IOP Conf. Series: Earth and Environmental Science 1176 (2023) 012012 doi:10.1088/1755-1315/1176/1/012012

Digitally Transforming Facility Management in Healthcare: A Systematic Review of Key Digital Technologies and Systems

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Abstract. The COVID-19 pandemic led to an acceleration of digitalisation in healthcare institutions, not only in the medical field but also within non-medical, which includes facility management (FM). FM organisations are increasingly confronted with the need to digitally transform their operations and to implement new digital technologies. This paper aims at providing scholars and professionals with an overview of the various digital technologies and systems that are relevant in shaping the digital transformation. An integrative literature review has been chosen, as it provides a systematic approach to map, collate and report on key findings and concepts from the literature for researchers and practitioners. Overall, 33 articles were systematically reviewed. 22 different digital technologies and systems were identified in the literature and were added to so-called technology clusters. From all the described technologies, Building Information Modelling (BIM) is most prominently cited. Furthermore, Internet of Things (IoT), Artificial Intelligence (AI) and Machine Learning (ML), Digital Twins (DT), and Blockchain technologies are commonly found. Additional technologies and systems mentioned in the literature, though not further detailed, were also added within a separate cluster. This study also discusses the implications for the digital transformation which is important when introducing novel digital technologies in healthcare organisations. It is argued that FM in healthcare needs to focus on integrating technologies, both at a technological level, and particularly at an organisational and interorganisational level.

1. Introduction

In the past few decades digital technologies have had a significant impact, in virtually all aspects of our lives and society [1] and are driving innovation and change across nearly every sector of industry [2]. The COVID-19 pandemic especially accelerated digital disruption in healthcare [3], as countries worldwide struggled to sustain their healthcare delivery [4]. The serious consequences of the pandemic were underlined by Ahsan and Siddique (2022) [5] who note "over 800 million people have been left without basic healthcare" (p. 1). Sætra and Fosch-Villaronga (2021) [6] suggest "technology is shaping the healthcare sector" (p. 12) and Alghamdi and Alghamdi (2022) [7] argue digital technologies have been central to global efforts to curb the transmission of the virus during the pandemic. Research by Lee *et al.* (2022) [8] highlight, that countries like South Korea have significantly increased their digital infrastructure in response to the pandemic. Tortorella *et al.* (2020) [9] describe this shift as 'Health Care 4.0', a concept centred around interconnected systems and real-time interactions. Ashan and Siddique

IOP Conf. Series: Earth and Environmental Science 1176 (2023) 012012 doi:10.1088/1755-1315/1176/1/012012

(2022) [5] argue that during the pandemic, healthcare and Industry 4.0 fused and evolved together, addressing issues including data security, resource allocation, and data transparency". Al-Jaroodi *et al.* (2022) [10] also note the importance of a supporting Healthcare 4.0 infrastructure in which "smart supply chain applications can improve equipment acquisition, provide effective scheduling for resources allocation, help different facilities share and exchange resources, and allow healthcare professionals to have access to all the resources they need, locally and remotely" (p. 1). Iadanza and Luschi (2020) [11] observe that state-of-the art healthcare facilities manage a large amount of information from various sources, thereby complying with various regulations and standards.

The link between health care and FM is made by several researchers including Shohet and Lavy (2017) [12] and Yousefli, Nasiri and Moselhi (2017) [13] who note the importance of FM supporting healthcare activities, by ensuring quality built assets support services which directly underpin healthcare processes. Redlein and Grasl (2018) [14] note that facility services in healthcare have been highly impacted by digitalisation with a focus on "maintenance and operation, energy optimization, safety, logistics, security, finance and procurement" (p. 6). Several key technologies are being utilized to achieve successful digital transformation in terms of healthcare and the FM processes, which combined, can better support healthcare. However, Rabello, Pêgo-Fernandes and Jatene (2022) [15] consider the current healthcare models to be "outdated", and therefore do not reflect the continuing digital transformation (p. 161). In order for FM in healthcare to deliver added value it is critical FM practitioners stay abreast of and develop a more comprehensive understanding of Healthcare 4.0 and the influences of digital transformation. It is important to establish an overview of the digital technologies that are driving the transformation in order to ensure support services can be best aligned with primary health care processes. Currently such an overview, specifically for the FM in healthcare domain, is lacking. The aim of this paper is to search and compile a comprehensive record of various digital technologies and systems that are influential in driving the digital transformation of FM in healthcare.

