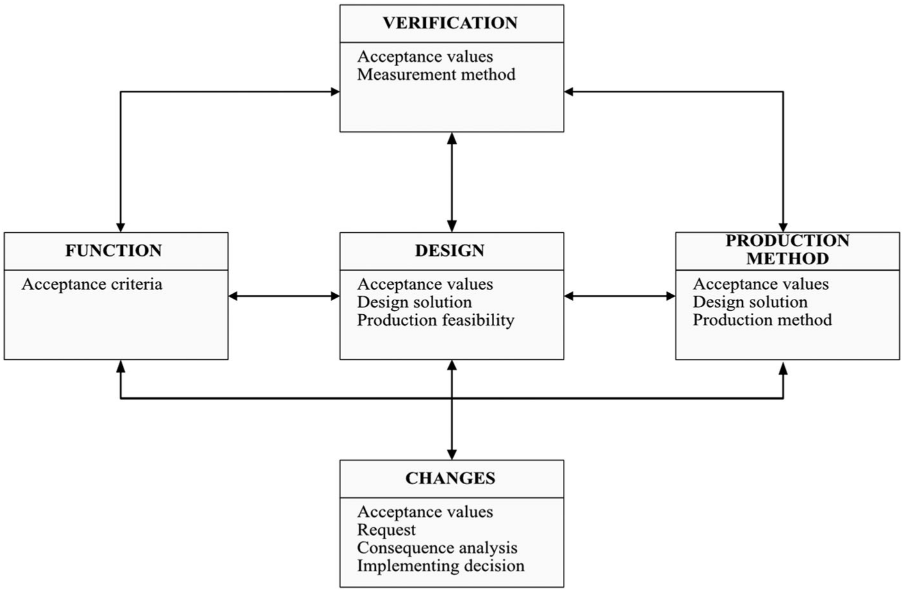

Figure 6. Conceptual model for systematic configuration information with the key areas as headings and the information relevant in construction projects below. The arrows represent the interrelationship between the key areas.

functional requirements are established at the end of the planning phase increases the risk of insufficient building performance (Kiviniemi 2005). Over half of the respondents considered design solutions were present at the end of the planning phase (see Figure 3). To maintain and verify the product performance decided by the client, traceability of the functions in the design specifications are important (Hallerstede, Jastram, and Ladenberger 2014). Information on design solutions should be complete at the end of the design phase and include interrelations to functions and production feasibility (ISO 2017), as the model in Figure 6 shows. New requirement were considered common in the production phase by 78% of the respondents considered, which implies that the basis for design specifications were incomplete. At the end of the design phase, almost all of the respondents considered that the design information was sufficient to select suitable production methods (see Figure 4). The information in the design specifications is important to reduce the risk of insufficient end-product performance (Chen and Luo 2014). However, the respondents ranked complete design specifications as the second least important for a high quality of the end-product (see Figure 5).

Production

In the model, the production methods refer to techniques required to achieve the configuration on site. During production, the configuration information should provide build status, i.e. account for preservation and delivery of intended functions (ISO 2017). Coordination between contractor and designers in the design phase, can enhance the quality of the configuration and ensure feasibility during construction (Porwal and Hewage 2013). Half of the respondents considered documentation on production methods to be present at the end of the design phase (see Figure 3). If realisation is not feasible, the implications can be unnecessary delays, costs and rework (Parvan, Rahmandad, and Haghani 2015). The functional requirement may need modification if there are no design solutions and/or production methods that can realise them. Figure 6 shows that any alteration in the key areas of function, design and production will start a flow of information between them. Most of the respondents considered that the information from these three key areas to be available cohesively (see Figure 4).

Change

The initiation of a configuration change starts with a request containing information about the change and the importance of its implementation (Cox et al. 1999). Thereafter, a consequence analysis is performed, in which causes and effects are weighed against each other (Ullah et al. 2018). Finally, the client makes decisions regarding implementation. Changes that are to be implemented requires updating of configuration information, as well as assurance that the functional requirements of all stakeholders still are fulfilled (ISO 2017). Consequently, information about changes needs to be available throughout the construction process (Chun and Cho 2015). Fewer respondents considered that documentation of configuration changes was available after the design phase than after the production phase (see Figure 3). Changes to the configuration can affect the performance of the end-product (Chun and Cho 2015). However, control over configuration changes was considered to have the lowest impact on the quality of the final product by most respondents (see Figure 5). As the proposed model shows, the information on configuration changes is interrelated to all other key areas (see Figure 6).

Discussion

The results of this study indicate that systematic management of configuration information can apply to construction projects, as described in the proposed model (see Figure 6). At the same time, the findings from the literature review and survey show that subject is not frequently applied to construction projects. Real time reliable information about the current configuration can ensure adequate product performance (Stasis, Whyte, and Dentten 2013). In the early construction phases, projects often go directly to design solutions instead of first acquiring required functions (Chun and Cho 2015), which the results from the survey confirm. Interconnection of information about functions, design solutions and feasible realisation methods can reduce the number of changes and improves efficiency during the production phase (Porwal and Hewage 2013). The survey results show that information about production methods was among the least documented. From planning to handover, verification enables to maintain the decided performance of the building (Chun and Cho 2015; Fernandes et al. 2015). In the survey, only half of the respondents considered continuous verification common in the construction process. Changes in construction projects are often considered inevitable by previous studies (Sun and Meng 2009; Shipton, Hughes, and Tutt 2014). However, clearly defined product configurations can reduce the number of changes and ensure building performance (Aljohani, Ahiaga-Dagbui, and Moore 2017). Unexpectedly, the respondents considered configuration changes to have the least impact on the quality of the end-product.

In complex constructions, such as healthcare facilities (Van Hoof et al. 2015), the information about the configuration is especially important (Lindkvist, Stasis, and Whyte 2013). The lack of systematic management of configuration information in Swedish healthcare projects can cause problems with insufficient building performance. The survey results are not directly generalisable to other project contexts. However, the conceptual model is generalisable, since the basis is international guidelines and research on configuration information. A shift towards more focus on configuration control in construction projects can ensure development, production and delivery of high performance buildings. Digital building information and automated processes offer new possibilities to manage configuration information systematically (Ding et al. 2017). The proposed model shows that configuration information needs to be interrelated and flow between the construction phases (see Figure 6). Therefore, any deficiency or insufficient interrelation of information between the key areas of configuration information may impair the building performance.

Conclusions

In the context of construction projects, the findings show deficiencies in configuration information for each key areas of the proposed model. However, most noticeable was the lack of systematic management of the information. The results of this study indicate that the application of configuration information in accordance with the proposed model can solve several issues that construction projects encounter. In addition, to reach the full potential of digital information and automated production techniques, the AEC industry will have to manage configuration information more systematically. The knowledge from this study can serve as a basis for further investigations regarding the application of configuration information in construction projects.

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