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Systematic Review

A Review of Building Information Modelling (BIM) for Facility Management (FM): Implementation in Public Organisations

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Abstract: Building Information Modelling (BIM) has been extensively studied and applied within the AEC sector, particularly in design and construction. In recent years, Facility Management (FM) processes are becoming more digitalised, thus requiring effective BIM-FM integration. BIM adoption in many countries, such as the UK, Italy and Brazil, has been publicly driven. Generally, adoption was targeted at design and construction implementation, with little effort in framing public action for FM implementation. The lack of an integrated approach for BIM-FM implementation resulted in numerous bespoken implementation approaches that mimic the private sector and hinder knowledge exchange. Therefore, there is a need for assessing and amalgamating knowledge about BIM-FM for public organisations. This research aims to leverage knowledge about BIM-FM in the public domain by analysing and classifying articles published between 2010–2021. The research was carried out through a systematic review and comparative thematic analysis investigating the use of BIM for different public buildings (e.g., schools and hospitals) and the implementation for FM purposes. Research results outline prevalent trends and areas of research from three perspectives: people, process and technology. Results show an increasing number of publications about BIM-FM. However, the divide between BIM-FM for public and private organisations is unequal. BIM-FM research for public organisations is still limited and lacks standardisation. This state-of-the-art review makes an incremental contribution to knowledge by identifying progress, gaps and new industry directions on the subject matter.

Keywords: Building Information Modelling (BIM); Facility Management (FM); public buildings

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1. Introduction

Facilities management is an area that benefits the most from BIM, yet it is the least developed area regarding implementation. Much of the BIM for design and construction literature has informed hard FM and capital expenditure (Capex) projects. However, research is still embryonic concerning soft FM and operational expenditure (Opex). Implementing building information modelling became crucial in the context of extreme pressures arising from climate change, reduced budgets for building operations and maintenance and current and future unforeseen events, such as the COVID-19 pandemic. Despite the potential for alleviating such pressure, its wider adoption by the public sector has not yet materialised. Whereas some movement has been seen in the private sector, BIM-FM within the public sector is still primarily the result of pilot research implementations. The mandate that stimulates BIM use for Capex projects did not have the same effect on Opex. Much still needs to be carried out to support BIM-FM implementation for public organisations.

Furthermore, FM represents one of the fastest-growing real estate and construction sectors [1,2], making BIM-FM even more relevant. In addition, many governments (e.g., UK, Australia, The Netherlands) have highlighted the need to revolutionise the FM sector by increasing the adoption of digital technologies [2,3]. Managing assets and asset information

has thus become one of the most critical areas for facility managers. It involves collecting data about assets from the earlier phases of the building life cycle, performing analysis and using them for decision support throughout the operations phase [2,4]. Hence, achieving asset operation efficiency through asset data availability is fundamental to reaching an improved total cost of ownership, especially for large and public buildings, where the range and complexity of the assets are more significant than for residential ones [5]. Therefore, BIM supporting lifecycle information management can unlock large economies of scale.

Concerning BIM adoption, to the present day, greater scholarly attention has been paid to the design and construction phases. Notwithstanding long-term benefits, emphasis has been given to the immediately tangible outcomes from the earliest process stages of a building project [6–10]. Levels of BIM adoption have revealed that it has been used most extensively in the first phases, whereas adoption and use for facility management is still a new issue [11,12], particularly in relation to its benefits to organisations (rather than projects). In addition, considering that the administration of public money differs from that of private organisations, the value proposition of BIM adoption (to a certain extent) is also different from that of private organisations. Therefore, BIM implementation differs in many aspects, such as training scalability. In other words, if the public sector is to provide training, how can training be achieved at such a large sector and who receives training first (i.e., hospitals, schools or other types of public infrastructure)? Such differences underpins the justification for further investigations.

Then, regarding challenges for implementation, the lack of BIM-FM expertise among professionals and the lack of support in the form of guidance and standards contribute to the low adoption rates for BIM-FM implementation [13]. Furthermore, many public bodies at different levels have established BIM programs, set up BIM goals and implementation roadmaps and published BIM standards [7]. Therefore, as public actors, they perform a crucial role in leading and supporting the industry towards BIM implementation.

In recent years, the BIM spread continues to increase intensively as many government bodies and non-profit organisations of different countries worldwide introduced BIM in their projects and provided BIM implementation's paths. However, nowadays, research and studies about the public sector's actions and efforts for BIM adoption do not look sufficient [7]. Even large public owners who have been early adopters of BIM, such as GSA or Senate Properties, have mainly used BIM to manage their construction projects rather than implement it into their operations and maintenance activities [14]. However, in some countries, the adoption of BIM in the FM stage is required, leading to a significant increase in the industry's interest in BIM-based FM in response to such policies [15]. Therefore, BIM has become an over-researched area when looking at design and construction matters; facility management topics are increasing, but not many articles have looked at BIM-FM, especially from a public perspective.

Previous studies in this area have focused mainly on applying building information modelling in the FM field in general [16–18], approaching the subject from a practical point of view [19–21] and without an in-depth analysis of the public involvement. On the other hand, several researchers investigated BIM-FM adoption, considering both the public and private sectors and discussing the overall implementation status [18,22]. Moreover, to a significant extent, scientific contributions provide sector-based works on BIM-FM implementation, dealing with investigations falling into specific contexts or specific topic areas. For example, Olanrewaju et al. [23] consider the level of BIM-FM in the public industry in Nigeria, Yang and Chou [24] review the integration status in Taiwan, Rahman et al. [25] analyse industry awareness in Brunei and Latif et al. [26] consider the Malaysian framework; on the other hand, other studies develop reviews on specific aspects of BIM for FM within the public sector. For instance, Fernández et al. [27] provide a review on MEP issues, Latif et al. [26] present a study on the level of BIM-FM adoption for controlling energy performance; Di Giuda et al. [28] represent the state-of-the-art of methods and tools (included BIM) for post-occupancy evaluations. Moreover, several publications review specific building categories without cross analysing results across different building

types. Examples of this type of research include Pavón et al. [20], whose study focused on hospitals, or Latif et al. [26], Pinti et al. [29] and Mirarchi et al. [30], who concentrate on educational buildings.