2. Research Method

For this study an integrative literature review was chosen. According to Snyder (2019) [16] the aim of an integrative review is to assess, review, and synthesise literature to generate a new framework or perspective on a topic. Moreover, different perspectives can be combined, resulting in novel perceptions. In the case of this study, the perspectives of FM in healthcare on digital technologies relevant to the built environment were considered. The approach for conducting the review is structured corresponding to the framework by Torraco (2005) [17]. To help set the focal point for reviewing the literature, specific research questions (RQs) were formulated:

RQ1: *Which digital technologies, systems, and / or solutions within FM in healthcare are represented in the literature?*
RQ2: *Which digital technologies are used in the built environment within healthcare institutions (including hospitals, clinics, and elderly care homes)?*

Peer-reviewed studies were searched in primary databases, including Business Source Premier, CINAHL (EBSCO), Medline (Proquest), PubMed, and Web of Science Core Collection. The systematic literature search was conducted between 10th to 25th September 2022. Four additional studies were found using the snowballing technique, following up referenced articles during the review process. Figure 1 presents the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) diagram of the integrative review of this study. A total of 1629 articles were identified, including 4 additional records identified through other sources. After removing duplicates and screening the articles, 424 remained. Inclusion criteria constitute of all articles written in English that were published between 2017 to 2022, focussing on FM related digital technology topics within the healthcare-built environment domain. Studies describing IT or software technologies, systems, or products, not related to the built environment and FM were excluded (e.g., health informatics). Overall, 78 articles were studied in detail. Of these articles, 33 were included in the integrative review, as they fully matched the inclusion criteria.

Analysis was performed using thematic coding based on Flick (2007) [18]. Overall, 22 codes, representing the digital technologies, as well as 72 sub-codes, were inductively generated.

