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A Bibliometric Review of Research Trends in Facilities Management Technologies From 2000 to 2023

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Abstract

Technologies such as building management systems, building information modelling, computer aided design, virtual reality, internet of things, geographic information systems and robotics have been adopted to achieve effective Facilities Management (FM). However, little attempt has been made to map global research trends in FM technologies. This paper presents a bibliometric review on the application of technology in FM with the aim of determining research trends and gaps in this research area. A total of 107 publications on FM technologies from 2000 to 2023 were reviewed. The analysis was done with the VOSviewer software (version 1.6.13). The analysis focused on bibliographic coupling of countries, co-authorship of authors, citation of documents, and co-occurrence of keywords, which were presented as network visualization maps. The findings revealed that the publication trends in FM technologies have been upwards since 2000, although not completely gradient. Italy, United States, Mainland China, South Korea, Australia, United Kingdom, Sweden, China Taiwan, Canada, and Malaysia are the countries that have had great impact in this research area. Both the keywords and documents citation analysis revealed three distinct phases in the evolution of FM technologies research – energy efficiency technologies, BIM technologies, and advanced BIM technologies/internet of things. It also became evident that Africa lags in this area of research. This study helps to determine the range of technologies used for managing facilities and how such technologies have evolved. This can help facilities managers to become familiar with the current and cutting-edge technologies that could promote effective and efficient FM. Only one data source - Scopus - was used. Therefore, the representation of publications presented in this study are limited. However, the findings contribute to the body of knowledge in FM technologies.

Keywords: Facilities Management, Network visualization maps, Scientometric, Technology, Trends

1.0 INTRODUCTION

The use of technology has gained popularity in all industries. Technology is this context relates to the application of scientific knowledge and discoveries for practical purposes in a particular industry. Although many industries and organisations adopted technologies for their operations decades ago, the advent of Fourth Industrial Revolution (4IR) since 2016 has added an extra impetus to the uptake of technologies. Fourth industrial revolution, 4IR, is a term define by Klaus Schwab, founder of the World Economic Forum, as a world where individuals move between digital domains and reality of connected technology to enable and manage their lives (Xu et al., 2018). 4IR is a collective term for technologies and concepts which are brought together via digital systems such as the internet of things (IOT), cloud technology, big data, predictive analytics, artificial intelligence, augmented reality, robotics and other emerging technologies (Adama and Michell, 2017). These technologies offer several benefits and, thus, underscores the need for more research on technologies in all fields of study, including construction.

Research on the application of technologies in the construction industry abounds. For example, Ahsan et al. (2007) conducted a study entitled "Mobile technologies for improved collaboration on construction sites" way back in 2007. Studies on the application of technology in the construction industry has gain attention in recent time. Recently studies including Akinlolu et al. (2020), Nnaji et al. (2021), Agyekum et al. (2022), Ejidike et al. (2022) and Kabir et al. (2023) have been conducted on the application of technologies in the construction industry. Research on the application of technologies in FM, like the other fields of construction, also thrive. For example, Oti (2016) conducted a study entitled "a framework for the utilization of BMS data in building information models for building design and operation". Several other authors including Patacas et al. (2015), Golabchi et al. (2016), Ye et al. (2018), Mirarchi et al. (2018), Hu et al. (2018), Bortoluzzi et al. (2019), Siccardi and Villa (2023) and Sampaio et al. (2023) have also conducted research in FM technologies. Although studies on FM in general and the application of technology in FM abound, there is no evidence of studies that identified the research trends and determined the evolution of FM technologies (i.e. technological tools applied in FM). Evidence of bibliometric reviews in this area of studies is lacking. This paper presents a bibliometric review on FM studies, specifically focusing on technologies. Thus, the main question addressed in this paper is: how has studies on facilities management technologies evolved over the last 23 years?

Accordingly, the purpose of the study is to determine FM technologies research trends and gaps in this research area. This information can help facilities managers to become familiar with the current and cutting-edge technologies that could promote effective and efficient FM. Moreover, it can help researchers to determine gaps where future research in this field of study should address. The focus of the analysis is on the output of publications, key authors, and the collaborations among authors and countries, as well as the network of keyword. With the aid of a network visualization maps these areas are explored to identify research trends and determine the evolution of technologies applied in FM.

2.0 LITERATURE REVIEW

2.1 Overview of FM and FM Technologies

Tucker and Masuri (2016) opine that the definition of Facility management (FM) and its role has evolved over the decades. FM has now expanded beyond the traditional role of building maintenance and services management. FM is "a profession that encompasses multiple disciplines to ensure functionality, comfort, safety and efficiency of the built environment by integrating people, place, process and technology" (IFMA, 2017). The main role of a facility manager or facilities department is to ensure that facilities are managed to create an environment that is conducive for the facility's purpose. Atkin and Brooks (2015) stated that health, safety, security and environment (HSSE) has become an important function of FM. The Covid 19 pandemic has further elevated the health and safety role of FM. This further reinforces the fact that the role of FM will continue to evolve as the requirements and needs of facility users and situations change. Technology is an important tool that helps the facility manager or facilities department to successfully execute their role. Just as the definition and the role or function of FM has evolved, so has the technologies too.

As indicated already, the approach to how facilities are managed has radically evolved. The approach begun to evolve in the early 1970s (then, 2004). Becker (1990) and Amaratunga (2001) are of the opinion that FM was propelled by five factors which were information technology, cost of mistakes, high cost of space, employee expectation and globalization. Thus, "efficiency" was one of the key drivers of FM evolution; therefore, earlier technologies adopted were driving towards optimizing cost and reducing utility bills. Technologies such as energy management system, building automation systems, computerised maintenance management system, electronic document management system and computer aided facility management dominated during the early era of FM. Araszkiewicz (2017) indicated that these early technologies lacked interoperability, thereby limiting their functionality. As technology improved and the uptake of technology grew, the application of technologies in FM also increased. Koch et al. in 2017 suggested that blockchain, internet of things (IoT), big data technology, augmented reality and building information standards will drive FM in future (Koch et al., 2017). To buttress the prediction of Koch et al., Valks et al. (2019), Siccardi and Villa (2023) and Sampaio et al. (2023) have noted that in addition to BIM technologies, current technologies adopted to ensure effective and efficient FM operations include, internet of things, big data management systems, intelligent agents, semantic web technology, augmented reality, virtual reality, robotics, drones, wearable technologies, blockchain, artificial intelligence, cloud-based technologies. Table 1 provides some of the key FM technologies identified in literature. The table also reveals how FM technologies has evolved over the years.

Table 1 Facilities management technologies

Author(s)	FM Technologies
Patacas et al. (2015)	BIM technologies, computerised maintenance management systems, electronic document management systems, building automation systems.
Oti et al. (2016)	Computer aided design, building management system, building information modelling.
Araszkiewicz (2017)	Building information modelling, energy management system, building automation systems, computerised maintenance management system, electronic document management system, internet of things, big data management systems, computer aided facility management, GPS technology.
Koch et al. (2017)	Building Information Modelling, blockchain, Internet of Things (IoT), big data technology, augmented reality and building information standards.
Ye et al. (2018)	Computer aided design, building management system, building information modelling, internet of thing, blockchain.
Wong et al. (2018)	Building information modelling, reality capture technology, the internet of things, radio frequency identification, sensor network technologies, geographic information system, computer-aided design.
Sampaio et al. (2023)	Building information modelling, artificial intelligence, robotics, internet of things.
Siccardi and Villa (2023)	Building information modelling, internet of things, and digital twin, blockchain, artificial intelligence, cloud-based technologies, machine learning, and augmented reality.