Overall, much of BIM-FM research focuses on school or hospital buildings or specific themes within the area of BIM-FM, such as IoT and virtual reality. So far, no review has covered various topics simultaneously aiming to analyse the progress of BIM-FM in public organisations. Therefore, discussions concerning the broad implementation of BIM are scarce. Thus, investigating the current situation regarding BIM-FM implementation in the public domain is necessary to assess the state-of-the-art and identify research trends and future developments.

In light of these issues, this research aims to report on the status of BIM for FM in the public domain through a systematic review based on research articles published between 2010 and 2021. 2010 was considered to be a plausible landmark for starting the investigation because, prior to that, very little was discussed about standards for BIM implementation in general, and even less for facilities management. In addition, some of the currently available technology to enable collaboration (such as Clouds for CDEs) was very embryonic. It was also considered that international leveraged discussions about BIM implementation started back in 2009 with the establishment of the UK Mandate. The message within the mandate echoed the developments in research and practice taking place in Finland, the USA and the UK (initially). It also triggered action in other countries and communities, such as CEN in Europe. The investigation focused on answering the following central question: What is the status of BIM use and knowledge in managing public buildings? To answer such a question, this article is structured in the following manner: Section 2 describes and justifies the research method and classification criteria used to identify, include and exclude articles from the review; Section 3 presents both a bibliometric and thematic analysis of the selected sources; finally, Section 4 discusses the final results.

2. Materials and Methods

This research is based on some aspects of Systematic Literature Reviews (SLR). SLR was deemed appropriate since it targets specific criteria, thus filtering relevant articles from many BIM articles published within the last ten years. SLRs are also suitable for mapping out research and identifying trends. The SLR developed in this research focused on public-sector BIM-FM implementation within the public section from 2010 to 2021. Anything published before 2010 was considered to be potentially superseded by the panel of experts that suggested 2010 as a baseline year. The Population, Intervention, Comparison, Outcome (PICO) was used to narrow the research scope (Table 1). In addition, a research protocol was established to synthesise the structure and criteria for conducting the SLR (Table 2).

Table 1. PICO table.

Item	Content
Population	Buildings owned and managed by the public sector
Interventions	All instances referring to the status of BIM use and knowledge in managing public buildings
Comparisons	Thematic comparative analysis of building typologies, trends and research areas concerning people, process and information technology
Outcomes	Similarities and differences in outcomes
Study method	Quantitative and qualitative analysis

Table 2. Research protocol.

Item	Content
Aim	
Key-objective	To establish contextual knowledge on BIM-FM implementation and research in the public domain through the analysis and classification of articles published between 2010–2021
Research Questions	
Main question	What is the status of BIM use and knowledge in managing public buildings?
Sub-questions	Which types of public buildings have demanded or used BIM for FM? To what extent is BIM-FM research addressing people, process and IT issues?
Search Methods	
Electronic Databases	Scopus; Web of Science
Selection criteria-Filters	
Keywords	((“BIM” OR “Building information model*”) AND (“fm” OR “Facilit* management”) AND (“Public”))
Year of publication	2010–2021 inclusive
Type of publication	Articles, books, book chapters, conference papers.
Idiom	English
Exclusion criteria	
	Not related to BIM-FM, public, outside the investigated area of research
	Outside the defined period
	Abstract not available for download
	Not written in the defined idioms
Method of Review	
Data extraction	Excel spreadsheets to track papers and status based on the protocol. One reviewer (author) to action.
Narrative Synthesis	Bibliometric Analysis: • Geographical location of authors; • Publications over time; • Publications’ distribution in journals; • Methodology applied. Thematic Analysis: • Analysis of selected publications: building type, research focus, people, process or IT research; • Description of findings, outcomes and relationships.

The Scopus Database, coupled with the Web of Science, was considered as appropriate for this study since it provides relevant scientific publications on the theme. Therefore, two rounds of research were performed. Firstly, the keywords and Boolean operators used to select publications of interest included “BIM, Building Information Model*” AND “FM, Facilit* Management”. The first round, depicted in Figure 1, generated an overview of BIM-FM research within the studied period and initial insights regarding the industry inclination towards BIM-FM implementation. The period set for this step was 1988 to 2021 to identify early publications related to BIM-FM. Subsequently, in round two, the keyword “public” was added to the screening process, and the period was constrained to 2010 to 2021. This round was relevant for identifying key contributions related to the public sector and generating comparisons between public and private BIM-FM implementation. Round two steps are presented in the Prisma flow diagram (Figure 2).

