The modern way of performing construction management responsibilities

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Abstract. Digital technologies are becoming increasingly wide-spread both in our personal and in our professional lives. This change has been evident also in the construction industry, although the industry has been identified as one of the least digitalised industry sectors. This research investigates how various digital technologies have become and are becoming part of construction management responsibilities. Construction management responsibilities have been identified through a document analysis as eight responsibility groups including management of time, cost, quality, health and safety, environmental factors, resources, and contracts, and development of human resources and processes. Construction management related digital technologies on the other hand have been identified through a document analysis and a systematic literature review and categorised under communication and other enabling technologies, technologies combining hardware and software in intelligent systems, and data technologies. The way how the construction management responsibilities and the digital technologies interlink forms a description of the modern way of performing construction management responsibilities. Some of the technologies are in everyday use across construction management professionals, however, many are at their pilot stage offering a perspective not just to the present but to the near future for the whole discipline.

1. Introduction

The number of digital technologies in our everyday lives is rapidly increasing. We are surrounded by computers not just on our desks, but in our pockets, on our wrists, in vehicles, shops and buildings that we use. Mobile phone wakes us up in the morning and it is many times the last thing we look at before we go to sleep. Digital devices might be with us even when we sleep, on our wrists, monitoring our sleeping patterns. Digital technologies are adjusting our environment (adjusting temperature, air flow/air conditioning) or even influencing our behaviour (warning of a sudden change in heartbeat or when driving too close to another car).

Although the AEC industry has been reported to be one of the least digitalised industry sectors [1] many digital technologies are already in wide use in the industry and many more are at a prototype stage [2][3]. Desktop computers, laptops and mobile phones are the most common digital technologies that we use and are heavily dependent on. Drones and laser scanners can be seen on construction sites. Robotics have been used in manufacturing for decades and now they are entering the construction sites as well. Sensors are collecting data and intelligent systems are being utilised to make sense of our surroundings and large datasets. Digital technologies are changing how we do our work, and this change is constant [4].

The context of this research is construction management. Definitions of construction management vary from narrowly focused such as Fryer *et al.* [5] who defined construction management as planning, organising, directing and controlling tasks on a construction project to extensive such as the Chartered Institute of Building [6] definition, which encompasses the management of the

development, conservation, and improvement of the built environment in society as a whole. For this study a definition developed at an earlier stage of the research has been used: "Construction management addresses the forecasting and planning, organising, communicating, coordinating, monitoring, and controlling functions required to manage time, cost, quality, health and safety, security and environmental aspects of a construction project" [4 p9].

The aim of this research was to understand how construction management responsibilities and digital technologies interlink. The responsibilities are looked at from the construction management professionals' perspective. The connections between the two are investigated to understand how they form the modern way of performing construction management responsibilities.

2. Literature review

2.1. Construction management responsibilities

Responsibility can be defined in many ways. Terms such as accountability, answerability, causality, liability and duties have been linked with the term, some arguing on the differences [7][8] and some seeing many of them as synonyms [9][10]. In this research, responsibility is seen through the role and tasks of construction management professionals. McGrath and Whitty's [11] definition of responsibility, "an obligation to satisfactorily perform a task" (p9) has been adopted.

There are many studies discussing a specific construction management role and the responsibilities in the role. Gluch [12] discussed the role of environmental professionals, Aulin and Capone [13] the role of health and safety coordinators, and Cameron *et al.* [14] the role of the safety advisor to name a few. There are also studies, such as Hussin and Omran [15] and Arditi and Alavipour [16], which discuss construction management responsibilities wider, however, not from the perspective of the professionals rather from the legal and company perspective.

2.2. Types and categories of digital technologies in construction management

The term 'digital technologies' has been defined at an earlier stage of this research as "Digital technologies include all types of electronic equipment and applications that produce, store or use information in the form of numeric code" [4 p2]. The nature of digital technologies is complex ranging from simple components to very complex systems. Most digital technologies are a combination of digital technologies, the software cannot be used without appropriate hardware and in general vice versa, and digital technologies sit at different levels where some digital technologies are general and enabling in nature and some more specific [4].

Examples of digital technologies in construction management extend from basic computers and office software applications to construction specific applications such as BIM, extended reality (ER), and other advanced applications such as digital fabrication and digital twins to name a few. BIM has been discussed by many authors from a wide variety of angles including project stages [17] and role specific views [18], project objectives such as quality [19], risk management [20] [21], and from educational and competence perspectives [22] [23] [24]. Augmented reality (AR), virtual reality (VR) and mixed reality (MR) have attracted the attention of many authors [25] [26]. Digital fabrication is being used for pre-fabrication widely and its subset additive manufacturing to create everything from small components to whole buildings [27]. Digital twins is a newer concept and more focused on buildings in use, but there are applications and uses that need to be considered during construction such as creating the as-built model and installation of the sensors [28]. Digital twins can be used as an example of the complexity of digital technologies. When creating the as-built model for the digital twin, various technologies such as digital imaging and generative design might be used. Intelligent systems within the digital twin might include sensor technology, internet of things (IoT), machine learning and computer vision. IoT can be further broken down to other digital technologies (Figure 1).

