Emerging technologies in Facility Management in Brazil

Journal:	*Journal of Facilities Management*
Manuscript ID	JFM-05-2021-0052.R3
Manuscript Type:	Research Paper
Keywords:	Built Environment, Digital Transformation, Management, Operation & Maintenance, COVID-19, PRISMA Statement

Emerging technologies in Facility Management in Brazil

Marcus Vinicius Rosário da Silva[a,b1], Marcelo Jasmim Meiriño[a], Júlio Vieira Neto[a], Sheila Walbe Ornstein[b]

[a]*Laboratory of Technology, Business Management & Environment Professional Master in Management Systems, Fluminense Federal University, rua Passo da Pátria, 156 - Block E, room 324 - São Domingos, Niterói, CEP 24210-240, Brazil*

[b]*Faculty of Architecture and Urbanism, University of São Paulo, rua do Lago, 876 - Cidade Universitária, São Paulo, CEP 05508-080, Brazil*

Abstract

Purpose – An interaction between Emerging Technologies (ETs) for Facility Management (FM) activities and stakeholder skills is necessary to promote the optimization of FM performance. Previous studies do not show strategies for the selection of ETs in FM considering the technological competencies of stakeholders. Thus, this study analyzes the interactions between ETs and FM from the perceptions of Brazilian professionals, identifying the most appropriate and effective technological solutions, based on a broad literature review.

Design/methodology/approach – The steps of the methodology are: (1) Systematic Literature Review (SLR); (2) Detailing the ETs for FM; (3) online questionnaire based on SLR findings; (4) sample of Brazilian FM professionals; (5) statistical treatment; and (6) discussion.

Findings – Results indicate WSN, IoT, BIM, and Big Data as ETs in FM with greater potential for optimization in the performance of FM activities, from survey respondents.

Research limitations/implications – The scope of possible findings may have been biased, considering the small number of research participants and current transformations resulting from the COVID-19 pandemic (e.g., changes to Standard Operating Procedures – SOP).

Practical implications – The results ensure greater security to Facility Managers in the effective implementation of ETs in FM activities.

Originality/value – The research explores the published studies and the consultation with Brazilian FM professionals in the selection of ETs.

Keywords: Built Environment, Digital Transformation, Management, Operation & Maintenance, COVID-19, PRISMA Statement, Inferential Statistics.

Paper type original article.

Article classification: research paper.

1. Introduction

Emerging Technologies (ETs) have the potential to optimize the performance of daily Facility Management (FM) activities, resulting in more efficient processes, more effective services, and more satisfactory user experience (ARUP, 2019). Thus, these premises are in line with the improvement of the well-being and productivity of people recommended by the latest normative series dedicated to FM (ISO, 2017).

On the other hand, interaction between the technical and technological processes and the skills of stakeholders is necessary to promote cost savings, estimated at 10-17% in the phase of

[1]Corresponding author.
Email address: marcusrosario@yahoo.com.br (M. V. R. Silva).

use, operation, and maintenance of non-residential buildings (Atkin; Bildsten, 2017; Koch, I.C.; Hansen; Jacobsen, 2018; Craveiro *et al.,* 2019).

Particularly, the FM market in Brazil had revenues of US$ 18 billion in 2018. The FM sector was expected to exceed US$ 25 billion by 2024 due to its growth trend in Brazil. However, the Brazilian FM market has become uncertain due to the COVID-19 pandemic. The Southeast region accounts for 53.7% of the total market, led by State of São Paulo with 32.5% (Techsci Research, 2019; Lobo, 2020).

The processes, places, and people generate a large amount of data and it is up to the Facility Manager to select and oversee the implementation, monitoring, and control and to implement opportunities for improvement, emphasizing the need to collect data, information from project stakeholders, avoiding allocation of significant additional costs (Wong; Ge, Ge, He, 2018).