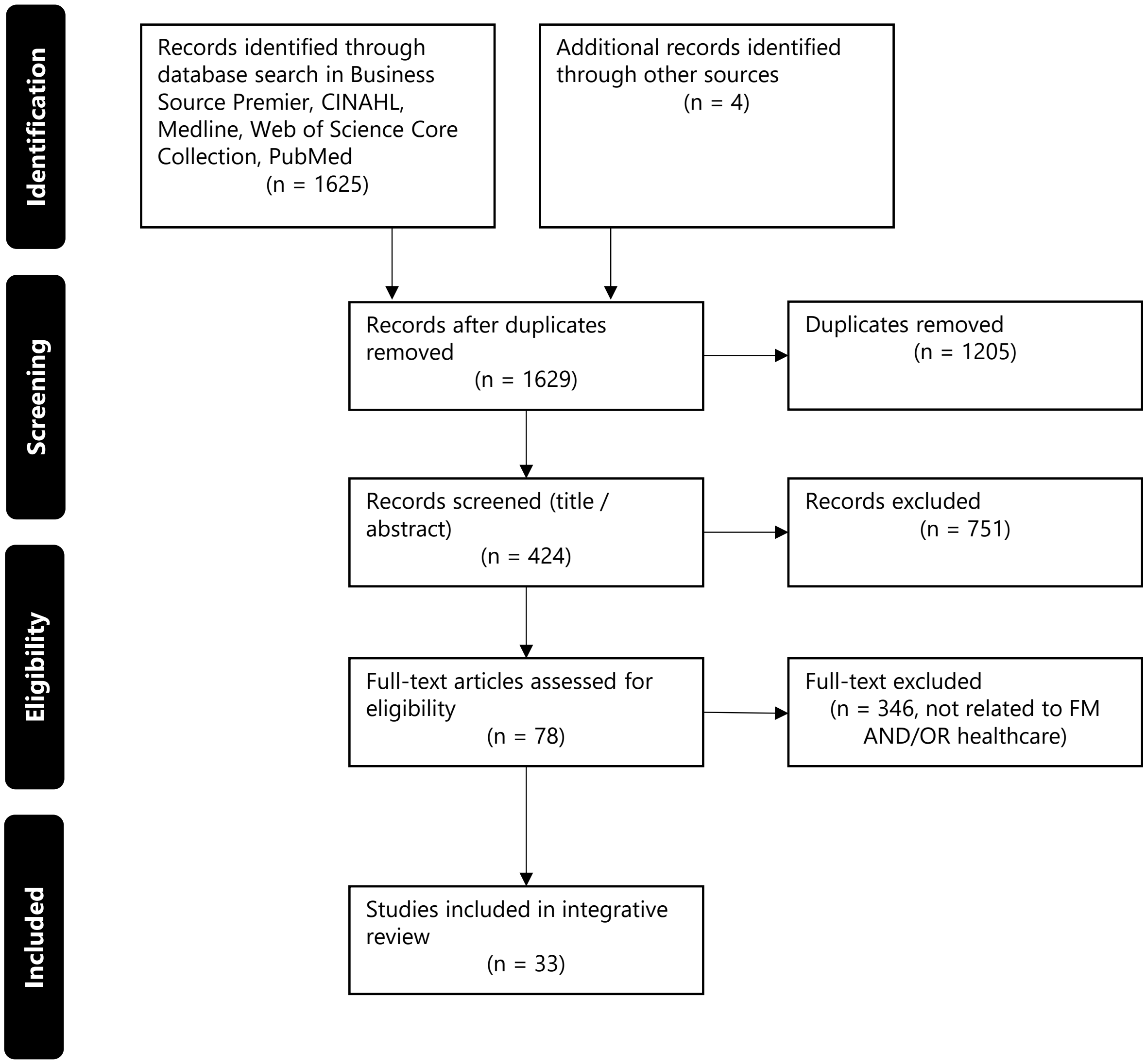

Figure 1. PRISMA diagram of the integrative review based on Page et al. (2021) [19].

3. Results

In the following section, the results from the integrative review of digital technologies in FM in healthcare are presented. Overall, 22 digital technologies were identified. The designations (incl. abbreviations) were inductively derived from the articles. Their relationship structures to each other were also formed, based on the descriptions in the articles. To obtain a better overview, the individual technologies (codes) were assigned to higher-level clusters. The so-called technology clusters represent comparable or related technologies. Note, that the technology clusters were formed by the authors based on their estimation. Technologies that are used synonymously in the literature are combined. Figure 2 shows an overview of the clusters with the individual technologies, as well as their relationships to each other (represented by the blue lines between technologies). Below, an overview of the included studies per technology cluster is presented.

