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Review

Digitisation in facilities management: A literature review and future research directions

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ABSTRACT

Research into digital technology (DT) in construction practices has gained widespread attention. While the application of different DTs in facility management (FM) has been growing, to date, there is no holistic review of the various DT developments and research into FM. A total of 120 academic journal papers, conference proceedings and other technical notes published on the subject, mainly between 2004 and 2017, were reviewed in this paper. The applications of various major DTs, including 1) building information modelling (BIM), 2) reality capture technology (including 3D laser scanning, point cloud), 3) the Internet of Things (IoT) (including radio frequency identification (RFID) and sensor network technologies) and 4) geographic information system (GIS), were reviewed and scrutinised. The review identified a number of possibilities for future research into DT in FM, including, enhancing the interoperability of data, improving the accuracy of point cloud data for developing as-built models for existing facilities, and generating effective BIM/GIS asset database integration. It is hoped that this review and the future directions highlighted in this paper will assist researchers in identifying the areas where further research efforts are most required and in identifying which future directions would be most helpful for digital FM research.

1. Introduction

The advancement of digital technology (DT) has had a profound impact on the way many traditional industries perform their daily functions. Easy access to information and acceleration of the pace of communication has revolutionised most knowledge-based industries, including the construction sector. While advances in computer-aided design (CAD) software and building information modelling (BIM) have progressively changed traditional design practices and communication methods, a recent study in the United States argued that the architecture, engineering and construction (AEC) sector stands accused of a slow rate of digitisation, specifically in terms of building digital assets, expanding digital usage, and creating a highly digital workforce, as compared to many other manufacturing industries [55,112]. This need for digitalisation of the AEC sector at a faster pace has been acknowledged by both researchers and practitioners (e.g. [14,111,132,142]). There are many studies on the application of DT with the aim of promoting and transferring digitisation to design and construction stages (for a detailed review of the application of DTs in construction safety see [161]), the use of radio frequency identification (RFID) in construction [149] and the use of BIM in construction processes [17]. However, relatively less research has been performed to review the application of DTs in the operation and maintenance (O&M) stage of the building life cycle. Renovation, retrofitting and refurbishment are important components of facility management (FM), and there has been even less research and implementation in this area, compared to the design and construction stages [144].

Interest in adopting DT in FM has grown over the past few years and many governments (e.g. Australia, UK) have highlighted the need to revolutionise the FM sector by increasing adoption of DTs [144]. Recently, there has been a growing number of studies into the potential applications of BIM (e.g. [4,21,22,38,126,127,151,154,157]) as well as the use of other DT applications in FM, for example, reality capture technology (e.g. 3D laser scanning, point cloud), the Internet of Things (IoT) (e.g. RFID and sensor network technologies) and geographic information system (GIS). BIM is a computer product developed to create, share, exchange and manage information between all stakeholders throughout the building lifecycle [73]. Reality capture technology involves the use of photogrammetry and 3D laser scanning to acquire accurate geometrical/spatial information and generate point cloud data for the establishment of a digital model of existing facilities (e.g. [18,152]). The IoT allows for rapid collection, transmission and

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exchange of data using embedded sensors and wireless technologies [74,118]. Among the enabling technologies in the IoT, RFID and sensor network technologies are considered two of most fast-growing information and communication technologies [62]. RFID consists of four basic components, including a tag, a reader (antenna), software and a computer network [96]. GIS helps to comprehend and visualise data in many ways so as to expose the relationships and forms of maps, globes, reports and charts [133].

With increasing industry interest, a systematic review of the current status, and description of a future research agenda, of digital applications in FM is needed. A comprehensive overview of the existing literature will help to delineate the key problems for creating disciplinary connections, in consideration of the current DT advancements in the FM discipline. Such a study would also provide insight into where more detailed research is required, thereby providing future research directions for enabling DT in FM. The aims of the current study were: 1) to give an overview of the main research efforts on DT that apply to improving the FM process for buildings and infrastructure; and 2) to identify gaps in the research and introduce a roadmap for further research on digital FM.

2. Digital technology (DT) and facilities management (FM)

DT is considered the division of 'scientific or engineering knowledge that deals with the establishment and application of computerised or digital devices, methods, systems etc.', which can improve the immediacy, accuracy and flexibility of communication [43]. Technological advancement has not only transformed the daily life of many people, but has also changed many traditional industry practices; for example, large corporates in the automotive (e.g. BMW, Bosch) and aerospace industry (e.g. Boeing) have been digitalised to improve operations, increase revenue and drive (R&D) innovation. According to the McKinsey Report [112], the global construction industry is the least digitalised and technologically innovated of all industries. The investment spent on R&D is less than 1% of revenue in general, which is much less than other sectors, e.g. the automotive and aerospace sectors in which 3.5–4.5% of the revenue is spent on R&D. The construction and building sector has not yet embraced new DTs, has remained uncoordinated between the office and the site, and paper is often still used to manage the processes and deliverables, such as design drawings and daily management [2].