■3.0 METHODOLOGY

The methodology of this study is based on bibliometric techniques. The author selected the Scopus database as the data source for this study. Hosseini et al. (2018) believe that the Scopus database has a wide coverage of publications from diverse areas. Moreover, scientific research database such as Scopus provides researchers with information on the most important academic literature in any scientific domain (Chadegani et al., 2013). This makes Scopus a credible/trustworthy data base. This study focused specifically on the application of technologies or technological tools in FM. Consequently, the specific keywords used for the search were: "Facilities Management" AND "Technology" AND "Building" AND "Tools". The search was limited to documents published from 2000 to 2023 (present). This helped to clearly demonstrate how research on FM technologies have evolved over time and to further show which technologies have dominated over the years. The first search resulted in a total of 480 documents. Most FM articles are published in engineering, business management, multidisciplinary, social science, energy, and environmental science subject areas. Therefore, the search was further refined to include only Articles, Conference Papers, and Book Chapters published in the subject areas of Engineering, Business, Management & Accounting, Multidisciplinary, Social Science, Energy, and Environmental Science. This resulted in a reduction from 480 to 336 documents. The search was further limited to only documents published in English resulting in a reduction from 336 to 329 documents.

The second stage was the screening; the titles and abstract of the 329 documents were further screened to eliminate papers which do not align to the research title or theme. This was done by analysing the content of the titles and abstracts. After the screening, a total of 107 documents were deemed appropriate for the study. The search/filtering and screening of the titles and abstract was done on 30th March 2023.

A bibliometric review was then conducted at the third stage to analyse the 107 documents obtained at the second stage. The bibliometric review was done with the VOSviewer software (version 1.6.13). Bibliometric review is a quantitative technique involving the visual and logical analysis of articles by assessing, mapping, and identifying structural patterns in a research domain using mathematical models, visualization clusters and algorithms (Olawumi and Chan, 2018). It helps to explore and/or uncover emerging trends in a field of study, research constituents, collaboration patterns, and the intellectual structure of a specific domain in the existing literature (Donthu et al., 2021; Verma and Gustafsson, 2020). Van Eck and Waltman (2014) clarified that the VOSviewer software, a bibliometric analysis tool, can help to display large visualization networks such that it becomes easily interpretable. Therefore, for this study, data was imported from the Scopus database unto the VOSviewer software to create network and overlay visualization maps. Four visualization maps are presented in this study. The visualization maps used for the study are bibliographic coupling of countries, bibliographic coupling of authors, citation of documents, and co-occurrence of keywords. The network visualization map represents items by their labels in a circle. Three factors – size, colour, and link – influence the analysis of the network visualization map (Van Eck and Waltman, 2019). First, the size of the label and the size of the circle of an item has a relation to the weight of the item; thus, bigger labels/circles represent higher weight. Secondly, all related items in a cluster network are presented in the same colour. Finally, items are linked with lines; thus, the distance between two items indicates their relatedness. For example, the closer two items are to each other, the stronger their relatedness (Van Eck and Waltman, 2019). Figure 1 shows the steps adopted in this study.

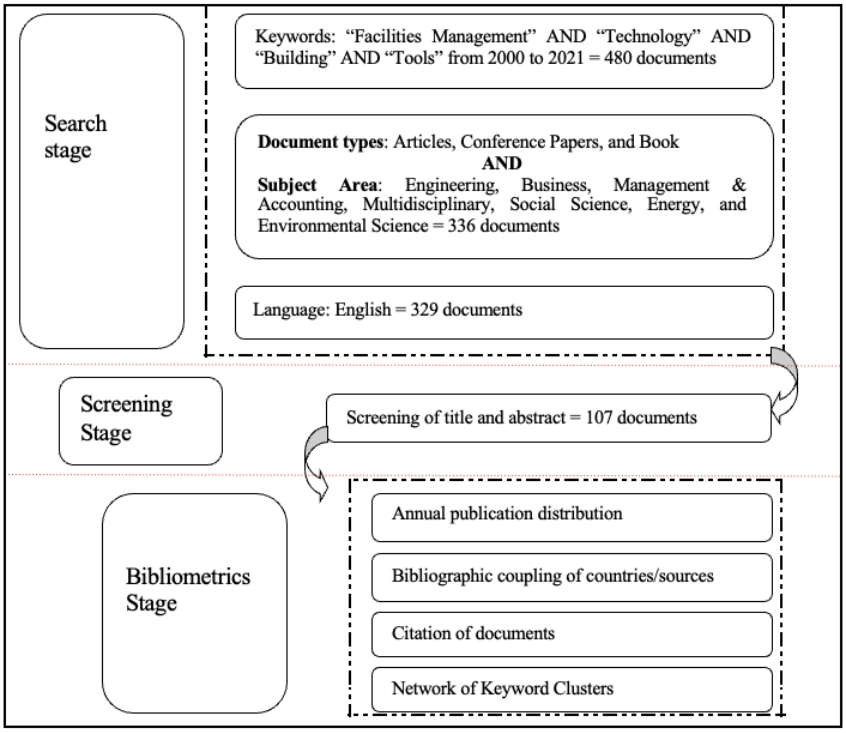

Figure 1 Bibliometric review process

4.0 RESULTS

4.1 Annual publication Distribution

The number and trends of publications from 2000 to 2023 is demonstrated in Figure 2. It is evident that no publication was recorded in 2000 and 2002 whereas one was recorded from 2003 to 2006. The number of publications rose from one in 2006 to four in 2007; but, declined in 2008 and further declined to two in 2010. 2013 recorded a remarkable increase i.e., from four in 2012 to 10 in 2013. This is probably due to the ISARC conference. However, the number declined from 10 in 2013 to six in 2014. The number of publications rose again from six in 2014 to eight in 2016. There was a dip in 2017 whilst the highest increase was recorded in 2018, i.e., from four in 2017 to 11 in 2018. A drop was recorded in 2019; since then, there was a gradual increase until 2022. Meanwhile 2023 has recorded two publications as of 30th March. Although the trend has not been smooth and steep, the general trend of publications has been upward since 2000.

