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Potential of automated configuration control to reduce hospital building deficiencies

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Abstract

The configuration of healthcare buildings is complex, especially emergency hospitals that require many functions. In this study, the aim was to explore if automated configuration control can reduce occurrences of hospital deficiencies in construction projects. A bow-tie risk analysis identified the causes and consequences of configuration deficiencies. Measures to prevent and recover from deficiencies were established from configuration management research. Three newly built emergency hospitals were studied to investigate to what extent causes, consequences, preventive and recovery measures were present. The most common causes of deficiencies were deviations from intended configurations, in the literature and the cases. The consequences were cost increase, time delays, insufficient deliveries and corrective rework. None of the examined cases had implemented preventive or recovery measures associated with configuration control. Altogether, these results indicate that automation of configuration control may effectively reduce hospital building deficiencies and subsequent effects.

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Keywords: Information management; Configuration management; Automation; Digital transformation; Healthcare buildings.

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1. Introduction

Compared to other industries, the digitalisation of the Architecture, Engineering, Construction and Operation (AECO) sector is slow. Standardisation and sequential work processes make it difficult to exchange data and information for analyses [1]. The basis for decisions is implicit knowledge rather than information derived from data analyses [2]. Configurations of hospital buildings are complex and automated control with digital techniques could reduce the risk of deficiencies. This study explores the causes and consequences of configuration deficiencies from construction project research and preventive and recovery measures from configuration management studies. The result was summarised in a bow-tie risk analysis describing the relationships between causes, prevention, recovery and consequences. In addition, the presence of configuration control measures found in the literature review was explored in three newly built emergency hospital projects.

1.1. Hospital buildings

There are many types of healthcare facilities and hospital buildings are one of the more complex, containing different units. The focus of this study is configurations of emergency hospitals that provide around the clock service and contain high-tech equipment for patient diagnosis, treatment and care. This places specific demands on the configuration of hospital buildings to ensure optimal functionality. Deficiencies in hospital buildings are therefore not uncommon [3]. There are few construction standards specifically for healthcare buildings. Instead, applications and adaptations are made based on general standards for buildings. Configurations based on digital data analysis from similar facilities may reduce deficiencies and create standards by evaluating buildings through their lifecycle [4].

1.2. Automated configuration control

Configuration management aims to establish and maintain intended functions throughout a product's life cycle. These functions are described in the baseline configuration that should be the basis for the choice of design solutions and implementation methods. Any changes to the baseline configuration should be investigated to ensure that the intended functionality is still achieved [5]. Changes from the baseline should be analysed and the client decides on implementation or not. Accepted changes are included in the baseline configuration [6]. Digital techniques for data collection and analyses can enable automated control of configurations during construction projects. Standards may be developed with digital tools analysing and learning from a large amount of data from similar configurations [7]. The use of sensors, mobile scanners and online cameras provide data that can be analysed to automate the verification of baseline functions in real time [8]. In the event of any deviations, stakeholders can immediately be informed. The AECO industry is changing due to automated processes and construction techniques, making control over configurations imperative. The use of robots [1] or prefabrication [9] will require predefined configurations to enable optimal implementation. Emergency hospital configurations should enable many functions. For example, concrete structures that withstand heavy equipment loads, reduce vibrations and shield radiation. Manual management of these complex and sometimes conflicting functionalities are difficult. Therefore, automated analysis of hospital building data enabling informed decisions may be especially beneficial.

1.3. Implications of insufficient configuration control

Configuration decisions affect healthcare building performance, which may have implications for patients' treatment, diagnosis and care [3]. Evidence based design aims to ensure the functionality of healthcare facilities. However, building configurations, feasibility and implementation issues are seldom considered, resulting in functional deviations during the project implementation [10]. Studies concerning consequences of insufficient configuration control often focus on outcomes, i.e. cost and time. Less explored are the relationship between configuration control and deviation from intended functions [11]. Several of the United Nations Sustainable Development Goals (SDG) are connected to the functionality and configuration of healthcare facilities [12]. Sustainable cities should provide healthcare services to citizens, which require functional facilities (SDG 3 and 11). Hospitals with round-the-clock activities are large consumers of energy and water (SDG 7 and 9), which require consideration. Purification of wastewater is important to prevent pharmaceutical residues, contagious pathogens, chemicals and biological tissues from affecting water quality and marine life (SDG 6 and 14). The AECO industry is a large consumer of natural resources and accounts for emissions [13, 14]. Configuration control has the potential to optimise hospital functionality and avoid deficiencies [15], which reduces unnecessary rework. Consequently, decreasing resource consumption and environmental impact (SDG 12) [16].