Many classifications of information and communication technology (ICT) and digital technologies exist for various purposes. Hamelink [29], in his discussion paper on the connection of ICT technologies, social development and cultural change, sub-divided ICT to five technology classes: capturing, storage, processing, communications and display technologies. Fifteen years later Ibem and Laryea [30], in their research on digital technologies in the procurement of construction projects,

expanded this classification to include also integration and collaborative technologies, and further developed a construction procurement specific classification with data acquisition, data processing and storage, communication, and intelligent systems as the categories. van Heddeghem *et al.* [31] categorized ICT by the main hardware to communication networks, personal computers and data centers, when investigating trends in worldwide ICT electricity consumption. Pagoropoulos *et al.* [32] as well used only three groups, data collection, data analysis and data integration, calling them the architectural layers of digital technologies. Pousttchi *et al.* [33] proposed communication and other enabling technologies, technologies combining hardware and software in intelligent systems, and data technologies as three major areas of technology when investigating digital transformation in companies.

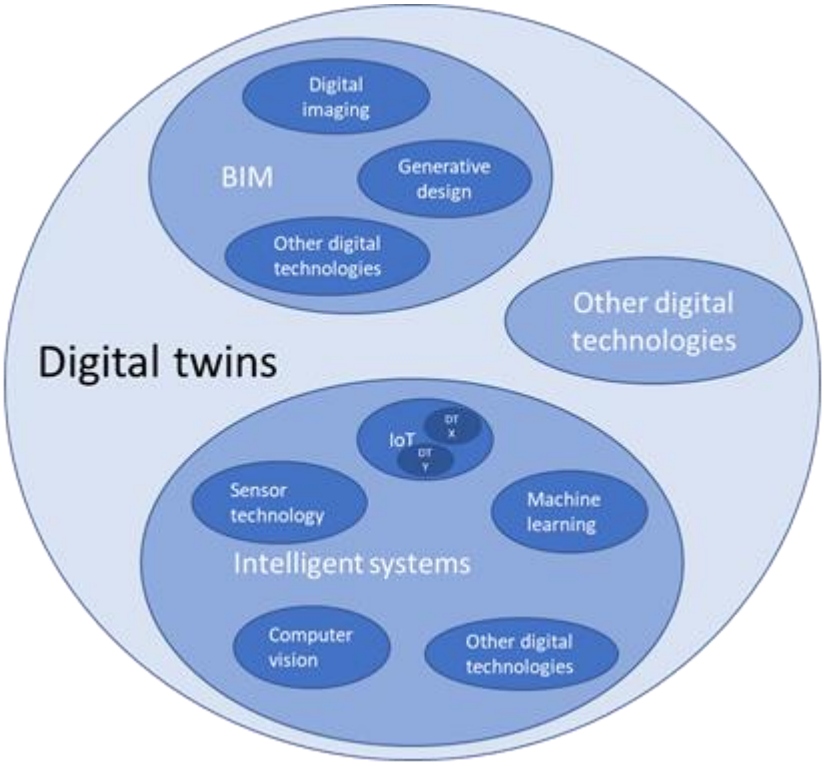

Figure 1. Digital twins technology as an example of the complexity of digital technologies

3. Research methodology

This investigation is part of an ongoing research on digital technologies in construction management. In earlier parts, the concepts of 'digital technologies' and 'construction management' have been defined. What digital technologies mean in the construction context and what the pace of change has been in the use of digital technologies have been investigated.

The aim of this part of the research was to understand how construction management responsibilities and digital technologies interlink. Two research questions were used to assist in achieving the aim:

1. What are the responsibilities of construction management professionals?
2. What are the construction management specific digital technologies?

The responsibilities and digital technologies were looked at specifically from the main contractors' point of view in building construction.

Document analysis using job advertisements as data was found to be a suitable method to answer the first research question as data was required across a wide range of construction management roles. This width of data would have been challenging to capture via other methods. Job advertisements as data are most commonly used to study competence requirements of roles, however, many examples

exist where they have been used to identify the role responsibilities. Hussain *et al.* [34] looked at the tasks and responsibilities related to Global software engineering, Meier [35] studied science and technology librarians' responsibilities, and Miller and Horan [36] identified 25 types of responsibilities in information preservation roles. When using job advertisements as data, one needs to understand that they are not necessarily an exact reflection of the responsibilities in practice [37]. There might be other drivers behind them such as company image and they might reflect the reality as perceived by the hiring manager and the recruiter. However, objectivity is managed well in document analysis, as the researcher is not inadvertently influencing the collected data [38] as is the case with surveys and focus groups. Ten large building construction companies from the UK and the USA were selected, to capture two somewhat different markets and a wide selection of roles. The final sample included 231 job advertisements with nearly 5000 references to construction management responsibilities. Content analysis was used to confirm if the adopted definition of construction management represented the responsibilities correctly and to understand the responsibilities more in detail.