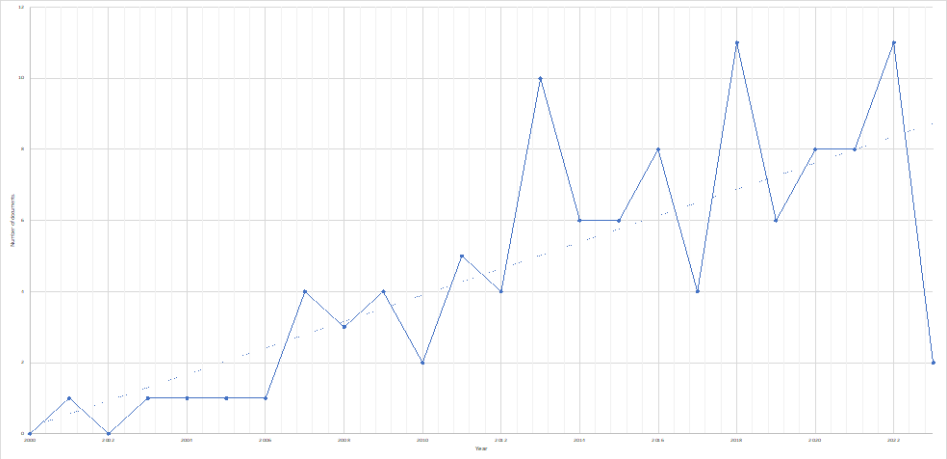

Figure 2 Annual publication distribution

4.2 Bibliographic coupling of countries

A bibliographic coupling analysis of countries was done to first determine the number of publications recorded by each country, and secondly to evaluate the level of collaboration between/among the countries. The minimum number of documents of a country was set at three whilst the minimum number of citations of a country was set at 10. Out of the 31 countries, only 12 met this threshold. United States had the highest number of documents, i.e., 27 with 426 citations whereas South Korea recorded the highest number of citations, i.e., 466, with only four documents. Similar to South Korea, Australia recorded a remarkable 460 citations with six documents. Italy recorded the second highest number of documents (i.e., 13 documents with 135 citations). It is worth nothing that no country in Africa met the threshold of three documents and 10 citations. This demonstrate that countries on the Africa continent lag in this area of research.

Regarding the link among the countries, Italy had the strongest link whilst Czech Republic had the weakest link. With the exception of Czech Republic which had a link with only Mainland China, all the countries had links with, at least, seven other countries demonstrating a satisfactory level of research link among the countries. The network visualization map also reveals three clusters: Cluster 1 (Canada, Malaysia, Spain, China Taiwan, and United State); Cluster 2 (Australia, Italy and South Korea, and Sweden); Cluster 3 (Mainland China, Czech Republic, and United Kingdom) (see Figure 3).

Table 2 Bibliographic coupling of countries

No.	Author	Documents	Citations	Total link strength
1	Italy	13	135	540
2	United States	27	426	474
3	Mainland China	6	173	535
4	South Korea	4	466	343
5	Australia	6	460	286
6	United Kingdom	10	234	218
7	Sweden	4	63	172
8	China Taiwan	5	180	151
9	Canada	4	68	93
10	Malaysia	12	32	79
11	Spain	3	28	24
12	Czech Republic	4	53	1

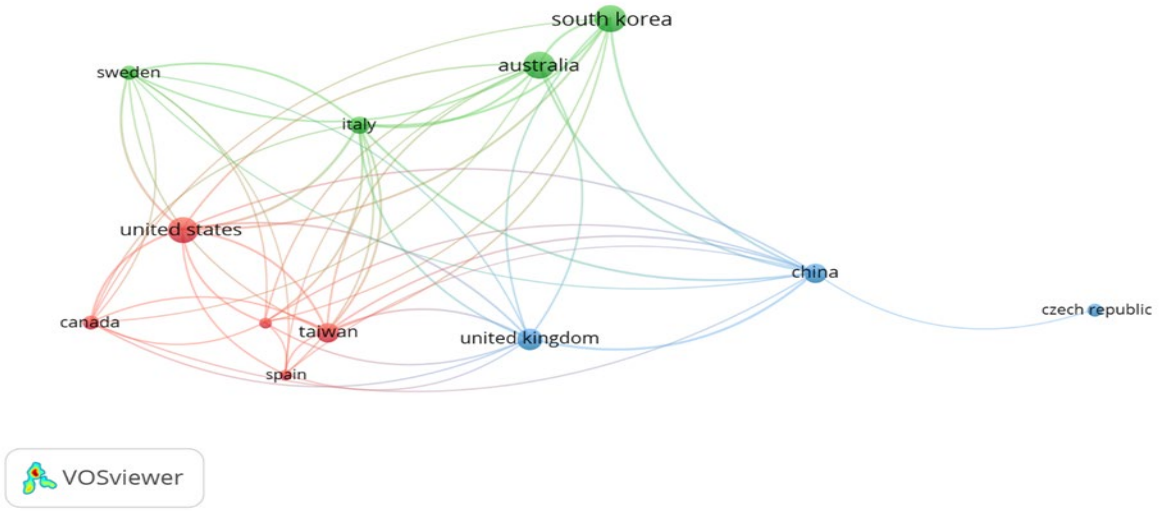

Figure 3 Country network visualization map

4.3 Bibliographic coupling of authors

An analysis was done to determine the number of publications per author, the level of citations of the authors, and the collaboration among the authors. The minimum number of citations of a document was set at 10 whilst the minimum number of documents of an author was set at two. Out of the 289 authors, 17 met the threshold generating eight clusters. Cluster 1 was made up of Issa, Liu, and Wang; Cluster 2 was made up of Dejaco, Maltese, and Re Cecconi; Cluster 3 was made up of Ismail, Naticchia, and Villa; Cluster 4 was made up of Aouad and Wu.; Cluster 5 had Irizarry and Gheisari; and Cluster 6 was made up of Lin and Su. These six clusters had more than one item; this implies that collaboration exist within these six clusters. The fact that six out of eight clusters had more than one item suggest that collaboration between/among authors exist. However, it must be noted that the collaboration among the authors were generally within the same country. Only Wang from South Korea had collaboration or link with authors from Australia.

Wang has had the greatest level of contribution with two publications obtaining 459 citations, followed by both Lin and Su. with two publications and 129 citations. In terms of the number of documents published, Ismail recorded the highest number of publications (i.e., 4 with 18 citations), followed by Irizarry (i.e., 3 with 74 citations) and Issa (i.e., 3 with 57 citations). Thus, as much as all the authors listed in Table 2 have contributed, it is Wang, Lin, Su, Ismail, Irizarry and Issa who have had the greatest level of contribution (i.e., citations and number of publications) in this research area. Again, it is evident that none of the authors is affiliated to an African institution.

Table 3 Number of publications per author

No.	Author	Affiliation	Doc.	Citations
1	Dejaco, M. C.	Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Italy	2	25
2	Maltese, S.	Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Italy	2	25
3	Re Cecconi, F.	Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Italy	2	25
4	Lin, Y. C.	Department of Civil Engineering, National Taipei University of Technology, Taiwan	2	129
5	Su, Y. C.	Department of Civil Engineering, National Taipei University of Technology, Taiwan	2	129
6	Issa, R. R. A.	Rinker School of Building Construction, University of Florida, United States	3	57
7	Naticchia, B.	Department of DICEA, Università Politecnica delle Marche, Ancona, Italy	2	23
8	Villa, V.	Department of Structural, Geotechnical and Building Engineering, Polytechnic of Turin, 10129 Turin, Italy	2	17
9	Liu, R.	Construction Science and Management Program, College of Architecture, United States	2	10
10	Irizarry, J.	School of Building Construction, Georgia Institute of Technology, Atlanta, GA, United States	3	74