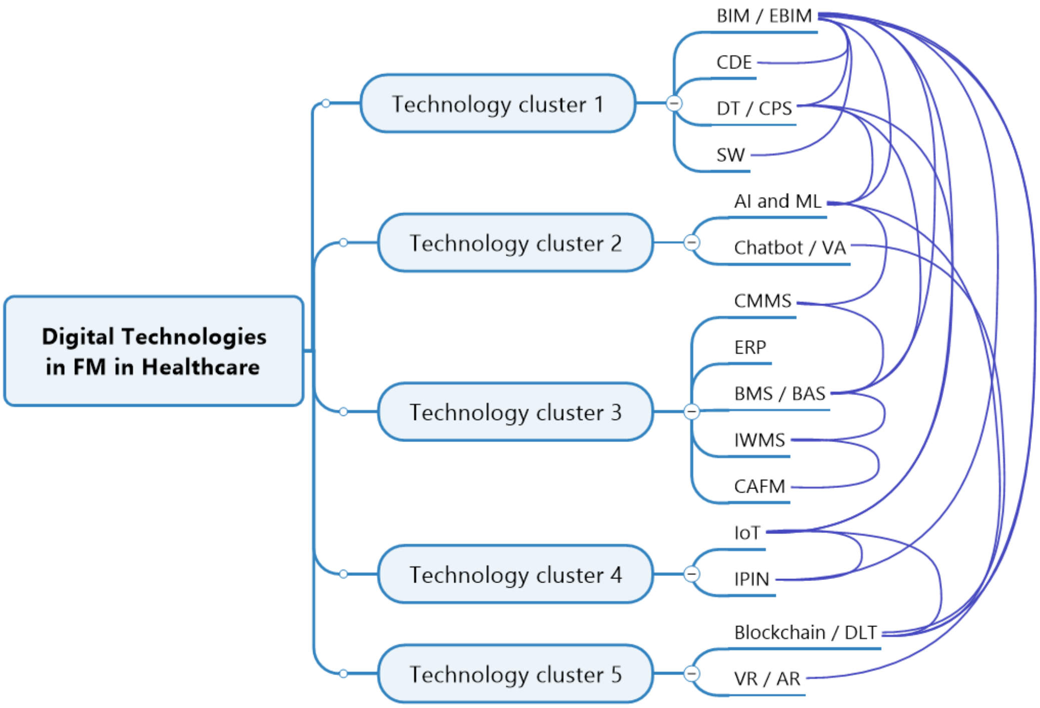

Figure 2. Overview of technology clusters of digital technologies relevant to FM in healthcare.

3.1. Technology cluster 1

In technology cluster 1 (see Table 1), the digital technologies (BIM) / Enterprise Building Information Modelling (EBIM), Common Data Environment (CDE), Digital Twin (DT) / Cyber Physical Systems (CPS), and Semantic Web (SW) are grouped.

Table 1. Technology cluster 1.

Technology	Description	Ref.
BIM / EBIM	Computer-generated model as a unified representation and single digital environment of all building assets. Type of virtual twin. EBIM as a concept involves the use of BIM in a structured way throughout the life cycle of a building.	[11,20–37]
CDE	Internet-based platform for managing processes, information delivery and sharing during building life cycle. Can be cloud-based.	[22,24]
DT / CPS	A complete virtual and functional description of the built environment. Consists of cyber and physical components.	[21,24,26,32,35,38,39]
SW	A set of technologies and standards that allow data to be shared and understood across different systems and platforms.	[24]

By far the most cited technology in the examined literature is BIM. Described as a unified digital representation (closely linked to CDE [22,24]), BIM can be considered as a 3D computer model that contains all data relevant of a buildings' life cycle [22]. Thereby non-graphical information specifying physical and functional characteristics, as well as building documentation, is also attributed to the model. Godager, Onstein and Huang (2021) [24] further expand on the concept of BIM, describing EBIM as "an emerging concept that places BIM use in a holistic structure" throughout the life-cycle of a building or portfolio (p. 42266). Wen, Tang and Ho (2021) [31] illustrate how BIM is used to improve the management of hospital projects, as it can reduce time [26], increase quality, enhance productivity, and promote on-time delivery [28]. The value of a BIM model can be extended through its integration with other technologies, creating a SW. DTs are virtual representations of physical objects, systems, and processes that allow for dynamic real time interaction between a building and information e.g., from sensors. This empowers simulation and analysis of their behaviour and performance (for instance BIM). According to Dahanayake and Sumanarathna (2021) [39], and supported by Godager, Onstein, and Huang (2021) [24] and Huynh and Nguyen-Ky (2020) [26], DTs provide a functional platform for modelling the components, systems and processes within a given environment. Dahanayake and Sumanarathna (2021) [39] detail how DTs are used in combination with IoT in hospital emergency management, to obtain interactive crisis-related information. CPS systems are described by Carbonari *et al.* (2020) [21] as computational entities that are interconnected with the physical surroundings in which data is generated by sensors within building components and systems, and integrated into a digital model [21,32].

3.2. Technology cluster 2

The second technology cluster includes the digital technologies Artificial Intelligence (AI) and Machine Learning (ML), and Chatbot / Voice Assistants (VA) (see Table 2).

Table 2. Technology cluster 2.