Thus, the challenge of implementing ETs is to understand the complexities and singularities of the building (Charlton *et al*., 2021), to validate the model empirically (Falorca, 2019), to know FM (Wen; Tang, Tang, Tang. Ho, 2021), to consider experienced analysts for analysis of information and application requirements (Chen; Lai; Lin, 2020) and to integrate data and information into a database (Jung; Cha, Jiang, 2020).

Recently, there have been a growing number of studies on FM technology applications, such as Building Information Modeling (BIM) (Abdelalim; O'Brien; Shi, 2017; Fargnoli *et al*., 2019), Augmented Reality (AR) and/or Virtual Reality (VR) (Carreira *et al*., 2018; Baek; Ha; Ha; Kim, 2019) Machine Learning (ML) (Bouabdallaou *et al.,* 2020; Assaf; Srour, 2021), Internet of Things (IoT) (Azizi *et al*., 2020; Dahanayake; Sumanarathna, 2021). However, the studies fail to consider the various ETs in FM and the importance of the technological competence of human resources for the effective selection of ETs.

In this situation, which emerging technologies stand out on the global FM scene today? What are the details of the technologies to be analyzed for a selection? How do the technological skills of human resources interfere in the definition of ETs for FM? Which technologies are most relevant to support specific FM activities in Brazil?

This article analyzes the interactions between ETs and FM from the perceptions and technological competencies of Brazilian FM professionals, identifying the most appropriate and effective technological solutions.

Thus, the work contributes to the process for conducting and evidencing the selection and for the analysis of ETs with a view to the different FM activities.

2. Literature Review

Among the various Facility Management activities, recent studies have developed solutions to optimize the performance of facilities, among those, stand out:

Structural components

For Condition Assessment, studies of ETs contribute to data transfer in pathological manifestations in buildings (Amano; Lou; Edwards, 2019); identification and analysis of failures, causes, and risks (Ismail, 2021a; 2021b); methodology for collecting and analyzing building systems (Matos *et al*., 2021); and model for bridge under load (Know; Park; Park, 2021). Charlton *et al.* (2021), in turn, are dedicated to the BIM/FM workflow in historical buildings.

Furniture and equipment in the workplace

Advances were obtained for a commissioning effect on building performance (Noye; North; Fisk, 2018) and on data transfer from commissioned assets (Kim; Poirier; Staub-French, 2020).

There is an impact on decision-making for maintenance (Ma *et al.,* 2020), improved prediction of the future condition of Mechanical, Electrical, and Plumbing (MEP) components (Cheng *et al.,* 2020), and complaints about thermal comfort (Assaf; Srour, 2021). Also, Integrated Fault Detection sending alerts (Villa *et al*., 2021), preventable defects in building systems (Eskandari; Noorzai, 2021); recommendations for Operations & Maintenance (O&M) assisted by Building Information Modelling (BIM) (Lu *et al.,* 2020); and platform for maintenance and replacement of sensors (Valinejadshoubi; Moselhi; Bagchi, 2021).

For preventive maintenance, there is the addition of a classification, analysis, and monitoring of Work Orders (WOs) (McArthur *et al.,* 2018); an information flow between the service provider and the manager (Fargnoli *et al.,* 2019); and an integrated maintenance management model (Falorca, 2019).

The lifecycle has benefited from increased facility functional capabilities (Mawed; Hajj, 2017) and research into the application of BIM and IoT) (Wong; Ge; He, 2018).

Specifically for WOs, Chen *et al*. (2018) provide a solution for the automatic generation of orders, while Bouabdallaoui *et al.* (2020) focus on reducing delays with maintenance operations.

For equipment inventory/asset information, there is a laser-based targeting method for interaction with large objects (Liu; Seipel, 2018), guidance and obstacle avoidance for maintenance (Diao; Shih, 2019), and classification of images for inspection and repair (Zhan *et al*., 2019). The understanding of technicians' cognitive level of learning was also considered through Augmented Reality (AR) (Nascimento; Velo, 2020).