11	Gheisari, M.	Mississippi State University, Starkville, MS, United States	2	55
12	Aouad, G.	School of the Built Environment, University of Salford, United Kingdom	2	18
13	Wu, S.	School of the Built Environment, University of Salford, United Kingdom	2	18
14	Wang, X.	Department of Housing and Interior Design, Kyung Hee University, Seoul, South Korea	2	459
15	Ismail, Z. A.	Faculty of Civil Engineering Technology, Universiti Malaysia Perlis, Arau, Malaysia	4	18
16	Costa, A. A.	CERIS, Instituto Superior Técnico, Universidade de Lisboa, Portugal	2	14
17	Kuda, F.	VSB – Technical University of Ostrava, Faculty of Civil Engineering, Czech Republic	2	11

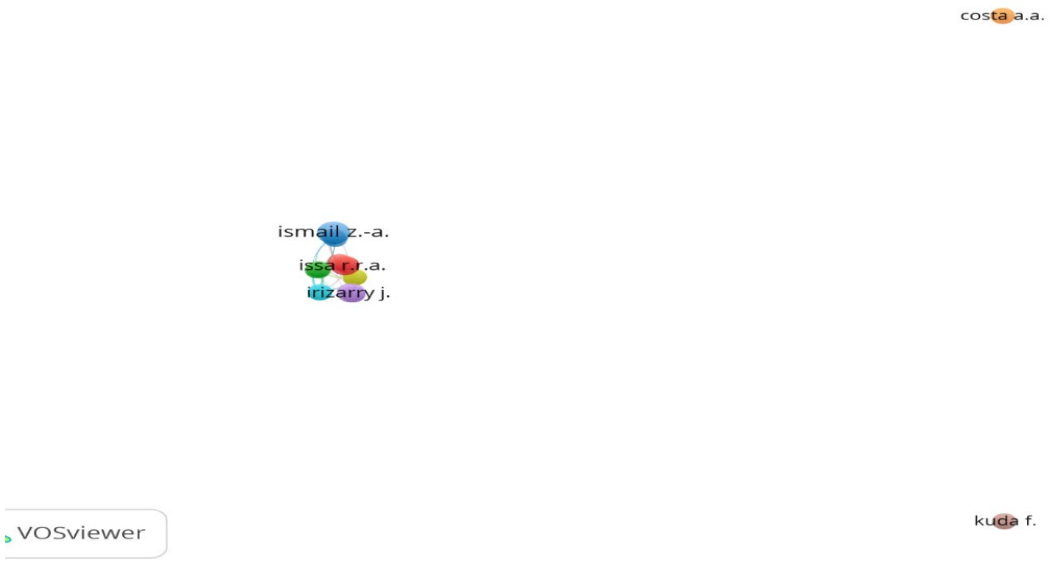

Figure 4 Authors network visualization map

4.4 Citation of documents

A citation analysis of documents was done to determine the level of citations of the specific documents. The minimum number of citations of a document was set at 15. Out of the 107 documents, 30 met the threshold generating 24 clusters. Only four clusters had more than one item. Cluster 1 and 2 were made up of three documents whereas both Clusters 3 and 4 were made up of two documents. It is worth mentioning that the focus of all the clusters was "the application of BIM in facilities management". A review of the remaining clusters' topics reveals a similar trend of research. However, other trends noticeable in the topics are GIS technology; V3dm; computer-aided facilities management; mobile augmented reality; energy performance improvements; intelligent, interactive, and immersive buildings; and IFC implementation. It can be inferred from the documents analysis that there are less collaboration between/among authors.

Table 4 Citation of documents

No.	Author	Title	Citations
1	Singh, V., Gu, N. and Wang, X. (2011)	A theoretical framework of a BIM-based multi-disciplinary collaboration platform	441
2	Mirarchi, C., Pavan, A., de Marco, F., Wang, X., and Song, Y. (2018)	Supporting facility management processes through end-user's integration and coordinated BIM-GIS technology	18
3	Patacas, J., Dawood, N., Vukovic, V., and Kassem, M. (2015)	BIM for facilities management: evaluating BIM standards in asset register creation and service life planning	75
4	Oti, A. H., Kurul, E., Cheung, F., and Tah, J. H. M. (2016)	A framework for the utilization of BMS data in building information models for building design and operation	73
5	Lee, W.L., Tsai, M.H., Yang, C. H., Juang J. R., and Su, J. Y. (2016)	V3dm+: BIM interactive collaboration system for facility management	32
6	Golabchi, A., Akula, M., and Kamat, V. (2016)	Automated building information modelling for fault detection and diagnostics in commercial HVAC systems	32

7	Hu, Z. Z., Tian, P. L., Li, S. W., and Zhang J. P. (2018)	BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase	112
8	Bröchner, J. (2003)	Integrated development of facilities design and services	34
9	Araszkiewicz, K. (2017)	Digital Technologies in Facility Management - The state of Practice and Research Challenges	48
10	Bortoluzzi, B., Efremov, I., Medina, C., Sobieraj, D., and McArthur, J. J. (2019)	Automating the creation of building information models for existing buildings	36
11	Re Cecconi, F., Maltese, S., and Dejaco, M. C. (2017)	Leveraging BIM for digital built environment asset management	22
12	Mayo, G., and Issa, R. R. A. (2016)	Nongeometric building information needs assessment for facilities management	47
13	Elmualim, A. and Pelumi-Johnson, A. (2009)	Application of computer-aided facilities management (CAFM) for intelligent buildings operation	17
14	Lin, Y.-C. and Su, Y.-C. (2013)	Developing mobile- and BIM-based integrated visual facility maintenance management system	87
15	Gheisari, M. and Irizarry, J. (2016)	Investigating human and technological requirements for successful implementation of a BIM-based mobile augmented reality environment in facility management practices	46
16	Zhang, J., Seet, B. C. and Lie, T. T. (2015)	Building information modelling for smart built environments	64
17	Hossain, M. A. and Yeoh, J. K. W. (2018)	BIM for Existing Buildings: Potential Opportunities and Barriers	17
18	Ye, Z., Yin, M., Tang, L., and Jiang, H. (2018)	Cup-of-water theory: a review on the interaction of bim, iot and blockchain during the whole building lifecycle	38
19	Lin, Y. C., Su, Y.C. and Chen, Y. P. (2014)	Developing mobile BIM/2D barcode-based automated facility management system	42
20	Mařík, K., Rojíček, J., Stluka, P., and Vass, J. (2011)	Advanced HVAC control: Theory vs. reality	42
21	Støre-Valen, M. and Buser, M. (2019)	Implementing sustainable facility management: Challenges and barriers encountered by Scandinavian FM practitioners	17
22	Artuso, P. and Santiangeli, A. (2008)	Energy solution for sports facilities	30
23	Junnila, S. (2007)	The potential effect of end-users on energy conservation in office buildings	27
24	Torrington, J. (2007)	Evaluation quality of life in residential care building	27
25	Hsieh, C.-C., Liu, C.-Y., Wu, P.-Y., Jeng, A.-P., Wang, R.-G., and Chou, C.-C. (2019)	Building information modelling services reuse for facility management for semiconductor fabrication plants	16
26	Villa, V., Naticchia, B., Bruno, G., Aliev, K., Piantanida, P., and Antonelli, D. (2021)	IoT open-source architecture for the maintenance of building facilities	17
27	Loftness, V., Aziz, A., Choi, J., Kampschroer, K., Powell, K., Atkinson, M., and Heerwagen, J. (2009)	The value of post-occupancy evaluation for building occupants and facility managers	38
28	Golparvar-Fard, M., Peña-Mora, F., and Savarese, S. (2011)	Integrated sequential as-built and as-planned representation with D 4AR tools in support of decision-making tasks in the AEC/FM industry	115
29	Karan, E. P. and Irizarry, J. (2014)	Developing a spatial data framework for facility management supply chains	19