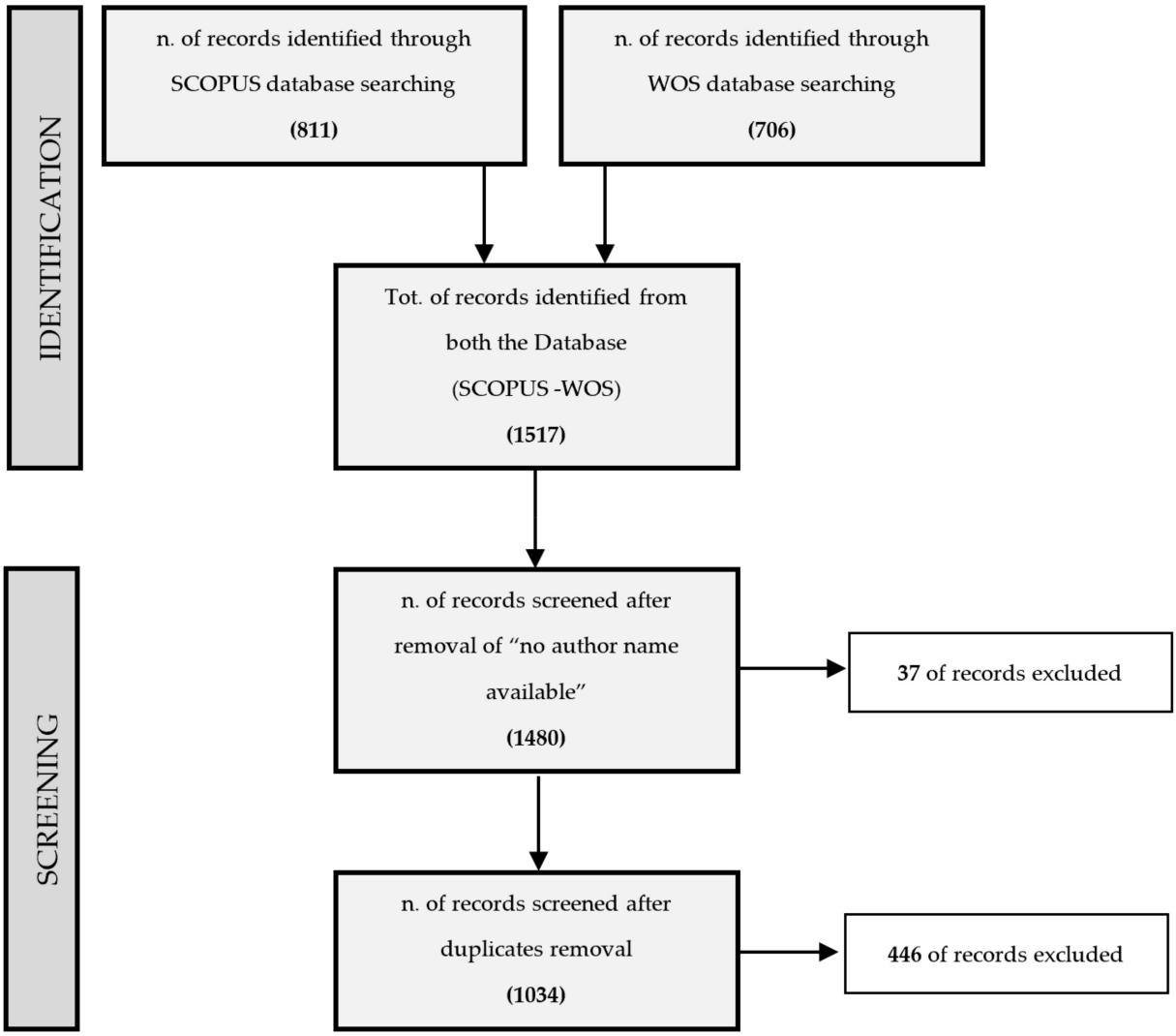

Figure 1. PRISMA diagram BIM-FM.

Figure 1 below shows the number of retrieved publications related to BIM-FM. In the sequence, Figure 2 shows the breakdown of the papers included in the review after applying the research protocol. Initially, 1517 records were collected and 483 were excluded. Therefore, a preliminary investigation outlines that 1034 publications discuss BIM in facility management; among them, only a minor part treats the subject in the public field. Thus, to address the study's objective, 122 publications were reviewed for the analytical investigation in the second stage: from 122 identified entries, 67 were considered eligible for further analysis after the screening process.

The selection criteria of a ten-year term were chosen to look at the evolution of the area concerning BIM-FM scientific production first and then BIM-FM in public contexts, since this is the period where issues on the theme are rapidly increasing. The period could be considered comprehensive for the usual period of systematic review in general, but, in this case, the decision was made to generate a robust sample.