Technology	Description	Ref.
AI / ML	AI refers to systems that perform tasks that would otherwise require human intelligence. ML is a field of AI which uses algorithms and statistical models to learn and improve over time. AI and ML systems can be used to improve building management and advanced automation.	[13,32,36,38,40,41]
Chatbot / VA	Intelligent conversational agents that allow end-users to communicate via natural language. The aim is to improve user interaction through conversation and request/response.	[42,43]

ML is a type of AI that involves using algorithms and statistical models to analyse data (self-learning and improving), and then make predictions or decisions based on that analysis [32]. Such systems can be used in various ways within FM to improve on organisational resources, processes, staffing, life cycle modelling or decision making [36,40]. Yadav and Pavlou (2020) [41] present use-cases of ML within supply chain management for process optimisation, automation of routine tasks, and risk mitigation. ML is also used as a decision support tool to predict building-related costs during construction and operation [36]. A distinct application of AI and ML mentioned in the literature are chatbots and VAs. These intelligent conversational agents or assistants, are used to communicate with end-users, using natural language processing (input via screen, text, speech and / or sound) [42,43]. Sezgin *et al.* (2020) [42]

observe these conversational agents gather information from different sources and deliver personalised content to the user. Valtolina, Barricelli and Di Gaetano (2020) [43] detail how chatbots are used in smart home environments (i.e. elderly care homes) allowing end-users to control parameters of different household appliances via speech.

3.3. Technology cluster 3
Technology cluster 3 includes five different digital technologies: Computerized Maintenance Management Systems (CMMS), Enterprise-Resource-Planning (ERP), Building Management System (BMS) / Building Automation System (BAS), Integrated Workplace Management System (IWMS) and Computer Aided Facility Management (CAFM) (see Table 3).

Table 3. Technology cluster 3.

Technology	Description	Ref.
CMMS	Computerised system and database of building information, containing service and maintenance information.	[38,44]
ERP	Digital management system integrating various information. Used for maintenance management, customer relationship, and supply chain management.	[13]
BMS / BAS	Digital system for monitoring and controlling building systems. Deployment in large and complex buildings.	[31,34,38]
IWMS	Management system to manage and optimise assets and facilities.	[11,38]
CAFM	Decision support system for FM to prioritise and assign interventions. Provides KPIs on healthcare structure performance.	[11,38]

The digital technologies associated in cluster 3 are used for the management of building assets and operations. CMMS can be understood as a digital logbook of a building, containing all relevant information [44]. It is used in operation and maintenance management to schedule, organise and supervise work orders, records, and services requests [38,44]. ERP are higher-level systems, used to manage and integrate information flows within organisations [13]. Yousefli, Nasiri and Moselhi (2017) [13] explore different application of ERP systems within healthcare facilities. They note that customised versions of ERP-systems are used in maintenance management. BMS and BAS are similar in function (cf. Lu *et al.* (2020) [38]) and are thus grouped together. BMS systems on the one hand are used in maintenance and operation management, to monitor and control building systems [31]. Such systems are used especially in large and complex facilities, like hospitals [31]. BAS on the other hand, are used to automate various facility-related tasks [34]. IWMS is used to manage and optimise assets and facilities and can be used to analyse workplace-related needs [11]. CAFM is understood by Iadanza and Luschi (2020) [11] as a decision-support tool that provides FM KPIs on healthcare structures, and allows for prioritisation and assignment of interventions.

3.4. Technology cluster 4
The technologies IoT, and Indoor Positioning and Indoor Navigation (IPIN) are presented in Table 4 and grouped in technology cluster 4.

Table 4. Technology cluster 4.

Technology	Description	Ref.
IoT	Network of interconnected physical objects that are embedded with sensors. Used for measurement of building metrics and tracking of objects with real time data. Predictive and condition-based maintenance possible. Can be used for a wide range of applications.	[21,24,26,32,39,45–48]
IPIN	Real-time location of people and devices within buildings.	[24]

IoT is understood as a network and interconnection of physical objects that are embedded with sensors and communication hardware [24]. This allows for real time accurate measurements of building metrics and processes [26]. This technology enables predictive and condition-based maintenance [45], and up-to-date information on building operations [39]. Mannino, Dejaco and Re Cecconi (2021) [32] describe how data collected by IoT systems can be integrated with BIM models and be used to continuously monitor the built environment. Similarly IPIN is described as a system for real-time location of people and devices within the built environment [24]. IPIN systems enable location-based indoor tracking solutions and real-time location systems (RTLS) [24].