Activities involving renovations in the space layouts present contributions from Azizi *et al.* (2020) concerning the efficiency in the use of spaces; Mo *et al*. (2020) for the determination of workforce and skills, Mohamed; Abdallah; Marzouk (2020) with the design of a framework based on semantic knowledge, and Wen; Tang; Ho (2021) for Building Maintenance Workflow.

Mechanical / Electrical / Plumbing (MEP) Systems

Studies were carried out to help locate the MEP components, adding value to the location and recognition of components (Wei; Akinci, 2019) and object detection to generate a MEP network (Wang *et al.,* 2021).

Advances made in performance monitoring are related to visualization and building performance management (Gerrish *et al.*, 2017); multi-objective control in performance evaluation (Bonci *et al.,* 2019); integration of technology with existing sensors (Kazado; Kavgic; Eskicioglu, 2019); collection and management of real-time information (Yin *et al.,* 2020); monitoring of building performance (Rogage *et al*., 2020); and smart buildings in the post-pandemic period (Xie *et al.* (2021).

Equipment

Models for predicting the residual value of heavy equipment were developed, indicating characteristics, such as equipment type, working hours, classification of condition, among others, from regression techniques (Alshboul *et al.,* 2021; Shehadeh *et al*., 2021). Also, a multi-objective and multivariate model to select heavy equipment was proposed (Shehadeh *et al.*, 2022).

Security and surveillance

For emergency evacuation, investigations were carried out on Geoinformation Systems for complex facilities (Gunduz; Isikdag; Basaraner, 2017) and safety in emergency exit routes and compartmentalization (Mirahadi; McCabe; Shahi, 2019).

In disaster prevention, there was added value from bidirectional interactions between man-machine during a fire event (Cheng *et al.*, 2017), object recognition by thermal imaging (Vandecasteele; Merci; Verstockt, 2017), studies on economic performance and losses of a building (Vitiello *et al.*, 2019), support for objective decision-making (Jung; Cha; Jiang, 2020), and seismic risk assessment in bridges (Nettis; Saponaro; Nanna, 2020).

While Oliveira *et al.* (2020) contribute to the monitoring of large outdoor areas, Arslan; Cruz; Ginhac (2019) provide an understanding of occupant behavior for indoor control, and Baek; Ha; Kim (2019) contribute to the visualization and management of pertinent information.

Building automation and information management

Contributions to the control of comfort parameters are related to the management of a wide range of information (Yang; Bayapu., 2020), monitoring of controlled ventilation systems (Schibuola; Scarpa; Tambani, 2018; Medina, 2020), decisions for retrofit from the simulation of scenarios (Alavi *et al.*, 2021), and the minimum interruption in monitoring services (Valinejadshoubi *et al.*, 2021).

For information management, there are advances in prediction and decision-making about maintenance (Peng *et al.*, 2017), precision and consistency of integration with BIM (Kim *et al.*, 2018), quality and form of acquisition of services (Halmetoja, 2019), preparation of the digitization process (Koch; Hansen; Jacobsen, 2019), implementation of digital technologies (Love; Matthews, 2019), exchange of protocols and BIM collaborative libraries (Sadeghi *et al.*, 2019), visualization of performance in time-space (Quinn *et al.*, 2020), asset information model (Patacas; Dawood; Kassem, 2020), the value of BIM integration (Wijekoon; Manewa; Ross., 2020), and Smart FM based on IoT-BIM (Dahanayake; Sumanarathna (2021).

Utility management

For water and energy consumption, Akil *et al.* (2019) contributed to identifying operational anomalies. Regarding energy analysis, there was value added in the hardware-software architecture (Ferrández-Pastor *et al.*, 2020), the process for energy saving (McGlinn *et al.*, 2017), energy optimization (Petri *et al.,* 2021), and global emission reduction (Xu; Mumford; Zou, 2021), at resilient and sustainable building management (Piselli *et al.*, 2020).