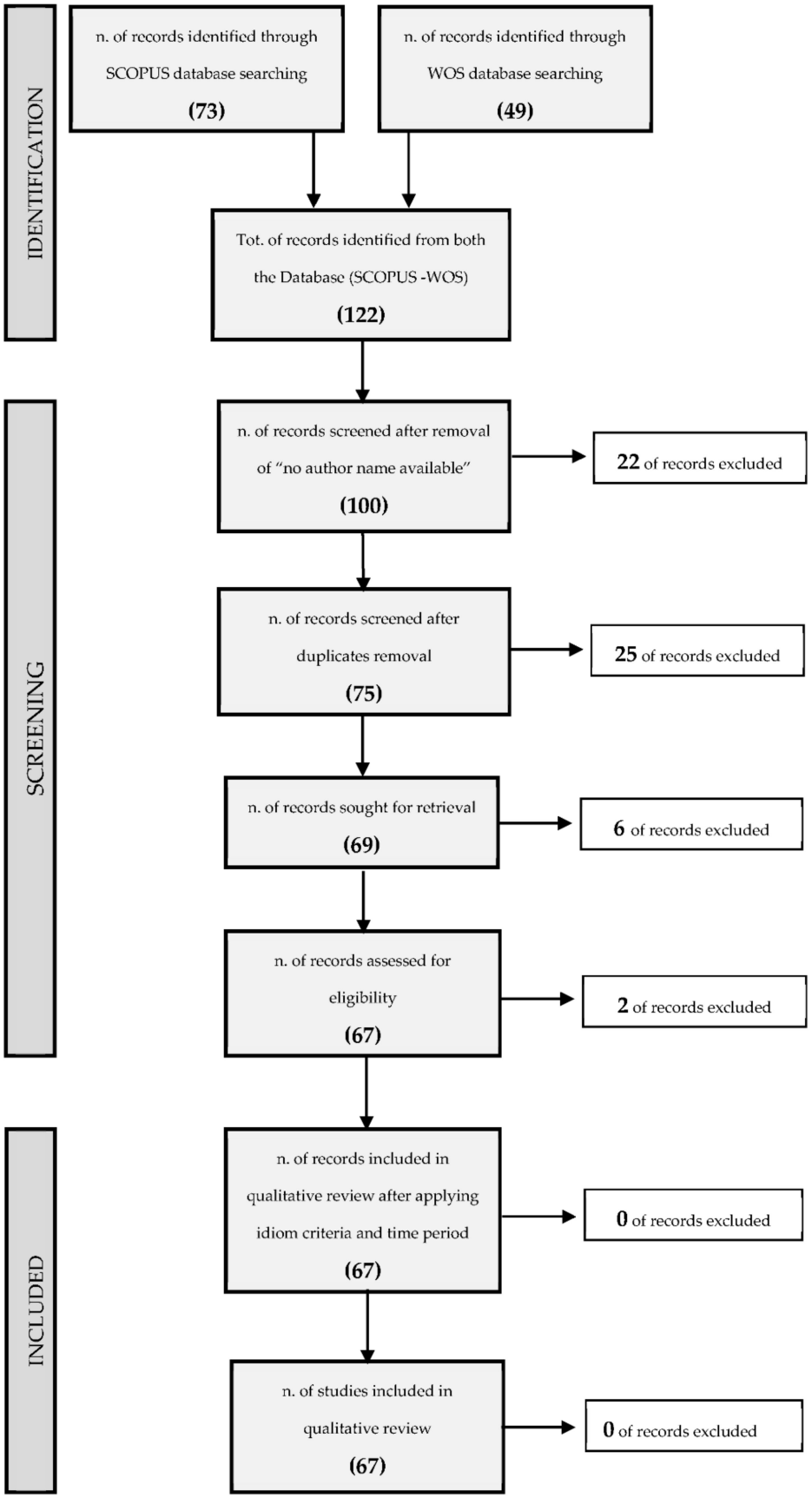

Figure 2. PRISMA diagram BIM-FM-Public.

3. Results

3.1. Bibliometric Analysis

Bibliometric analysis was used as an evaluation tool within qualitative research methods [31] since it can assess the impact of reviewed publications, and results can support decision-making processes [31]. The first analysis focused on the distribution of journal publications over time. As seen in Figures 3 and 4, studies about "BIM-FM" and "BIM-FM and Public" follow the same increasing trend. The years around 2015 have seen a significant change in the curve, with a peak in 2019–2020. However, studies related to the public sector only represent 15% of the articles. In addition, the curve for other than public sector studies is steeper, showing a faster growth for non-public buildings.

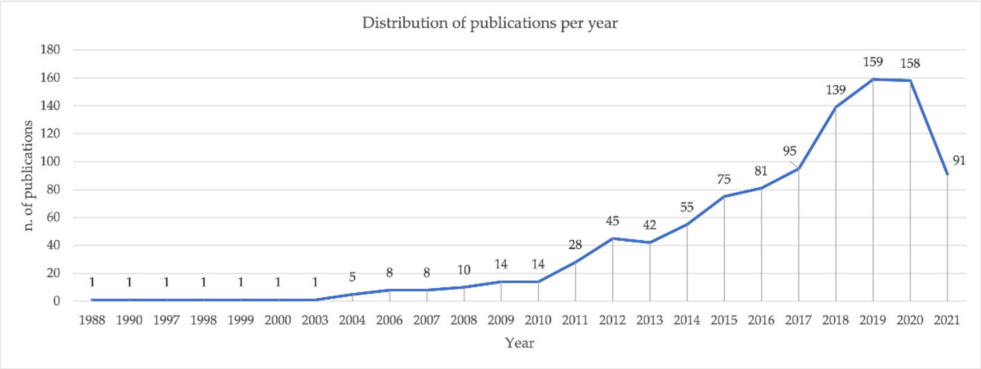

Figure 3. BIM-FM distribution of publications 1988–2021.

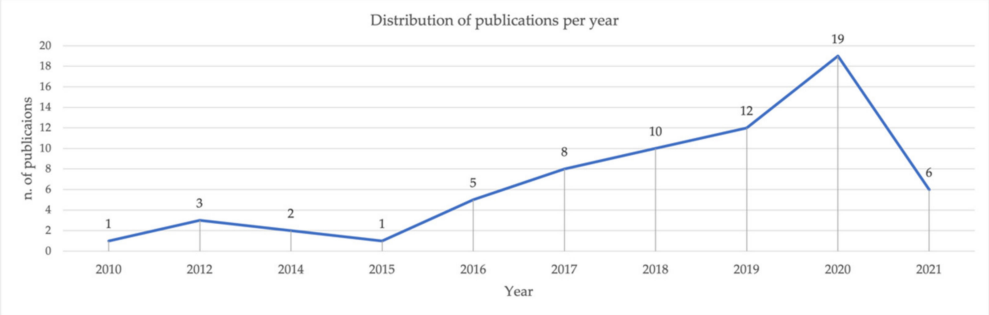

Figure 4. BIM-FM-Public distribution of publications 2010–2021.

Regarding scientific publications within peer-reviewed journals and conferences where research has been published, the results show that no specific publisher has been targeted for BIM-FM in the public domain. The detailed distribution of the articles within specific journals is illustrated in Table 3. The data show that BIM-FM for public assets is considered as a cross-cutting theme. There is a predominance of titles that focus on technology and an absence of publications in journals focused on public sector management.

Moreover, the bibliometric study shows the world regional distribution of research authors concentrating on BIM-FM in the public environment, as illustrated in Figure 5.

Table 3. Distribution of records published in journals per year.