3.5. Technology cluster 5

The two remaining technologies Blockchain / Distributed Ledger Technology (DLT), and Virtual und Augmented Reality (VR / AR) are added to technology cluster 5 (see Table 5).

Table 5. Technology cluster 5.

Technology	Description	Ref.
Blockchain / DLT	Digital information is shared over a peer-to-peer network and stored on a distributed, replicated, and immutable ledger.	[37,46,49–52]
VR / AR	Immersive visualisation of 3D models. AR integrates models into real world environment.	[34]

Blockchain technology and DLT enable secure and transparent business transactions without the need for a central authority or intermediary, by using a “distributed, replicated, and immutable digital ledger” [49]. Saeed *et al.* (2022) [46] note that Blockchain offers a new and advanced way to manage and distribute processes in the healthcare domain. Several use cases within FM in healthcare are described in the literature: Interorganisational automatic transfer of resources [49,50], asset tracking [46], regulation of ownership in BIM-projects, management of smart energy, autonomous vehicle transport [37], and access control for smart home settings [50]. VR and AR are technologies that allow users to experience and interact with 3D content in immersive ways. Whereas VR allows for a full immersion, AR overlays digital content onto the real world. Støre-Valen (2021) [34] describe how VR can be used to help visualise concepts while designing hospitals. At the same time, staff can be trained on how to operate the new facilities prior to the actual real-world operation. According to Støre-Valen (2021) [34] VR and AR also help to improve communication among different stakeholders involved in projects.

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4. Discussion

Overall, 22 different digital technologies and systems, grouped in 5 clusters, are presented. With 19 references, BIM / EBIM was by far the most cited technology. Following BIM/EBIM, IoT was cited 9 times and DT/CPS 7 times. Both, AI/ML and Blockchain were referenced in 6 articles reviewed. The frequency of these technologies in the literature is also reflected in the links between them in Figure 2. The number of citations and links indicate technologies that are central for the digital transformation of FM in healthcare. BIM/EBIM, in particular, involves a large number of links to other technologies and systems. The concept of BIM/EBIM as a single digital environment [23] representing graphical and non-graphical information, and thus functioning as the basis for developing a DT for the entire built environment of an organisation. However, the authors note an important factor i.e., that BIM is usually used for new build projects whereas in existing buildings other technologies like photogrammetry or laser scanning may be cheaper and more effective to capture reality and create a 3D model or digital twin. IoT serves here as the crucial link empowering the integration of other digital technologies. IoT thus is critical and serves as a network platform of interconnected and embedded sensors throughout the facilities [24]. The generated data can then be accessed by various systems and databanks. This assessment is confirmed through the research done by Redlein and Höhenberger (2020) [53] who analysed several hundred case studies on digital technologies for smart buildings. Notably, IoT was most prominently mentioned with 31%. Conversely, BIM was only featured in 2% of all analysed case studies. This discrepancy between the findings from the integrative review, might be explained due to the fact that there is an inclination towards BIM as a prominent technology in FM (especially with respect to new build projects), whereas IoT is used primarily in the background and would support data capture for use of sensors in existing buildings.

The 22 identified technologies represent those technologies that were explicitly named and described in the referenced literature. Besides these, there are several additional technologies mentioned that are cited, though not described. Zouari *et al.* (2021) [48], examining the supply chain management transformation, refer to a number of other technologies including Big Data (BD), Mobile Devices/Wearables (MDW), Robotic Process Automation (RPA), Cloud Computing, Advanced Human-technology Interfaces (AHTI), Advanced Smart Manufacturing Technologies (SMT), Location Detection Technologies (LDT), and Self-driving Vehicles (SDV). Also Godager, Onstein, and Huang (2021) [24] reference additional digital technologies linked to IoT and BIM that are however, not further discussed in their study, including wireless internet service provider, Near-field Communication (NFC), Radio Frequency Identification (RFID), Bluetooth Low Energy (BLE), Zigbee, Computer Integrated Manufacturing (CIM), and Web of Things (WoT). Arguably, Smart Home [43] could also be added as an individual technology. The referenced literature however, neither defines nor describes smart home and smart home technology in any detail. The above listed examples highlight that there is a wide range of additional technologies and systems relevant to FM in healthcare. These additional technologies are added as a separate cluster, as shown in Figure 3. No further classification and cross-linking with each other and with the other technologies was made.