Safety management

Knowledge about data transfer and solution identifications (Wetzel; Thabet, 2018), safety for FM during the asset lifecycle (Pärn *et al.*, 2019), noise impact during maintenance activities (Tan *et al.*, 2019), the assessment of infectious disease outbreaks (Li *et al.*, 2021), and the analysis of information and application requirements (Chen; Lai; Lin, 2020) received contributions.

Specific services for users

For the development of the Post-Occupancy Evaluation (POE), there was a flexible and dynamic data integration (Carreira *et al.*, 2018), performance monitoring (Edirisinghe; Woo, 2021), and operation data analysis (Seghezzi *et al.*, 2021).

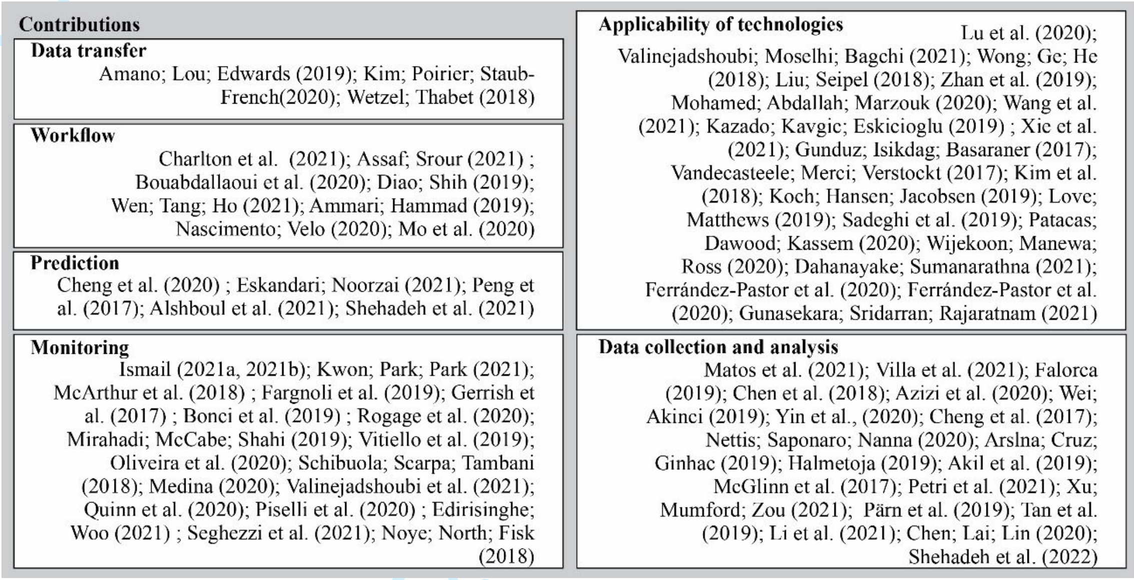
Service Providers

A solution for acquisition via Blockchain was developed (Gunasekara; Sridarran; Rajaratnam, 2021) with the structuring of work with mixed reality (augmented and virtual reality) for training teams (Ammari; Hammad, 2019).

Previous research, selected from the SLR, has essential contributions (Figure 1) and limitations (Figure 2) for advancing application ETs. From the contributions of the authors of previous studies, verifying congruences between the contributions is possible to verify: (1) organizational knowledge management (Workflow, and data collection and analysis); (2)

technological feasibility study (data transfer, and applicability of technologies); and (3) damage risk (prediction, and monitoring).

Figure 1 – Summary of main contributions from previous research



Source: The Authors

From the limitations highlighted by the authors of previous research, it is possible to verify congruences between the gaps: (1) technological issues (such as visualization, software, hardware, and modeling/algorithm); (2) FM knowledge issues (such as usage/FM specificities, skills and competences, and building data collection); (3) restriction regarding the recurrent use of literature without empirical validation or small samples of interviews and questionnaires applied to professionals in the sector. There is a need for greater involvement between academics and FM professionals to advance the development of technical solutions based on scientific research, as noted by Wong, Ge, and He (2018).