Journal	2010	2012	2014	2015	2016	2017	2018	2019	2020	2021	Sub.
eWork and eBusiness in Architecture, Engineering and Construction					2		2				**4**
Research for Development									3		**3**
Sustainability									2	1	**3**
Facilities								1		2	**3**
Journal of Information Technology in Construction		1					1				**2**
Journal of Building Engineering							1	1			**2**
Applied Sciences									2		**2**
Automation in Construction					1	1					**2**
Congress on Computing in Civil Engineering, Proceedings				1		1					**2**
Journal of Facilities Management									1	1	**2**
EDULEARN19 Proceedings: 11th International Conference on Education and New Learning Technologies								1			**1**
Computing in Civil and Building Engineering-Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering			1								**1**
BIM for Facility Managers							1				**1**
Built Environment Project and Asset Management								1			**1**
Construction Management and Economics									1		**1**
ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences								1			**1**
Advances in Intelligent Systems and Computing								1			**1**
Proceedings of International Structural Engineering and Construction									1		**1**
Building Cost Planning for the Design Team: 3rd edition					1						**1**
Computers in Industry										1	**1**
Applied Geomatics							1				**1**
Proceedings of the 22nd International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2017): Protocols, flows and glitches						1					**1**
eCAADe SIGraDi 2019: Architecture in the Age of the 4th Industrial Revolution, Volume 2								1			**1**
ISEC 2019—10th International Structural Engineering and Construction Conference								1			**1**
Energies										1	**1**
6th CSCE-CRC International Construction Specialty Conference 2017—Held as Part of the Canadian Society for Civil Engineering Annual Conference and General Meeting 2017						1					**1**
Journal of Marine Science and Engineering									1		**1**
Journal of Computing in Civil Engineering									1		**1**
Journal of Sustainable Architecture and Civil Engineering									1		**1**
Association of Researchers in Construction Management, ARCOM 2012—Proceedings of the 28th Annual Conference		1									**1**
Lecture Notes in Mechanical Engineering									1		**1**
MATEC Web of Conferences							1				**1**
Lecture Notes in Civil Engineering									1		**1**
Frontiers of Engineering Management									1		**1**
Less More Architecture Design Landscape		1									**1**
Green Construction and Engineering Education for Sustainable Future						1					**1**
Open Construction and Building Technology Journal						1					**1**
IFIP Advances in Information and Communication Technology			1								**1**

Table 3. *Cont.*

Journal	2010	2012	2014	2015	2016	2017	2018	2019	2020	2021	Sub.
Proceedings of the 2018 IEEE International Conference on Advanced Manufacturing, ICAM 2018								1			**1**
INTED2017: 11th International Technology, Education and Development Conference						1					**1**
Proceedings of the 36th International Symposium on Automation and Robotics in Construction, ISARC 2019								1			**1**
International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences—ISPRS Archives	1										**1**
Scientia Iranica									1		**1**
International Journal of Strategic Property Management									1		**1**
7th International Conference on Engineering, Project, and Production Management 2016						1					**1**
International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM									1		**1**
in_bo-Ricerche e progetti per il territorio la città e l'architettura							1				**1**
IOP Conference Series: Earth and Environmental Science								1			**1**
EDULEARN16 Proceedings: 8th International Conference on Education and New Learning Technologies					1						**1**
IOP Conference Series: Materials Science and Engineering							1				**1**
25th International Conference on Fracture and Structural Integrity								1			**1**
ISARC 2018—35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things							1				**1**
Total	**1**	**3**	**2**	**1**	**5**	**8**	**10**	**12**	**19**	**6**	**67**
Journal with Impact Factor $\leq$ 3000											
Journal with Impact Factor 3001 $\leq$ x $\leq$ 6000											
Journal with Impact Factor $\geq$ 6001											

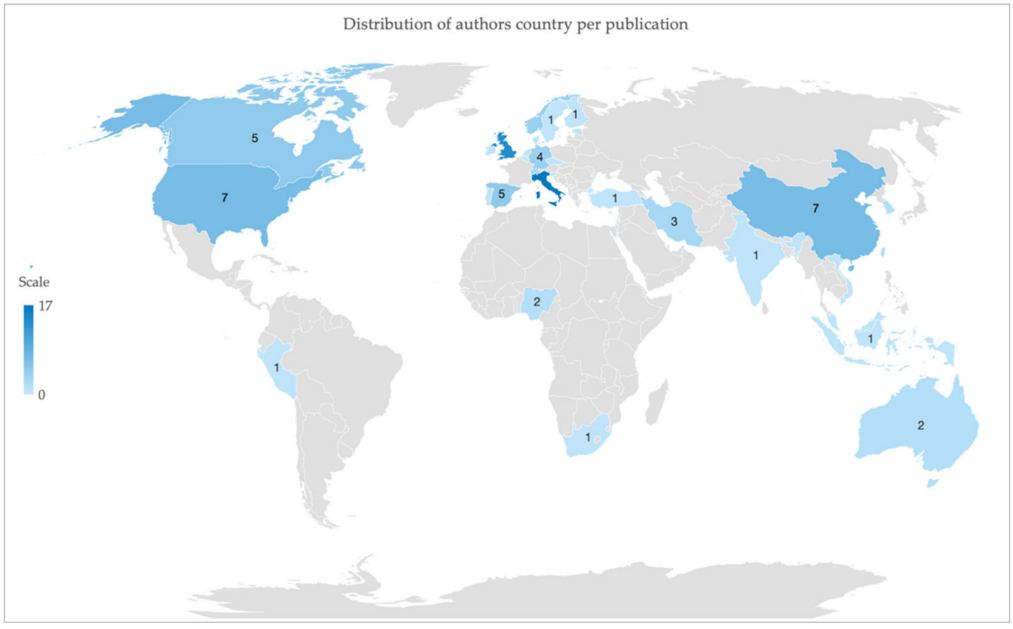

Figure 5. "BIM-FM-Public" distribution of authors per publication.

The authors are predominantly from Italy (17.17%) and the UK (14.14%), followed by China and USA (7.07% each). Approximately 45.45% of the total number of publications are distributed among these territories, whereas the remaining countries present fewer than five studies each, demonstrating research opportunities on the topic in those regions.

The last element explored within the bibliometric analysis was the research methods used to investigate BIM-FM in the public domain. Three research strategies are predominant in the sample analysed: case study research, literature reviews and mixed methods approach. Case study research is adopted in 33 of the research works, followed by the other two categories (literature and mixed methods), which count approximately the same number of studies (32). The distribution of research articles according to their research method is shown in Figure 6.