The operation and maintenance stages account for the largest proportion of whole life costs of the building process. The costs of operations and maintenance represent 50–70% of the total annual facility operating costs [134] and 85% of the entire lifecycle costs are spent on FM [147]. Maintenance management and energy consumption are two important aspects for daily management of properties [99]. Building maintenance decisions require the analysis and integration of different types of information and knowledge, such as maintenance records, work orders, causes and knock-on effects of failures, etc. generated by different stakeholders in the project team [121]. Ineffective decisions can be made and significant costs incurred if the information/knowledge from project team members is not captured. A well-integrated data system is becoming important for FM companies to manage the huge amount of staff and facilities data, and to accommodate the constant changes occurring in the facility [136]. The management systems in many facilities are separate and independent of one another, which means FM is relying heavily on numerous different and incompatible systems to manage building maintenance, asset value management, etc. The diversity in software tools and interoperability issues remain a challenge in the adoption of DTs in the FM sector [22]. Data (or information) from various FM processes are often organised and managed in various dispersed information systems including *Computerized Maintenance Management System* (CMMS) and *Computer-Aided Facility Management* (CAFM). While both CMMS and CAFM help manage and record a database of daily maintenance operations (e.g. asset management, inventory control, service request generation, work order management) from an organisation, CAFM provides extra functions like reactive maintenance and planned preventative maintenance management, space and move management, resource scheduling, etc. [34]. A wide variety of commercial software applications, including ARCHIBUS [12], BIM 360 Ops/BIM 360 Field [16], EcoDomus [48], Onuma [124], QFM Facilities Management Software [139] and IBM TRIRIGA [70], are available on the market to meet the requirements of FM. Many of these applications share similar asset and maintenance management functions, but most current FM software fails to encompass the diversity of all requirements of FM [34,136]. The current FM systems fail to capture and retrieve detailed information and knowledge generated from building maintenance or operations, including causes of failure, reasons for selecting specific methods of maintenance, selection of specialist contractors, and ripple effects on the other building elements [121]. A supportive data management system for building maintenance, which can support and integrate data and information generated by project team members, can have a significant impact on building performance. The potential for extending the application of major DTs, such as BIM, reality capture technology (including 3D laser scanning, point cloud, photogrammetry), RFID and GIS, for the purpose of capturing, transferring and storing big data/information from the design and construction stages through to building operation and maintenance stages, has drawn wide attention. Consequently, a growing number of innovations have been developed in recent years [33].

3. Research methodology

The selection of DTs to be included and investigated in this review paper was undertaken according to the following two steps developed by Geddes [56]. First, an initial scanning and review of existing literature and practice was undertaken, and major DTs commonly discussed in the literature were identified. In this paper, the discussion of DT applications fall into four distinct categories., including 1) BIM, 2) GIS, 3) reality capture tools (including 3D laser scanning, point cloud and photogrammetry), 4) IoT (including RFID and sensor network technologies). Then, discussion about the chosen DT applications was conducted with a panel of five FM and information engineering experts and industry practitioners, including a senior property director, property asset management director, engineering manager and academics. They confirmed that the DT applications identified in the previous step are major existing/potential technologies in FM, and should be included and scrutinised in this study.

Minimising subjectivity in selecting publications for study and analysis is an important issue for systematic reviews of particular areas/topics [23]. During data collection and selection in this study, a wider range of journals were considered, reviewed, and adopted, in order to obtain as many articles and discussion papers as possible, since DT in FM is a rather new area of study [71,151]. This method is different from the traditional approach of only focusing on high- or top-ranking journals when choosing data sources in a well-developed research area [111]. Given the limitations associated with the use of a sole search engine (e.g. Scopus) [114,160], the use of two search engines, such as *Scopus* and *Google Scholar*, is beneficial to provide a more accurate and comprehensive picture of the scholarly field [114]. The review started with a wide-ranging search of the literature based on the 'title', 'abstract' and 'keyword' search in academic databases and scholarly publication search engines, including *Scopus* and *Google Scholar*. *Scopus* covers a wide range of journals, allowing multidisciplinary exploration and identification of indexed documents and citations in the studied fields [51]. *Google Scholar* covers conference proceedings and indexes 'a wide variety of document types, some of which may be of significant value to researchers and others' [114]. The use of *Scopus* for literature searching is common in the engineering and technology research fields (e.g. [20,63,67,83,86,113,131,143]).

The 'keywords' approach is widely adopted for systematic data