Figure 2 - Summary of the main limitations of the research

Limitations

Small sample Ismail (2021a, 2021b); Lu et al. (2020) ; Rogage et al. (2020); McGlinn et al. (2017) ; Medina (2020); Nascimento; Velo (2020)	**Model/algorithm** Kwon; Park; Park (2021); Cheng et al. (2020) ; Assaf; Srour (2021) ; Chen et al. (2018) ; Bouabdallaoui et al. (2020); Jung; Cha; Jiang (2020); Alavi et al. (2021); Peng et al. (2017) ; Quinn et al. (2020); Akil et al. (2019) ; Ferrández-Pastor et al. (2020); Tan et al. (2019) ; Carreira et al. (2018) ; McArthur et al. (2018) ; Wei; Akinci (2019); Shehadeh et al (2021); Shehadeh et al. (2022)
Tests/cases Cheng et al. (2017) ; Kim et al. (2018); Koch; Hansen; Jacobsen (2019)	**Hardware** Noye; North; Fisk (2018); Valinejadshoubi; Moselhi; Bagchi (2021); Nettis; Saponaro; Nanna. (2020); Oliveira et al. (2020); Alshboul et al. (2021)
Visualization Amano; Lou; Edwards (2019); Liu; Seipel (2018); Zhan et al. (2019); Wang et al. (2021); Ammari; Hammad (2019)	**Use / FM specifics** Charlton et al. (2021; Wen; Tang; Ho (2021); Halmetoja (2019); Sadeghi et al. (2019)
Literature Gunduz; Isikdag; Basaraner (2017); Vandecasteele; Merci; Verstockt (2017); Mohamed; Abdallah; Marzouk (2020); Dahanayake; Sumanarathna (2021)	**Skills and competencies** Wong; Ge; He (2018); Baek; Ha; Kim (2019); Chen; Lai; Lin (2020); Gunasekara; Sridarran; Rajaratnam (2021)
Validation lack Villa et al. (2021); Falorca (2019); Mawed; Hajj (2017); Yang; Bayapu (2020); Love; Matthews (2019); Patacas; Dawood; Kassem (2020); Piselli et al. (2020) ; Xu ;Mumford; Zou (2021) ; Wetzel; Thabet (2018) ; Seghezzi et al. (2021); Fargnoli et al. (2019)	**Data** Kim; Poirier; Staub-French (2020); Ma et al. (2020); Eskandari; Noorzai (2021); Azizi et al. (2020) ; Xie et al. (2021); Wijekoon; Manewa; Ross (2020); Petri et al. (2021) ; Li et al. (2021); Arslan; Cruz; Ginhac (2019); Vitiello et al. (2019); Yin et al. (2020)
Software Matos et al. (2021); Diao; Shih (2019); Bonci et al. (2019) ; Kazado; Kavgic; Eskicioglu (2019) ; Mirahadi; McCabe; Shahi (2019); Edirisinghe; Woo (2021) ; Mo et al. (2020)	