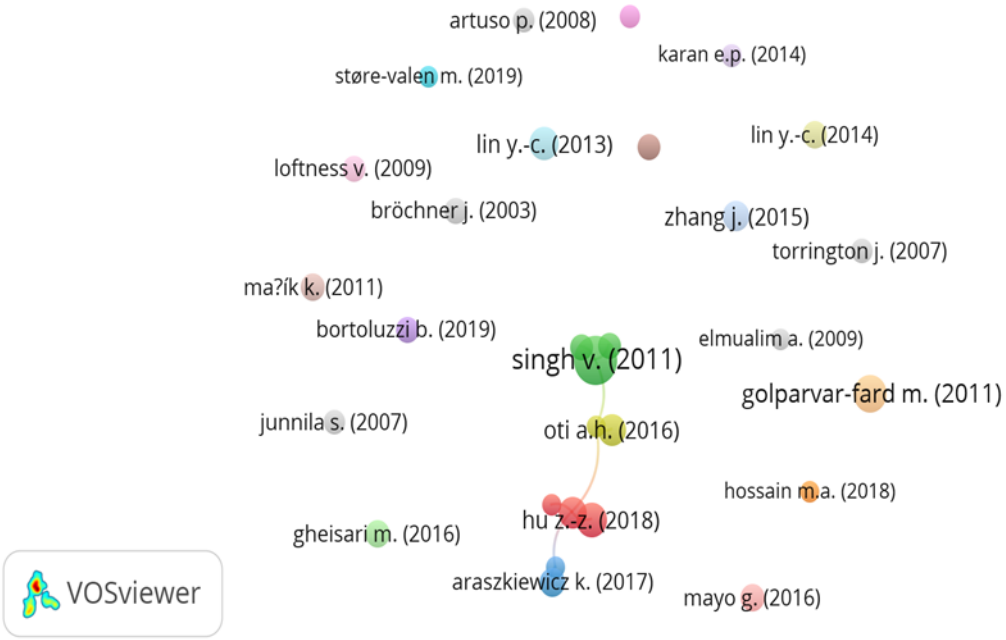

Figure 5 Documents citation network visualization map

4.5 Network of Keyword Clusters

A keyword co-occurrence analysis was conducted to determine the trends and evolution of FM technological tools. Hu et al. (2018) revealed that cluster analysis helps to identify patterns by grouping sources that share similar words and attribute value. The scope of any research study is determined by the keywords. A network of keyword clusters was derived from a total of 956 keywords. A minimum number of three co-occurrence of keywords was set and 94 keyword co-occurred. To ensure that only relevant keywords were captured in the network visualization map, some words such as maintenance, research, facilities, building industry, case study, investment, Malaysia and survey were taking out.

A total of six clusters emerged from the analysis. Cluster 1 had 12 keywords; some of the noticeable keywords in this cluster are big data, asset management, BIM, internet of things, and intelligent agent. Cluster 2 had 12 keywords; notable keywords in this cluster are energy management, energy efficiency, energy utilization, optimization, industry foundation classes (IFC). Cluster 3 had 11 keywords; some of the keywords related to FM technology in this cluster are augmented reality, automation, 3D modelling, BIM, digital technologies, digital twin, and virtual reality. Cluster 4 had nine keywords including BIM technologies, BIM, automation, computer aided design and information technology. Cluster 5 had nine keywords; notable keywords in this cluster are efficiency measures, energy management, communication technology and utility bills. Cluster 6 had eight keywords; notable keywords in this cluster are decision support system, robotics, frequency modulation, and geographic information systems.

To allow for an informed discussion, the clusters are presented in different colours to demonstrate the timeframe where such words dominated (see the visualization map in fig. 6). It can be inferred from Figure 6 that keywords in Cluster 2 and 5 are represented in purple-blue and purple; these were the keywords which dominated until 2010. Keywords in Clusters 4 and 6, represented in blue-green and green, dominated after 2010 and continued until 2017 (i.e., between 2011 and 2017). The keywords in Cluster 1 and 3 are represented in yellow-green and yellow; these keywords (i.e., big data, digital twin, virtual reality and internet of things) dominated from 2018 until now.