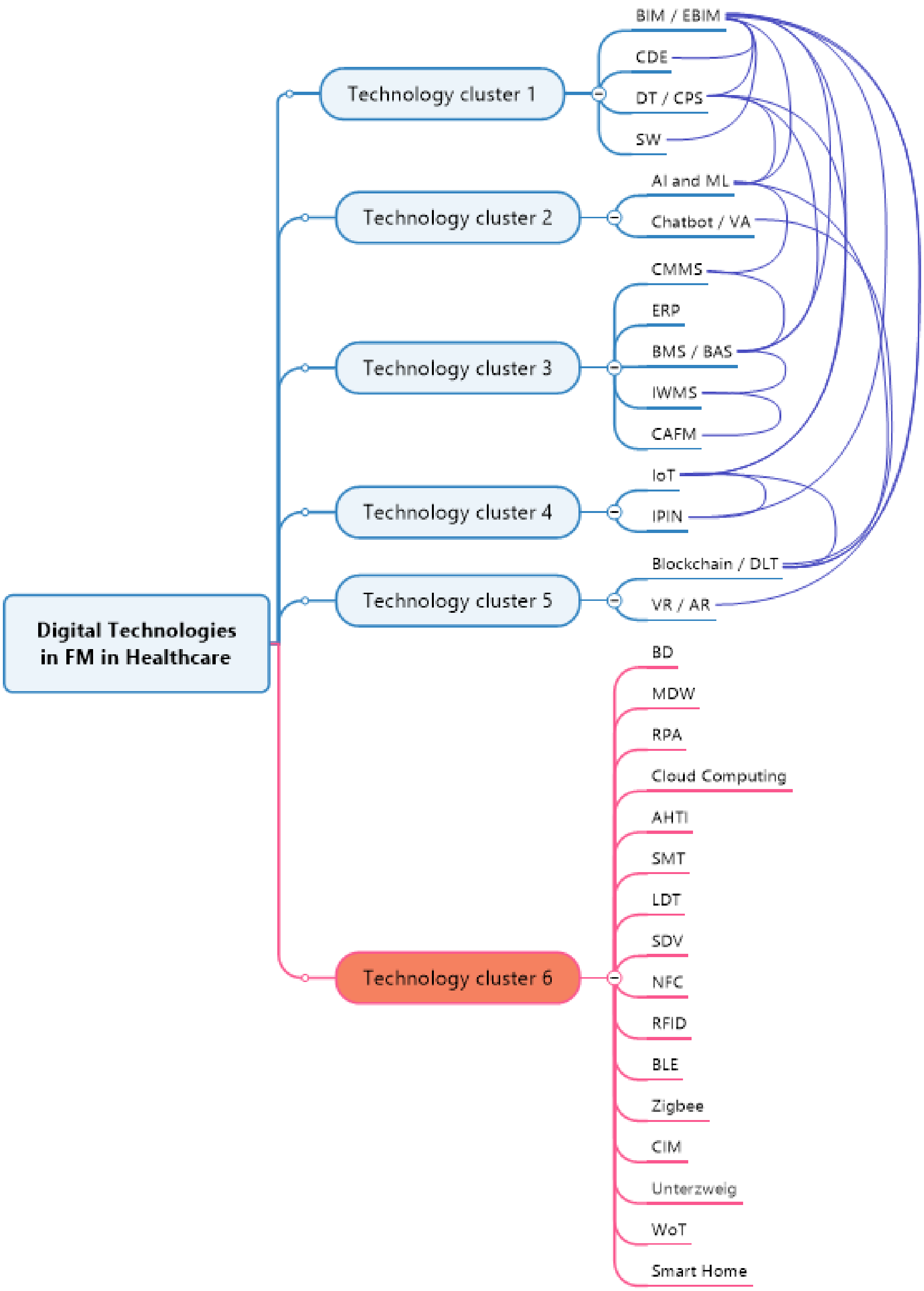

Figure 3. Extended technology clusters of digital technologies relevant to FM in healthcare.