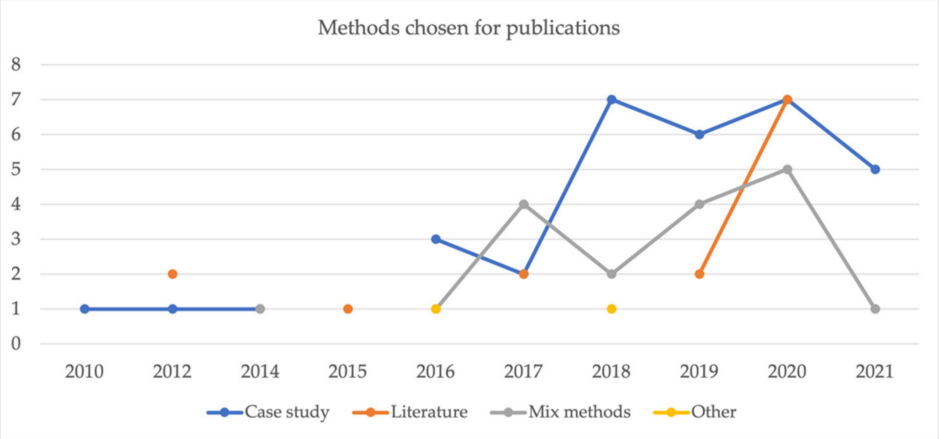

Figure 6. Research methodology of included publications.

3.2. Thematic Analysis of Selected Articles

3.2.1. Building Typology

The first element investigated within the thematic analysis was building typology. Next, the reviewed articles were classified into different categories according to the building's intended use, as presented in Table 4.

Table 4. "BIM-FM-Public" distribution of publication per building typology.

Buildings Typology	Numerical Reference of Reviewed Publications
Construction productivity/Manufacturing	[32,33]
Educational buildings	[19,20,26,29,30,34–39]
Generic	[11,16–18,21–25,27,28,40–61]
Historic monuments/buildings	[62]
Hospitals/Clinics	[63–68]
Infrastructures	[69–75]
Institutional buildings	[14,76]
Museums	[77]
Public urban space	[78–81]

The data highlight that, apart from research developed on the educational buildings category or the infrastructure one, most of the studies refer to BIM-FM implementation in the Public Administration (PA) field in general. There are also publications for which the "public" is not addressed as the main focus, but this issue can directly influence it. Therefore, in that category, publications on BIM-FM in the AEC industry in both the public or private context or dealing with public–private partnerships are included. In the *Generic*

category, there are also studies in which the specific public body is not explicitly mentioned, although it is evident that the studies referred to processes conditioned by the public management of assets. In Table 4, when a study addresses more building typologies, it is included in both the corresponding groups.

Publications within the *Generic* category include works such as Ullah et al. [16], who describe how public authorities are approaching BIM adoption, underlining planning strategies and steps of implementation. In addition, Kim et al. [17] explore the impacts of the lack of data in public organisations; Abdirad and Dossick [43] draw a map for collecting data through BIM in the management phase of two large public owners in the U.S; a similar approach, discussed from the point of view of public actors in general, is given by Brunet et al. [45], who define a methodological approach for taking advantages of BIM for asset management purposes. Other publications refer to the level of awareness that public players have in a broad meaning, assessing the current BIM execution level and public knowledge on this subject [25]. Finally, works such as Chung et al. [21] propose an information exchange process to effectively integrate BIM into AR-based smart maintenance on public facilities in general, not addressing a specific building typology.

Concerning school buildings within the *educational* category, Pavón et al. [19,20,34] set the research work on BIM-FM techniques and self-designed sensors for a University complex to develop a Smart Campus concept. Among contributions treating educational buildings, Latif et al. [26] approach the theme in Malaysian universities; then, Pinti et al. [29] and Mirarchi et al. [30] propose a study on approximately 450 school buildings of an Italian public authority, developing a system for adopting BIM in the facility management phase; Hijazi et al. [39] present a 3dwebGIS solution, whereas Ji et al. [37] present an augmented-reality-based system for the management of a university campus.

For *hospitals and clinics*, Alvanchi and Seyrfar [63] investigate how BIM can improve the FM phase in public hospitals in Iran, Koch et al. [64] examine FM digitalisation through BIM in Scandinavian hospital buildings, and, similarly, De Luca et al. [54] takes into account 42 clinics for the study.

In the end, within *infrastructures*, Valdepeñas et al. [69] concentrate on port infrastructures, applying BIM for its management and conservation; Besenyoi et al. [71] discuss the case of the Tempelhof airport, focusing on ordinary management tasks or event management purposes; and Liu and Gao [72] aim to support public authorities in adopting BIM for FM.

Overall, there is no specific theme that is explored per building typology. However, the overall theme of BIM implementation seems to refer, essentially, to either Capex projects or to the maintenance of the fabric of existing buildings (i.e., hard-FM), including planned and reactive maintenance. The body of knowledge is smaller concerning operational services (i.e., soft-FM), such as security, cleaning, waste management, etc. These aspects are further explained in the following.

3.2.2. Research Trends

The conducted thematic analysis provides evidence on the focus of research on hard-FM. In Table 5, publications about maintenance management and FM procedures represent a total of 28.72%, followed by 17.02% of studies focused on data and information exchange topics and 14.89% dedicated to the sector's current developments and awareness in approaching the theme. The last emerging category analyses PA procedures with BIM-FM (12.77%). Some of the studies consider more than one area, and, in such cases, it was considered within more than one group.

Table 5. Classification of research themes.