It was originally thought that the job advertisements would contain enough information also regarding construction management specific and advanced digital technologies and their connection to the construction management responsibilities to answer the second research question and address the main aim of the research as well. However, this was not the case, and another research method needed to be deployed. At an earlier stage of the study in 2018, a systematic literature review had been completed to collect longitudinal data to understand what digital technologies mean in the construction context, and to understand what the pace of change had been in the use of digital technologies in construction [39]. The reason for using a systematic literature review as the method was the underlying premise that the discussion in the literature reflects the developments in the industry including also prototype and pilot stage experiments. This type of data was found to be useful in complementing the job advertisement data. The data collection completed in 2018 was extended until July 2021 to capture the most recent literature on digital technologies in construction management using the same journal selection as in the earlier study in 2018. The search criteria were changed to focus more specifically on construction management as defined by Puolitaival *et al*. [4]. The journal selection and the search criteria are explained further in Puolitaival *et al.* [39]. 95 articles mentioning 'digital technologies' in the title, keywords, abstract or subject of the article were identified by the search. When reading the articles through, it was noticed that some were general discussions i.e. not reporting on any specific use of digital technology and some were not focused on construction management in building construction, rather the focus was on the design or facilities management, or infrastructure construction. The final sample included 44 articles, six of these were literature reviews offering a view on many more articles discussing digital technologies.

To achieve the research aim, the job advertisements and the literature investigated was looked at in terms of how digital technologies had been connected in them with the responsibilities of construction management professionals.

4. Findings and discussion

4.1. Construction management responsibilities

In the content analysis, the construction management responsibilities from the job advertisements were mapped initially under six management objects according to the adopted definition of construction management. These were time, cost, quality, health and safety, security and environmental aspects. The analysis revealed, however, that the construction management responsibilities actually were about managing time, cost, quality, health and safety, environment, resources and contracts, and development of human resources and processes. These were used as construction management responsibility groups to be connected with the digital technologies.

4.2. Digital technologies

Comparing the systematic literature reviews from 2018 and 2021, blockchain was the only new digital technology introduced since 2018. Blockchain technology in construction is still in its infancy and the

related studies are fairly recent [40]. Autonomous and unmanned vehicles, construction equipment and robotics, blockchain, BIM, various collaboration and communication technology, digital fabrication, digital imaging, digital twins, extended reality (ER), gaming, intelligent systems, location and positioning technology, project management software, sensor technology and IoT, and wearable technology were among the digital technologies mentioned in the literature. Zabidin et al. [41] argued that the industry has adopted "BIM as construction's version of Industry 4.0" (p304). This was evident in this literature sample as well with BIM being the mostly discussed digital technology as a standalone technology, but also as connected to other digital technologies such as digital imaging, ER, location and positioning technology, and sensor technology.

In the job advertisement data, digital technologies were mentioned with specific digital technology related roles such as BIM manager or BIM coordinator, and as required competences. Excluding the specific digital technology roles, the digital technology competences were rather generic such as "demonstrated computer skills and experience with Microsoft Office suite programs" (Safety manager, USA), "excellent IT skills, particularly MS Excel" (Senior cost consultant, UK) or just "good IT skills" (Site manager, UK), instead of mentioning construction specific digital technologies. In addition to the generic digital technologies, some construction specific software applications were mentioned in the job advertisements. Most often these were project management applications such as Asta Powerproject, MS Project and Primavera. BIM applications mentioned included Navisworks, Revit and Tekla. The only hardware mentioned was digital field tools. When the literature discussed construction management specific and mostly just advanced digital technologies, the view in the job advertisements was more conventional with the exception of BIM related applications. This aligns with the literature stating that there are considerable challenges in the adoption of advanced digital technologies and the adoption is low in the construction industry [3][42].

As discussed earlier, the nature of digital technologies is a complex one. Due to these complexities, classification of digital technologies into mutually exclusive categories is challenging. This is necessary, however, for a better understanding of the connections between digital technologies and construction management responsibilities. Pousttchi et al. [33] categorisation; communication and other enabling technologies, technologies combining hardware and software in intelligent systems, and data technologies, was found to be suitably accommodating for the purposes of this study. Table 1 introduces examples of digital technologies from the data under the three categories.