2. Objective and methods

The objective of this study was to explore if automated configuration control may reduce the risk for hospital deficiencies at the delivery of construction projects. Bow-tie risk analysis starts with an event from which causes and consequences are derived [17]. A fault tree represents a reverse analysis of causes and preventive measures based on an event, while an event tree describes consequences and recovery measures of the same. A literature review based on construction research identified the causes and consequences of configuration deficiencies. From configuration management research, preventive and recovery measures for deficiencies were identified, as shown in Figure 1. The case study consisted of three newly built emergency hospitals in Sweden in which the presence of causes, prevention, recovery and consequences was studied.

1. What are the causes and consequences of hospital building deficiencies in construction projects?
2. How can configuration information contribute to the prevention and recovery of hospital building deficiencies in construction projects?

2.1. Literature review

The Elsevier Scopus database was used to search for articles from 2016 onwards with the search criteria shown in Figure 1. Causes and consequences were derived from construction project research, while prevention and recovery measures were explored in configuration management studies. Among the findings from the search, manual assessment of abstracts, results and discussion identified the most relevant regarding deficiencies and configurations. Among the initially found articles concerning construction projects, studies not concerning buildings were excluded. For configuration management, the studies excluded were not addressing deficiencies of products. Manual assessment of the texts identified evidence regarding causes, prevention, recovery and consequences connected to configuration deficiencies.

2.2. Bow-tie analysis

The purpose of a bow-tie diagram is to identify and evaluate risks and control barriers, using fault and an event analysis [17]. The fault analysis investigates the causes of an event and preventive measures form a barrier against its occurrence [18]. Event analysis starts with an event that has occurred from which consequences are derived. Recovery measures mitigate the effects of the event [17]. Data from the cases enabled quantification with numbers or probability in percent of causes and consequences. The preventive and recovery measures that constitute the barriers against deficiencies were qualitatively assessed due to a lack of quantitative data. This precluded the possibility to explore dependencies other than on a conceptual level based on the included articles.

2.3. Case study

The cases consisted of three newly built emergency hospitals, whose background information is shown in Table 1. There were units in the buildings associated with different kinds of around the clock services, such as emergency admittance rooms, intensive care, operating theatres and medical imaging. Causes, prevention, recovery, and consequences were studied in the project documentation, mainly consisting of Microsoft Excel and Word files. Internal database systems used in the project organisations were the source for the economic data from the cases. Despite access to digital building data, it was not used in practice to provide information regarding causes, prevention, recovery or consequences.

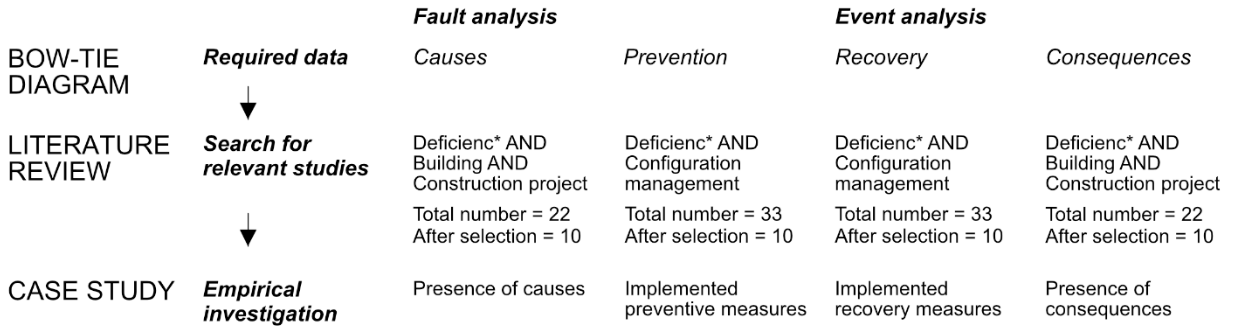

Fig. 1. Overall research design.