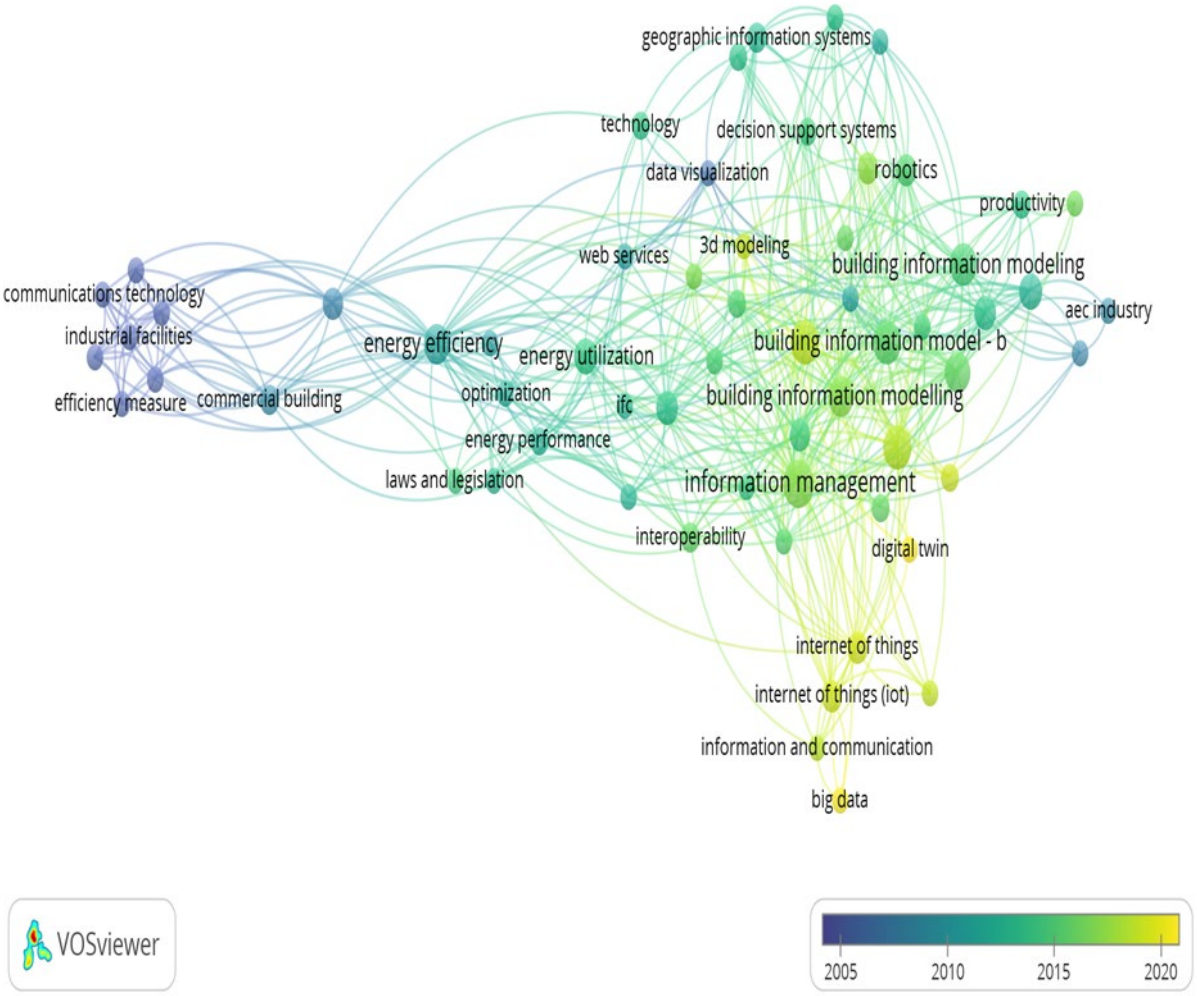

Figure 6 Overlay visualization map of co-occurring keywords

5.0 DISCUSSION

It is evident that the general trend of FM technologies publications, although not completely gradient, has been upwards since 2000. Other studies do present a similar trend. For example, a study conducted by Akinlolu et al. (2020) revealed a similar upward trend in the publications of construction safety management technologies from 2016. The advent of 4IR in 2016 has definitely had a positive effect on the publication trends in technology related subject. This upwards trend is likely to continue and as such open up more research opportunities in FM technology related areas. This implies that researchers have a responsibility to focus more attention on technology-based research in FM.

It also became evident from the country analysis that whereas countries in Asia (i.e., China Taiwan, Malaysia, South Korea, and Mainland China), Americas (i.e., United States and Canada), Europe (i.e., United Kingdom, Spain, Czech Republic, Sweden and Italy) and Australia (Australia) have had great impact in this research area, no country in Africa was found to have had a significant contribution in this research area. This finding correlate with those of Aghimien et al. (2019); Akram et al. (2019) and Akinlolu et al. (2020) which revealed that countries in Asia, Americas, and Europe have greater research focus on the application of digital technologies in the construction industry compared to those in the other continents. This is not particularly surprising because the general uptake and application of technologies in most of the countries on the African continent is low. In fact, studies suggest that countries from Americas, Europe, Australia, and Asia are the most digitally innovative in the world (Martınez-Aires et al., 2018; Institute of Management, 2018). Again, the bibliographic coupling of authors and the analysis of authors affiliation confirm that authors affiliated to African institutions have not yet made a great contribution in this research area. This demonstrates a gap in this area of research in Africa. The implication is that academic and research institutions as well as researchers in Africa need to focus more attention on the application of technologies in the construction industry. Moreover, this opens up an opportunity for researchers in advanced countries such as Mainland China, United States, Canada, United Kingdom, Spain, Sweden and Australia to collaborate with those on the Africa continent.

Six clusters emerged from the network of keywords; however, Clusters 2 and 5 had similar keywords which were highlighted as purple-blue and purple. Keywords in Clusters 4 and 6, were highlighted in blue-green and green whilst the keywords in Clusters 1 and 3 were highlighted in yellow-green and yellow. As much as six clusters emerged, three distinct stages/phases could be associated with the trend and evolution of the FM technologies. The analysis of the topics also reveals similar trend. Clusters 2 and 5 make up the first phase, Clusters 4 and 6 make up the second phase, and Clusters 1 and 3 make up the third phase. It can be inferred that most of the keywords identified in Clusters 2 and 5 are highlighted in purple. It is evident that such keywords dominated until the year 2010. The keywords reveal the trend of research from 2000 until 2010. Topics such as "energy solution for sports facilities" (Artuso and Santiangeli, 2008), "the potential effect of end-users on energy conservation in office buildings" (Junnila, 2007), "decision model for energy performance improvements in existing buildings" (Augenbroe et al., 2009) dominated this period. It can be inferred that the trend of research during this period was on achieving efficiency, optimizing cost, and reducing utility bills through the application of building automation systems, communication technologies and energy management system. Basically, the first era of FM technology evolution was marked by energy efficient/management technologies. This was the era where much attention was placed on technologies such as energy management system, building automation systems, computarised maintenance management system, electronic document management system and computer aided facility management (Araszkiewicz, 2017).

It is evident that the keywords identified in Cluster 4 and 6, i.e., green/blue-green, dominated between 2011 and 2017. Some of the topics that confirm the trend of FM technologies during this period are "developing mobile BIM/2D barcode-based automated facility management system" (Lin et al., 2014), "BIM for facilities management: evaluating bim standards in asset register creation and service life planning" (Patacas et al., 2015), "a framework for the utilization of BMS data in building information models for building design and operation" (Oti et al., 2016), and V3dm+: BIM interactive collaboration system for facility management (Lee et al., 2016). The keywords and document analysis suggest that the use of automation, simulation, computer aided design, and BIM technologies were frequently adopted for FM during this era. The era was dominated by the use of BIM as an FM tool to ensure the effective management of organisation's facilities and to promote the wellbeing of facility users. Thus, BIM technology application dominated this era.

The keywords that dominated in Clusters 1 and 3 were yellow in colour demonstrating that such keywords dominate from 2018. The fourth industrial revolution has paved way for the development and advancement of several technologies some of which are adopted in FM. Some of the notable keywords in Cluster 3 are BIM technologies, big data, digital twin and internet of things. These keywords correspond with the document/topic analysis. Some of the topics revealing this trend are "cup-of-water theory: a review on the interaction of BIM, IoT and blockchain during the whole building lifecycle" (Ye et al., 2018), "supporting facility management processes through end-user's integration and coordinated BIM-GIS technology" (Mirarchi et al., 2018), "BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase" (Hu et at., 2018), "automating the creation of building information models for existing buildings" (Bortoluzzi et al., 2019), "trends in adopting BIM, IoT and DT for facility management: a scientometric analysis and keyword co-occurrence network review" (Siccardi and Villa, 2023). It is evident that BIM is still very relevant in the FM field. Other technologies that have gain popularity in this era are augmented and virtual reality and robotics. The uptake of similar technologies was identified by Akinlolu et al. (2020). To buttress, Ye et al. (2018), Valks et al. (2019), Siccardi and Villa (2023) and Sampaio et al. (2023) revealed that augmented reality, virtual reality, BIM technologies, internet of things, big data management systems, intelligent agents, semantic web technology, information system, intelligent agents, semantic web technology, drones, blockchain, cloud-based technologies and robotics are among the current technologies adopted to achieve effective facilities management. In essence, advanced BIM technologies, internet of things and the application of AI are the current trend in FM technologies.

Although 4IR has added an extra impetus to the uptake of technologies, the study reveals that Africa lags in both the development and adoption of technologies in facilities management. Several studies confirm that Africa lags in this area of research. This creates an opportunity for researchers on the continent to focus more attention in this research domain to help address the gap in this research area. This underscores the need for organisations and research institutions on the continent to provide support to promote this research agenda. This also opens up an opportunity for research collaboration and partnership with countries outside the continent – e.g Mainland China, United States, United Kingdom, Italy, Australia, China Taiwan, Malaysia, Canada, Spain, Czech Republic, Sweden South Korea – who have made progress in this research domain.