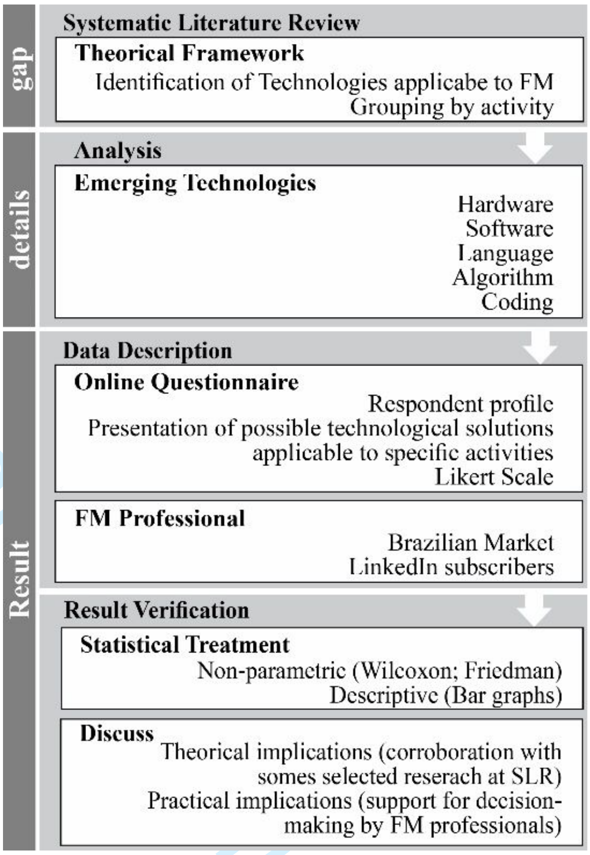
Source: The Authors

The gap common to all previous studies consists of the lack of evidence in the process of selection of the technology(ies) applied to studies among the various existing options and little or no interaction with FM professionals to support the choice of the technology to be adopted to solve the problem.

1. Methodology

The research methodology consisted of five steps: (1) a Systematic Literature Review (SLR); (2) an analysis of the details of the technologies; (3) the development of an online questionnaire (survey) based on the SLR results; (4) an application to a sample of Brazilian FM professionals; (5) a statistical treatment; and (6) a discussion of theoretical and practical implications (Figure 3).

Figure 3 – Step-by-step methodology



Source: The Authors

Conducting an SLR

The study was initiated by the Systematic Review of the Literature (SLR), using the StArt software (Silva et al., 2021). The developed protocol (Figure 4) was inserted into the software to guide the document selection and extraction steps.