It also must be taken into account, that digital technologies in FM in healthcare should not be considered in isolation. This is because ultimately, they will be part of an ecosystem of various technologies that form and support Healthcare 4.0. These main technologies of Healthcare 4.0 include among others robotics, remote patient care, smart logistics, wearables, mobile applications, digitally mediated diagnostics and treatment, telehealth, 5G, and data analytics [8,54–58]. Together these digital solutions have the potential to improve healthcare delivery and quality and can empower patients and physicians to better achieve health objectives [55,59,60]. This is driving improvements and efficiencies in service delivery, and helps enhance operational performance [61]. Abernethy *et al.* (2022) [1] note

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that “[s]eamless connectivity and communication among health care-related devices are essential prerequisites for promoting optimal health.” (p. 15). This, however, requires compatibility and interoperability. Interoperability of systems is also highlighted as a key issue that needs to be considered in the analysed literature on digital technologies and systems for FM in healthcare [20,24,26–28,37,38].

5. Conclusion

In this paper the literature has been systematically reviewed to identify and collate digital technologies and systems relevant for FM in healthcare. As a result of the systematic approach from the integrative review process, a qualitative description of the digital technologies, as well as a quantitative account on the most-referenced technologies can be made. Not only are the technologies listed and described, but they are also clustered into similar groups (apart from cluster 6 containing the remaining technologies). The associations between the different technologies, as described in the literature, are visually represented by the blue lines between technologies in Figures 2 and 3. From this, it becomes clear the various technologies and systems have many linkages to others. Principally it can be concluded that most digital technologies and systems are used in combination or are integrated with each other. This finding is also confirmed by other studies, such as from Lee *et al.* (2022) [8], who note how hospitals are implementing and unifying an assortment of different systems. It is precisely this aspect that can present some of the biggest challenges to realising efficiencies and highlights a central argument for a better overview of the digital transformation of FM in healthcare; namely the need to focus on the integration of digital technologies. Often digital systems deliver most value when brought together, to enable the creation of more connected, efficient, and digitally responsive environments. Moreover, not only the integration of technologies with each other is necessary, however, they need to be aligned with the strategy, business model, business processes and operations, organisation, and customer needs [62]. Cripps and Scarbrough (2022) [59] advocate that it is essential to understand not only the end-user perspective when introducing digital technologies in healthcare, but also taking the context in which they are deployed, into account. By the same token, the context in which these technologies are embedded must be viewed beyond an organisations’ system boundary [30,63]. Ecosystems and platforms increasingly play an instrumental role in technology distribution. This also requires understanding how technologies are combined with business processes, intra-organisational value chains, and product and service offerings. Karahanna *et al.* (2019) [64] write “that it is not a single technology but a rich composite of technologies supporting a hospital’s various functions and processes that gives the hospital a competitive advantage“ (p. 115).

This is where FM in healthcare has so far fallen short. None of the reviewed papers genuinely consider a holistic approach. Godager, Onstein and Huang (2021) [24] do note how Enterprise Modelling (EM) using DTs are used to support strategic decision making by creating a common data environment for business processes. Nonetheless, the description and analysis remain mainly on a technical level. Atta and Talamo (2020) [30] observe that traditionally, FM has implemented digital tools to meet specific operational needs within their organisational units, often neglecting collaboration and information sharing. This leads to disconnected and inefficient systems. Conversely, novel digital technologies are now forcing FM in healthcare to rethink their approach.

6. Outlook

The limitation of this paper is a more detailed description on how the different digital technologies are integrated with each other, as well how they align with FM processes and services in healthcare organisations. Here, further research is necessary to understand specifically how these digital technologies can be integrated in FM in healthcare organisations and how they shape the provision of services to align and better support primary health care services. Furthermore, the integrative review highlights the lack of a clear discourse on how the digital transformation in healthcare organisations affect FM organisational units and how these should respond to align their efforts. Finally, an extended search for additional technologies, with a different search strategy and search strings is necessary to provide a complete overview.

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