3. Results

Deviations from the initial scope were the most common cause for configuration deficiencies in construction project research. Measures to prevent deficiencies from configuration management research were the standardisation of functions, solutions and realisation methods. Consequences of the deficiencies were cost increase, time delay, inadequate deliveries and corrective rework. Recovery of these in configuration management is achieved by establishing a baseline configuration containing all required functions with acceptance values, which are thereafter verified through the implementation.

3.1. Bow-tie diagram

The literature review identified deviations from the intended end-product as a frequently cited cause of configuration deficiencies (see Table 2). Other main findings of the review were the standardisation of functions to avoid deviations and the consequences on cost and time. The case data shows that deviations and deficiencies are connected to decreased areas and corrective rework (see Figure 2). However, few studies in the literature review identified a clear relation between deviations and inadequate deliveries Construction research refers to standard designs and procedures, but the connection to fulfilling functions is missing [2]. The consequences of deviations found in the literature were also present in the case. Not all of these may be due to deficiencies, but rework to correct inadequate functions was related to increased costs and time duration (see Table 3). In configuration management, a prerequisite for fulfilling functions is establishing and maintaining a baseline configuration [17]. There was no mention of establishing a baseline configuration in the construction project research. The deviations were related to the initial agreements with the client rather than from baseline with acceptance values. Vaguely defined functions with no acceptance values were common in the cases. For example, “facilities that allow for vibration sensitive equipment”. This requirement was the same in all cases but was differently interpreted. Upon delivery, only one of the cases met the vibration isolation requirements from the manufacturers of the equipment that were to be installed. In summary, the cases' causes and consequences were consistent with the results from the construction project research. Prevention and recovery measures to avoid deficiencies in configurations found in the included articles were not practised in any of the cases.

Table 1. Background information about the cases.

Case	Finish year	Area (square meters)	Initial budget (million euro)	Units
1	2019	28 700	138	Emergency room, Floor for technical installations, Intensive care, Intervention treatment, Medical imaging, Operating theatres and Sterilisation
2	2019	28 600	143	Floor for technical installations, Intervention treatment, Medical imaging, Operating theatres, Personnel cloth changing rooms and Sterilisation
3	2017	18 700	111	Childbirth and maternity ward, Emergency room, Floor for technical installations, Intensive care, Open care receptions, Operating theatres and Sterilisation

Table 2. The results of literature review.

Area			References	Number of articles
Causes	Deviation from initial configuration		[19-28]	10
Prevention	Standardise	function	[29-38]	10
		solution	[29, 32, 33, 35-38]	7
		realisation method	[30-38]	9
Recovery	Baseline functions with acceptance values		[29, 31-35]	6
	Fulfil acceptance values		[29-33, 35-38]	9
	Verify acceptance values		[29, 31, 32, 34, 36-38]	7
Consequences	Cost increase		[19-28]	10
	Time delay		[19-28]	10
	Inadequate delivery		[21, 22, 24, 26]	4
	Corrective rework		[19, 22, 25-28]	6

3.2. Fault analysis

Both the literature review and the case study showed that deviations from the initial scope cause configuration deficiencies. Figure 2 shows there were 2360 deviations from the initial scope in the cases and 152 shall requirements were unfulfilled. This increases the risk for functional deficiencies that may impair daily operations and affect patient care. Standardisation of functions, solutions and realisation methods were the most common preventive measures in the included configuration management studies, as shown in Table 2. Development and establishment of standards were considered an important part of configuration management to ensure quality and efficiency during planning, design and production. Methods for developing the standards were testing, assessment and prioritisation of functions. In the cases, there were standards for building constructions, national as well as international. However, there were no configuration standards connected to the fulfilment of functions.

3.3. Event analysis

The consequences of construction projects' deficiencies from the literature review included time delay, cost, rework and inadequate deliveries, as shown in Table 2. In the cases, all of the consequences were present (see Figure 2). Cost increased by 20% simultaneously as the delivered area decreased by 9%, which reduced the value creation of the investment. Rework to correct inadequate functions constituted 44% of the total cost increase. The time delay was the significantly most mentioned consequence in the included articles. The cases were delayed by an average of 14 months, which had implications for daily healthcare operations. Table 3 shows the causes and consequences for each case.