Apart from the 4IR drive for the uptake of technologies, COVID-19 also presented a 'new norm' where the use of technologies were inevitable. Although the pandemic is over, it underscored the need for organisation to adopt and where necessary adapt technologies to promote their operations. On the one hand, FM ought to promote overall health, safety and wellbeing of facility users; on the other hand, any pandemic, like Covid-19, will present a challenge to health, safey and wellbeing of facility users. This presents an opportunity for FM researchers to expand their research into technologies that can be adopted to promote and improve total health, safety and wellbeing of facility users.

■6.0 CONCLUSION

The application of technologies in FM have evolved over the years. This study presented a bibliometric review on the application of technology in FM using publications from the Scopus database. A total of 107 relevant publications were used for the analysis focusing on the number of publications annually, the publication distribution across countries and continents, bibliographic coupling of authors, citation of documents, and co-occurrence of keywords. On the one hand, it has been found that studies on the application of digital technologies in FM has significantly increased over the years. On the other hand, it became evident that this area of research is under-represented on the African continent. This implies that researchers on the continent have a responsibility to focus more attention in this research domain to help address the gap in this research area. Government, research institutions and other stakeholders on the continent also have a responsibility to provide support to promote this research agenda. Both the keywords and the documents citation analysis were done to provide researchers with a trend of existing literature on FM technologies. The keywords and the documents citation analysis revealed three distinct phases in the evolution of the FM technologies. The first phase focused on achieving FM efficiency through the application of building automation systems, communication technologies and energy management system; the second phase related to the

use of automation, simulation, and bim technologies in FM; whilst the third, current phase, is the use of augmented reality, big data, digital twin, virtual reality, bim technologies, internet of things, semantic web technology, and robotics in FM. This trend provides a direction to guide future investigation in this area of research. The representation of publications presented in this study are somewhat limited since the data set used for the analysis was limited to Scopus database. Furthermore, only documents published in English were considered, excluding other possibly relevant documents published in other languages. French is popular language in Africa; thus, limiting the search to only articles published in English presents a further limitation. Therefore, the study recommends further studies be conducted using more than one database and possibly other languages. Moreover, the focus of this paper was on the trends of technologies adopted for FM over the past 23 years, further study could focus on the role and functions of technologies in FM.

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References

Adama, U. and Michell, K. (2017). Potential effects of technical innovations on facility management practice. Available at: http://www.ureru.uct.ac.za/sites/default/files/image_tool/images/383/Effects%20of%20Technological%20Innovations%20on%20FM%20Practoce.pdf (accessed on 23rd January 2022).

Aghimien, D., Aigbavboa, C., Oke, A. and Thwala, W. (2019). Mapping out research focus for robotics and automation research in construction-related studies: A bibliometric approach. *Journal of Engineering, Design and Technology*, 18(5), 1063-1079.

Agyekum, K., Pittri, H., Botchway, E. A., Amudjie, J., Kumah, V. M. A., Kotei-Martin, J. N., and Oduro, R. A. (2022). Exploring the Current Technologies Essential for Health and Safety in the Ghanaian Construction Industry. *Merits* 2022(2), 314-330. https://doi.org/10.3390/merits2040022.

Akinlolu, M., Haupt, T., Edwards, D. J. and Simpeh, F. (2020). A bibliometric review of the status and emerging research trends in construction safety management technologies. *International Journal of Construction Management*, DOI:10.1080/15623599.2020.1819584.

Akram, R., Thaheem, M. J., Nasir, A. R., Ali, T. H. and Khan, S. (2019). Exploring the role of building information modelling in construction safety through science mapping. *Safety Science*, 120, 456–470.

Araszkiewicz, K. (2017). Digital Technologies in Facility Management – The state of Practice and Research Challenges. *Procedia Engineering*, 196, 1034-1042.

Artuso, P. and Santiangeli, A. (2008). Energy solutions for sports facilities. *International Journal of Hydrogen Energy*, 33(12), 3182-3187.

Ahsan, S., El-Hamalawi, A., Bouchlaghem, D., and Ahmad, S. (2007). Mobile Technologies for Improved Collaboration on Construction Sites. *Architect Eng Des Manag*., 3(4), 257–272.

Amaratunga, R. D. G. (2001). Theory building in facilities management performance measurement: application of some core performance measurement and management principles. PhD thesis, University of Salford.

Atkin, B. and Brooks, A. (2015). *Total Facility Management*. Fourth Edition, John Wiley and Son New York, NY.

Augenbroe, G., Castro, D. and Ramkrishnan, K. (2009). Decision model for energy performance improvements in existing buildings. *Journal of Engineering, Design and Technology*, 7(1), 21-36.

Becker, F. (1990). The total work place; facility management and elastic organisation. New York: Van Nostrand Reinhold.

Bortoluzzi, B., Efremov, I., Medina, C., Sobieraj, D. and McArthur, J. J. (2019). Automating the creation of building information models for existing buildings. *Automation in Construction*, 105, https://doi.org/10.1016/j.autcon.2019.102838.

Bröchner, J. (2003). Integrated Development of Facilities Design and Services. *Journal of Performance of Constructed Facilities*, 17(1).

Chadegani, D. A. A., Salehi, H., Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M. and Ebrahim, N. A. (2013). A comparison between two main academic literature collections: web of science and Scopus. *Asian Social Science*, 9(5), 18-26.

Donthu, N., Kumar, S., Pandey, N. and Lim, W. M. (2021). Research Constituents, Intellectual Structure, and Collaboration Patterns in Journal of International Marketing: An Analytical Retrospective. *Journal of International Marketing,* 29(2), 1-25.

Elmualim, A. and Pelumi-Johnson, A. (2009). Application of computer-aided facilities management (CAFM) for intelligent buildings operation. *Facilities*, 27(11/12), 421-428.

Ejidike, C. C., Mewomo, M. C., and Anugwo, I. C. (2022). Assessment of construction professionals' awareness of the smart building concepts in the Nigerian construction industry. *Journal of Engineering, Design and Technology*, (ahead-of-print).

Gheisari, M. and Irizarry, J. (2016). Investigating human and technological requirements for successful implementation of a BIM-based mobile augmented reality environment in facility management practices. *Facilities*, 34(1/2), 69-84.

Golabchi, A., Akula, M. and Kamat, V. (2016). Automated building information modelling for fault detection and diagnostics in commercial HVAC systems. *Facilities*, 34(3/4), 233-246.

Golparvar-Fard, M., Peña-Mora, F., and Savarese, S. (2011). Integrated sequential as-built and as-planned representation with D4AR tools in support of decision-making tasks in the AEC/FM industry. *Journal of Construction Engineering and Management,* 137(12), 1099-1116. DOI:10.1061/(ASCE)CO.1943-7862.0000371.

Hosseini, M. R., Maghrebi, M., Akbarnezhad, A., Martek, I. and Arashpour, M. (2018). Analysis of Citation Networks in Building Information Modelling Research. *Journal of Construction Engineering and Management*, 144(8).