Year	Energy Management/ Plant Management	Cost Savings	Maintenance Management/FM	COVID-19 BIM Management/ Occupancy Level	PA role and Management/ Administrative Procedures	Data/Information Protocol/ AIM/Information Exchange	Current Development and Awareness in the Industry	Other
2010			1			1		
2012	1					2	2	
2014			2		2		2	
2015						1	1	
2016		3	1				1	
2017	1	1	3			1	1	2
2018	1	1	5		3	2	2	
2019	2		3		3	3		
2020	2	2	7	3	4	4	4	2
2021	1	1	5	1		2	1	1
Total	**8**	**8**	**27**	**4**	**12**	**16**	**14**	**5**

Concerning the maintenance management and facility management category, Pavón et al. [19,20] show some evidence that a BIM model can be set at the centre of the management phase since it could be connected to other applications, databases or FM tools for moving the building to a smart building. Valdepeñas et al. [69] concentrate on a maintenance database for maritime port infrastructures, and Alvanchi and Seyrfar [63] discuss, as the main topic, the improvement of facility management tasks enhancing coordination and communication in order to optimise costs and improve energy efficiency; this is the reason for why this publication is placed in multiple categories. Concerning BIM application to FM objectives, Besenyoi et al. [71] propose a system for managing unexpected FM activities for events or temporary situations. Guzzetti et al. [79] approach the theme of improving O&M through BIM and virtual reality, and Alvanchi et al. [32] focus on BIM-based corrective maintenance models. Kiviniemi and Codinhoto [76] document some of the issues involved in adopting BIM for the FM stage. Carbonari et al. [55] concentrate on a cyber-physical paradigm to guide O&M and the long-term refurbishment processes of buildings: real-time diagnosis, indoor comfort and health are some of the principal matters. Moreover, Lin et al. [65] attempt to build a GIS query and QR code model to establish a visual management system for maintenance functions. As mentioned before, publications in the maintenance management and facility management category focus on energy management aspects [19,55] or cost savings factors [19,57,63,66] several times, which are also placed in the corresponding categories.

The other relevant research objective when discussing BIM-FM implementation is related to information. For example, Kim et al. [17] highlight the relevance and also the efforts of defining an Asset Information Model (AIM) and concentrate on analysing the handover process, extracting data and populating the models with O&M documents; then, Dejaco et al. [42] and Di Giuda et al. [35] propose information frameworks and protocols for FM, AIM and Organizational Information Requirements (OIR); another contribution toward information through BIM within the built environment field is that of Brumana et al. [62] discussing heritage BIM. Concerning data security, another topic is that of

blockchain application to AEC information management systems [46]. Finally, IFC [61] and Cobie [21,80] are discussed in relation to standardisation and interoperability.

Looking at the PA category, it is underlined that some of the studies are linked to those represented in the first step of thematic analysis since these do not address a specific building typology but describe BIM-FM implementation in the PA management context in general.

In addition, the research trend analysis shows evidence that more recent articles that have focused on COVID-19 BIM management, combined with occupancy control and flow management, is a new area; indeed, these are presented in recent publications [19,20,28,34]. In light of the current context, these subjects promise to have a central role in future research work investigations.

3.2.3. Research Core Areas: Process, People and Technology

The last step of the thematic review investigated the core areas of publications following a process, people and technology classification (Table 6).

Table 6. Publication distribution of research core area.

Buildings Typology	Number of Reviewed Publications
People	[25,54,56,60,72]
Process	[11,14,16–24,26–30,32–45,47–53,55,57–59,61–71,73–81]
Technology	[46]

As the first category, people represent studies dealing with frameworks, methodologies and models for BIM-FM implementation in the public environment. The second one, process, refers to papers discussing the learning shift from 2D to digital twin models or publications focused primarily on the change management subject in overcoming people resistance. Publications were classified as "Process" when BIM-FM implementation was based on a technological tool or IT developed platforms, but it was described as a methodology or a procedure that can be applied to other contexts and for which the technological tool was not treated as the core point of the investigation. The last category is Technology, which compiles studies concentrating on software systems, platforms, and tools for BIM-FM implementation.

The results show that the Process category has a considerably higher number of publications discussing BIM-FM implementation frameworks and methodologies in the public domain. For example, Guzzetti et al. [78] provide a method based on BIM to manage the urban space; moreover, Di Giuda et al. [35] define a university guideline to allow the public entity to procure works and to manage the building portfolio. Shohet and Nobili [66] present a KPI framework for maintaining public clinic facilities. Then, Fernández et al. [27] concentrated more on MEP issues, providing a method for modelling building equipment from a maintenance objective, whereas Chung et al. [21] discuss an information exchange process for smart facilities maintenance. Regarding data, Kim et al. [77] focus on the information retrieval process.

In addition, Pinti et al. [29] and Mirarchi et al. [30] describe the development of an application based on a reproducible methodology for managing facilities of a public portfolio through BIM Additionally in the process category are publications on BIM-FM implementation discussing the subject from a people-related perspective [14,34,45,49] or a technological orientation [33], but still emphasising methodological frameworks and work processes.

Concerning people, Rahman's study [25] is structured on a survey taken of 90 participants for testing BIM FM awareness, and other research works concentrate on the importance of the educational activity carried out for PA personnel [56]; furthermore, De Luca et al. [54] describe the subject of everyday users' engagement in smart cities development. Lastly, with regard to technology, it is possible to say that only the scien-

tific work of Shojaei [46] explain the subject under this lens, as he explores blockchain technology matters.

4. Discussion and Final Remarks

This systematic literature review investigated the analysed studies published in the past 11 years on BIM-FM in the public environment. Publications on the topic have significantly increased over the period, from 1 in 2010 to 19 in 2020, evidencing an expansion of investigations on the topic that can be partially ascribed to external factors linked to the consequences and effects of the pandemic. Thus, the COVID-19 pandemic has brought to light aspects, such as the check of occupancy levels, control of transportation flows, entry supervisions, etc., that are strongly connected to facility management tasks and are becoming more important in the COVID-19 management context (Table 5).

The countries in which research contributions are abundant include the UK and Italy. Concerning the UK, outcomes confirm the primary position of the UK industry development and progress towards BIM implementation, since it has been playing an active role from the public perspective, providing standards and regulations at the governmental level. Thus, one of the significant drivers of BIM adoption in the UK is government intervention and support. For example, in 2011, the BIM Government Task Group released its BIM policy. In addition, the British Standard Institute (BSI) introduced standards concerning BIM in 2019. Furthermore, since April 2016, the government strategy aiming to achieve 20% savings in procurement costs, and construction projects in the UK were required to reach BIM Level 2. Therefore, the BIM mandate has contributed to accelerating BIM adoption in the country. In addition, the data underline that research studies are going beyond BIM for design and construction towards BIM-FM implementation. However, although the BIM mandate was a government-led approach taken by the UK, the number of PA articles reporting the use of BIM is still deficient.