4.3. Interlinks between construction management and digital technologies

In the job advertisements, there were no digital technologies tied directly to the construction management responsibilities with the exception of the specific digital technology roles, however, some software applications were mentioned as competence requirements. The responsibilities listed under the roles in the job advertisements, and the fact, that the software applications mentioned were applicable only for a limited range of responsibilities, made it possible however to connect the applications with the construction management responsibility groups although these connections were not explicit in the job advertisements. The job advertisements indicate that project management applications are used to manage time, cost and contracts. In addition, BIM is used to manage time, cost, quality, health and safety, and resources. Under the specific digital technology roles, the connections were explicit. BIM was used across a variety of responsibilities: managing time, cost, quality, safety, resources, and contracts.

As the findings from the job advertisements were limited to project management software applications and BIM, the literature offered more information to form an understanding what the modern way of performing construction management responsibilities is. All the responsibility groups other than environmental management were represented in the literature reviewed. Digital technologies to manage environment has been reported with design related responsibilities [43][44], but it was not included in the construction management focused sample. Table 1 presents the construction management responsibility groups and the main digital technology categories including some examples of specific digital technologies in the intersections of the two.

Table 1. Examples of digital technologies from the data mapped under the construction management responsibility groups and the main digital technology categories

	Time management	Cost management	Quality management	H&S management	Environmental management	Resource management	Contract management	Development of human resources and processes
Communication and other enabling technologies	BIM	BIM	BIM, Mobile communication	BIM		BIM, RFID	BIM	
Technologies combining hardware and software in intelligent systems	AR, Autonomous vehicles and equipment, Digital twins	Autonomous vehicles and equipment, Digital twins	AR	Drones, IoT VR, Wearable technology		Digital twins, IoT		Gaming, VR
Data technologies	IoT, Project management applications	Blockchain, Project management applications	Blockchain, Machine learning	IoT		Blockchain, Machine learning	Blockchain, Project management applications	

Discussion on autonomous vehicles and equipment in construction management included management of time and cost by automating assembly and complex tasks on construction sites (Cheng and Chen 2002 as cited in [45]) and the use of drone technology for safety inspections (Irizarry *et al.* 2012 as cited in [46]). Blockchain technology was used for automated contract payments and quality management [40], and for organising and hiring construction workers in project-based networks [47]. As an example of collaboration and communication technology for quality management, a real-time sharing method between the construction site and the office was introduced by Dong *et al.* [48]. Time, cost and quality were managed using various digital imaging applications for inspections [49] and tracking as-built, and as-designed and as-planned deviations (Omar *et al.* 2018 and Akhavian, and Behzadan 2015 as cited in [45]). Greif *et al.* (2020 as cited in [50]). proposed smart mobile warehouses as an application of the digital twin concept to manage material resources and save cost. There were multiple examples of ER in the sample from time management using AR glasses to compare as-planned and as-built [51] safety management using VR to detect safety hazards (Sacks *et al.* 2015 as cited in [46]). Gaming was applied to the training of construction workers (Dzeng *et al.* 2015 and Mohd *et al.* 2019 as cited in [46]). Computer vision and machine learning were used as forms of intelligent systems for quality management [52][53] and also to manage resources by tracking construction equipment [54]. Location and positioning applications overlapped considerably with sensor technology and IoT, a typical example being resource management using RFID tags to track equipment and material (Wang *et al.* 2017 as cited in [55]). Wearable technology included ER equipment, sensor technology and IoT and location and positioning technology for safety management (Omar and Ballal 2009 and Awolusi *et al.* 2018 as cited in [45]).

5. Conclusions and further research

The aim of this research was to understand how construction management responsibilities and digital technologies interlink to form the modern way of performing construction management responsibilities. Construction management responsibilities were identified through document analysis. Both a document analysis and a systematic literature review were used to identify the digital technologies and then the links between the responsibilities and the technologies. The job advertisements sample paints a picture of the industry where the majority of construction management professionals use only basic digital technologies such as traditional project management and basic office software applications. Although the use of advanced digital technologies is still in its infancy in many ways in construction management, several case studies are presented in the literature about digital technology implementation pilots. BIM is already used wider in the industry, and it seems that in many cases BIM works as a conduit to the use of other advanced digital technologies.

All research methods have their limitations. The limitations of the job advertisements as data are discussed in the Research methodology chapter. We believe that the method and the data type are suitable for capturing objectively a wide range of construction management roles and responsibilities.

The systematic literature review on the other hand is not necessarily able to capture all relevant articles needed to form an understanding of the digital technologies when performing construction management responsibilities. Therefore, an investigation is needed firstly, to target environmental management as a construction management responsibility, as it was not found in the sample, and secondly, to find out if some of the identified digital technologies cover a wider range of construction management responsibilities than what was found in the sample. This is completed in the next stages of the research with an additional literature review, but more importantly by interviewing construction management professionals to capture their understanding of the responsibilities, digital technologies and their connection in practice.

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