Hossain, M. A. and Yeoh, J. K. W. (2018). BIM for Existing Buildings: Potential Opportunities and Barriers, *IOP Conference Series: Materials Science and Engineering*, 371, 3rd International Conference on Building Materials and Construction (ICBMC 2018) 23–25 February 2018, Nha Trang, Vietnam.

Hu, Z. Z, Tian, P., Li, S. W, and Zhang, J. P. (2018). BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase. *Advances in Engineering Software*, 115, 1-16.

Hsieh, C.-C., Liu, C.-Y., Wu, P.-Y., Jeng, A.-P., Wang, R.-G., and Chou, C.-C. (2019). Building information modelling services reuse for facility management for semiconductor fabrication plants, *Automation in Construction* 102, 270-287.

Institute of Management (2018). World digital competitiveness ranking [accessed on 2020 July 15]. www.imd.org/wcc/world-competitiveness-centerrankings/world-digital-competitiveness-rankings-2018/.

Junnila, S. (2007). The potential effect of end-users on energy conservation in office buildings. *Facilities*, 25(7/8), 329-339.

Kabir, I., Fredrick, S. and Oluseyi, A. (2023). Benefits and challenges of wearable safety devices in the construction sector. *Smart and Sustainable Built Environment.* 10.1108/SASBE-12-2022-0266.

Karan, E. P. and Irizarry, J. (2014). Developing a spatial data framework for facility management supply chains. Construction Research Congress 2014: Construction in a Global Network. https://doi.org/10.1061/9780784413517.239.

Koch, C., Hansen, G. K. and Jacobsen, K. (2017). Yet another trojan horse? Is facility management ready for digitalisation? in Ruddock, L., Van-Dijk, H. and Houghton, C. A. M. (Eds), International Research Conference 2017: Shaping Tomorrow's Built Environment Conference Proceedings, University of Salford, Salford, 300-311.

Lee, W. L., Tsai, M. H., Yang, C. H., Juang, J. R. and Su, J. Y. (2016). V3DM+: BIM interactive collaboration system for facility management. *Visualization in Engineering*, 4(5), 1-15

Lin, Y. C., Su, Y. C., and Chen, Y. P. (2014). Developing mobile BIM/2D barcode-based automated facility management system. *The Scientific World Journal*, 4.

Lin, Y. C. and Su, Y.C. (2013). Developing Mobile- and BIM-Based Integrated Visual Facility Maintenance Management System. *The Scientific World Journal*, 10. https://doi.org/10.1155/2013/124249.

Loftness, V., Aziz, A., Choi, J., Kampschroer, K., Powell, K., Atkinson, M., and Heerwagen, J. (2009). The value of post-occupancy evaluation for building occupants and facility managers. *Intelligent Buildings International*, 1(4), 249-268. DOI:10.3763/inbi.2009.SI04.

Mařík K., Rojíček J., Stluka P., and Vass J. (2011). Advanced HVAC Control: Theory vs. Reality. IFAC Proceedings Volumes, 44(1), 3108-3113.

Martínez-Aires, M. D., López-Alonso, M. and Martínez-Rojas, M. (2018). Building information modeling and safety management: a systematic review. *Safety Sci*., 101, 11-18.

Mayo, G. and Issa, R. R. A. (2016). Nongeometric Building Information Needs Assessment for Facilities Management. *Journal of Management in Engineering*, 32(3)

Mirarchi, C., Pavan A., De Marco F., Wang X., and Song Y. (2018). Supporting Facility Management Processes through End-Users' Integration and Coordinated BIM-GIS Technologies. *International Journal of Geo-Information*, 7(5), 1-20.

Nnaji, C., Awolusi, I., Park, J., and Albert, A (2021). Wearable Sensing Devices: Towards the Development of a Personalized System for Construction Safety and Health Risk Mitigation. Sensors 2021, 21, 682.

Olawumi, T. O., and Chan, D. W. M. (2018). A Scientometric Review of Global Research on Sustainability and Sustainable Development. *Journal of Cleaner Production*, 183, 231–250.

Oti, A. H., Kurul, E., Cheung, F. and Tah, J. H. M. (2016). A framework for the utilization of Building Management System data in building information models for building design and operation. *Automation in Construction*, 72(2), 195-210.

Patacas, J., Dawood, N., Vukovic, V. and Kassem, M. (2015). BIM for facilities management: evaluating BIM standards in asset register creation and service life planning", *Journal of Information Technology in Construction*, 20, 313-331.

Re Cecconi, F., Maltese, S. and Dejaco, M. C. (2017). Leveraging BIM for digital built environment asset management. *Innovative Infrastructure Solutions,* 2(1). ISSN: 2364-4176

Sampaio, R. P, Costa, A. A. and Flores-Colen, I. (2023). A discussion of digital transition impact on facility management of hospital buildings. *Facilities*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/F-07-2022-0092

Siccardi, S. and Villa, V. (2023). Trends in adopting BIM, IoT and DT for facility management: a scientometric analysis and keyword co-occurrence network review. *Buildings*, 13(1), 15 - 28.

Singh V., Gu N. and Wang X. (2011). A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in Construction*, 20(2), 134-144,

Støre-Valen, M. and Buser, M. (2019). Implementing sustainable facility management: Challenges and barriers encountered by Scandinavian FM practitioners. *Facilities*, 37(9-10), 550-570.

Torrington, J. (2007). Evaluating quality of life in residential care buildings. *Building Research & Information*, 35(5), 514-528.

Tucker, M. and Masuri, M. R. A. (2016). The rationale to integrate facilities management into the development process. *Property Management*, 4(34), 332-344.

Valks, B., Arkesteijn, M. and Den Heijer, A. (2019). Smart campus tools 2.0 exploring the use of real-time space use measurement at universities and organizations. *Facilities*, 37(13/14), 961-980.

Van Eck, N. J. and Waltman, L. (2014). Visualizing bibliometric networks. In Y. Ding, R. Rousseau, & D. Wolfram (Eds.), Measuring scholarly impact: Methods and practice, 285–320.

Van Eck, N. J. and Waltman, L. (2019). Manual for VOSviewer version 1.6.13.

Verma, S. and Gustafsson, A. (2020), Investigating the emerging COVID-19 research trends in the field of business and management: A bibliometric analysis approach. *Journal of Business Research*, 118, 253-261.

Villa, V., Naticchia, B., Bruno, G., Aliev, K., Piantanida, P., and Antonelli, D. (2021). IoT open-source architecture for the maintenance of building facilities. *Applied Sciences*, 11(12):5374. https://doi.org/10.3390/app11125374.

Ye Z., Yin M., Tang L., and Jiang H. (2018). Cup-of-Water theory: A review on the interaction of BIM, IoT and blockchain during the whole building lifecycle. Proceedings of the 35th International Symposium on Automation and Robotics in Construction (ISARC) (2018): n. pag.

Xu, M., David, J. M. and Kim, S. H. (2018). The Fourth Industrial Revolution: Opportunities and Challenges. *International Journal of Financial Research,* 9(2), 90-95.

Zhang, J., Seet, B., and Lie, T. T. (2015). Building Information Modelling for Smart Built Environments. *Buildings*, 5, 100-115.