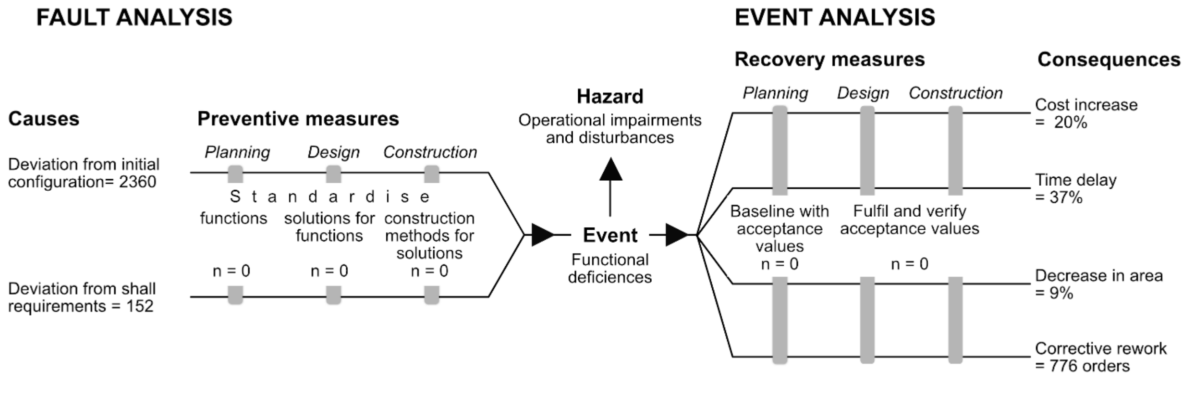

Fig. 2. Results from the literature review and case study combined in a bow-tie diagram.

Table 3. Summary of causes and consequences for the cases.

		Case 1	Case 2	Case 3
Causes	Deviation from initial configuration (number)	959	1012	389
	Deviation from shall requirements (number)	38	57	57
Consequences	Cost increase (million euro)	48	22	8
	Time delay (months)	24	9	9
	Decrease in area (square meters)	1 923	1 576	3 642
	Rework orders (numbers)	463	120	193

4. Discussion

This study aimed to explore causes, prevention, recovery and consequences of deficiencies in hospital building configurations. Previous studies on these subjects were reviewed to find evidence from these four areas. In addition, a case study investigated the presence of these in three Swedish newly built emergency hospitals. Causes and consequences were similar in construction project studies and the investigated cases. The preventive and recovery measures found in configuration management research were not implemented in the cases. Even though there can be no direct conclusions that this was a contributing factor for configuration deficiencies, the rework orders suggest a connection. These were established to correct deficient functions and contributed to cost and time increase. Rework and reduced delivered area was consequences connected to deviations in the cases (see Figure 2). However, the literature review did not frequently assess inadequate delivery to be a consequence of deviations (see Table 2). In the cases, the reduced delivery area and cost increase significantly reduced the value of the client's investment. Emergency hospitals require many complex functions and if these are not explicitly defined, the risk of deviations increases with deficiencies as a consequence [3]. A baseline configuration increases the control and makes continuous verification possible [6]. Connecting standardised functions to solutions and construction methods can further contribute to reducing the risk of deviations. This study was limited to establishing a conceptual connection between configuration management and hospital configurations. However, the results show that automated control of configurations using digital technologies has the potential to reduce risks for deficiencies. This will require the establishment of input data and the implementation of analyses to enable informed decisions about hospital configurations. The main funding of hospital construction projects in Sweden is public and reducing the risks for deficiencies may release funds for core activities, such as healthcare services.

5. Conclusions

Automated configuration control may potentially reduce deficiencies in hospital buildings by ensuring building functionality and reduce corrective rework. Thus, avoiding negative impact on outcomes and facilitate sustainable development. None of the cases had established a baseline configuration with acceptance values, decreasing the possibility of verifying and ensuring deliveries with fewer deficiencies. A first step towards automating configuration control is to use digital techniques to analyse data from building models, such as tools to compare models from different points in time to identify deviations, evaluate the impact of changes and enable informed decisions. Although the examined cases had access to building data and digital tools, they used analogue documents as a basis for their decisions. That can be one explanation for the lack of clear connections between function, solution and construction methods resulting in impaired control of the hospital configurations (see Figure 2). Together with the extensive consequences to cost, time and delivery, this indicates that automated configuration control has the potential to improve several areas. Additional research is required to establish connections between configuration control and hospital building deficiencies. One possible area for exploration is how digital tools may be used to automate the detection of deviations, enabling prevention or early recovery measures.

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