Concerning Italy, the data highlighted a trend that should be interpreted from a different point of view. Unlike the UK, which is still considered to be a skilled market, in Italy, there is no solid BIM action at the governmental level that is able to involve and drive the whole AEC; the government has postponed BIM application to 2025. Nevertheless, Italy is moving slowly towards BIM implementation with its recent increased interest in this approach. This situation is proved by the last Public Procurement Code (2016), which claims that tendering stations can require the use of BIM for interventions with an amount higher than certain thresholds. The implementation start was fixed in 2019 for public projects higher than EUR 100 million (D.M n. 560/2017–D.M n. 312/2021); BIM will be mandatory from 2025 for all public projects higher than EUR one million (D.M n. 560/2017–D.M n. 312/2021).

Moreover, Italy's higher research works production on BIM-FM implementation in the public sector can also be explained by an increasing interest in managing the built environment and preserving the historic building stock. Government actions strengthen existing subsidies, seismic safety and energy efficiency improvement, supporting the restart of public and private investments for the following years. Then, with the "D.L Rilancio" measures, the government supports renovations, the energy requalification of buildings and maintenance activities on the building stock. Moreover, the so-called "*Fondo investimenti e sviluppo infrastrutturale*", which consists of EUR 47 billion (plus EUR 36 billion added with Legge di Bilancio 2018) for the period 2017–2032, will finance transport infrastructure, soil protection, hydrogeological instability, public buildings and seismic risks prevention, and will contribute to the national plan "Casa Italia" for safeguarding Italian territory and real estate assets.

Regarding research methods, most publications have adopted a case study approach evidencing an orientation for developing practical applications for BIM-FM solutions linked to maintenance management. Then, the last years have been characterised by an increase in literature reviews aiming to establish knowledge on the status of BIM-FM integration in the public sector.

The results on building typologies underline that a generic description of public owners and administration involvement in BIM for FM is predominant, which assesses that the subject is approached at a general level. This category is followed by educational buildings that stand for campus, universities and infrastructural buildings, including maritime ports, airports and transport buildings in general. Concerning universities, the outcome is strongly related to the fact that these are linked to the academic context, which is, at the same time, a context of research and experimental studies. Thus, multiple publications are carried out on educational buildings, since researchers have the data available, and the work could be directly tested. Studies on infrastructure and hospital buildings, which is the other group following the first ones, prove that these categories require planned management and that their maintenance is of primary importance. In particular, this fact could be seen as a reaction to the COVID-19 pandemic and (especially in the Italian context) to infrastructural disasters, such as the collapse of Ponte Morandi or railway accidents.

Results on the research focus highlight the predominance of work on maintenance management or facility management procedures in operating building services. This topic has the highest percentage of publications in the field and a constant behaviour over time. Another prevalent topic that has been steady during the years is data and information exchange. This subject has always been predominant when investigating BIM for FM. Moreover, the other category following the first two groups publications about general public sector awareness concerning BIM-FM implementation. This group includes works on the current industry knowledge; most of the studies in this class correspond to those embedded in the "Generic" one in building type analysis. The analysis has also pointed out that a rising research trend is coming to light: COVID-19 BIM management can be considered to be a relatively new trend discussed in studies from 2020.

Looking at the last part of the research based on BIM-FM implementation from three clusters' perspectives, it is evident that this subject has been mainly addressed until now as a process. Notwithstanding that some publications propose new platforms or technological solutions for this implementation, the core of the research is still presented like a process, which expresses it through the integration of technologies. However, the study does not have a prevalent technological orientation since it is described through a process framework. Therefore, BIM-FM implementation in the public sector is described as a methodological process.

At the technological level, the limited number of publications underline that, at the moment, the systems are not fully capable of managing the overall FM phase.

The novelty of the subject and the overall predominance of processes propositions might explain the scarcity of the challenge and challenge's description, commonly identified in practical applications of BIM-FM implementation. Thus, publications usually prioritise benefits and positive matters rather than problems. The central implementation aspect can be summarised through this issue: the lack of standards. This is strongly linked to data and information exchange. Therefore, efforts should be taken to define a common approach for managing BIM in the FM field in the public environment.

Regarding the topics that the literature is silent about, the review showed an absence of quantitative information concerning organisational problems related to FM within the FM literature that can be used as a baseline for a meaningful analysis of the results from various pieces of research. In general, the reported cases are focused on improving the situation of a specific organisation, with no reference to problems within the sector or even within organisations constituted by multiple buildings. It was also found that the plethora of methodological approaches used in the research made the conduction of directive comparative analysis impossible. While methodological variety enriches the diversity of the evidence generated, it imposes difficulties related to the replicability and comparison of studies. Finally, positive bias towards BIM implementation was also identified in the literature. In other words, only positive (primarily qualitative) results of BIM implementation have been reported. The perception that BIM implementation

leads to positive results is not a problem per se. However, the absence of quantitative data in the portfolio of evidence available prevents understanding its feasibility meaningfully. Unexpectedly, no research addressing the public funding of BIM implementation was found. Based on the reported cases, the perception is that BIM implementation in the public sector is generally funded through bottom-up approaches. In other words, governmental mandates that limit the contracting of CAPEX projects only from BIM-enabled firms are focused on improving the construction sector's performance. Regarding resourcing the public workforce for receiving and using BIM for FM in the public sector, the literature is silent.

The analysis shows that BIM-FM integration in the public environment remains an embryonic area. This study contributes to knowledge by discussing relevant publications through a systematic review, providing a baseline for future investigations. In addition, the paper establishes contextual knowledge from the past eleven years, identifying trends on the topic advancement.

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