Figure 4 – Protocol

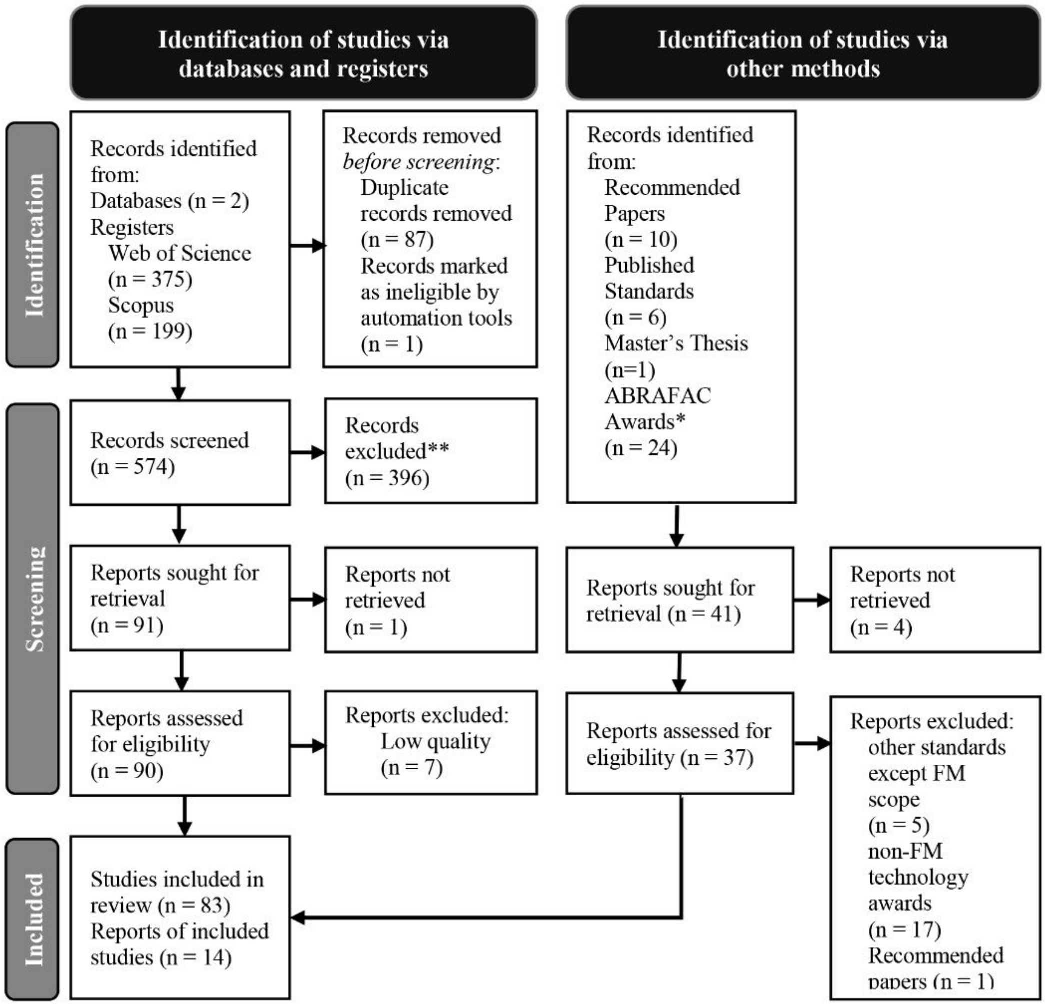
Protocol	
Objective	Identify emerging Technologies in Facility Management and their practical and theoretical implications.
Main question	What are the emerging Technologies in Facility Management (last 5 years)?
Secondary questions	What methodologies are used? What are the manegerial implications? What are the knowledge gaps?
String	TS= (((Facility* AND Management) AND ((Emerging AND Technology*) OR Big Data OR BIM OR Blockchain OR Photogrammetry OR GIS OR IoT OR Laser Scanning OR Machine Learning OR QR Code OR Augmented Reality OR Virtual Reality OR RFID OR Unmanned Aerial System OR Semantic Web OR WSN)))
Source selection criteria definition	Digital availability of the article Indexed database Journal articles
Studies language	English
Source search methods	PRISMA: Page *et al.* (2021) START: Silva *et al.* (2021)
Source	Web of Science (Elsevier, Mdpi, Springer Nature, IEEE, Emerald Group Publising); Scopus
Categories	Civil Engineering, Management, Construction Building Technology; Engineering, Business, Management and Accouting
Date range searched	2017 to 2021
Study selection criteria (inclusion)	Technology applied to FM General usage example Case example Theoretical background
Study selection criteria (exclusion)	Technology applied to core business Keywords do not match the topic Metadata na/or full document not accessible Restricted publication (Total or Partial)
Definition of study types	Qualitative and Quantitative
Initial selection of studies	Silva (2020), ISO (2017); Noye; North; Fisk (2018); McArthur et al. (2018); Mawed; Hajj (2017); Tan et al. (2018); Zhan et al. (2019); Gunduz; Isikdag; Basaraner (2017).
Quality assessment of studies	papers will be rated: 'very low' (0-2); 'low' (3-4); 'high' (5-6); and 'very high' (7-8). Papers classified as 'very low' and 'low' will be excluded.
Quality form fields * (yes=1; no=0) I **(yes=2; partially=1; no=0)	Is the introduction to the problem clear?* - Is the goal/purpose clear?* - Is the methodology/design clear?* - Are the results clear?* - Does the methodology/design match the purpose?** - Are the findings consistent with the methodology?**
Data extraction of form fields	Author(s) and year Technologies Algorithm Software Hardware Language Coding FM Activity Practical implications Research implications Limitations
Results summary	Theoretical Framework

Source: The Authors

In addition to the searches in the databases, the following were added: (1) relevant articles not captured in the systematic search of the two databases consulted; (2) the technical standards of the ISO 41,000 series, dedicated to FM (2017-), recently published; (3) Silva's Master Thesis (2020) – document of origin of this research and guide for the writing of this article; and (4) the winning works of the ABRAFAC (Brazilian Association of Facility Management, Property, and Workplace) award. All these documents were published between 2017 and 2021. Subsequently, four relevant articles were identified and included via 'other methods' (Alshboul *et al.,* 2021; Alshboul; Shehadeh; Hamedat, 2021; Shehadeh *et al.,* 2021; Shehadeh *et al.,* 2022).

A flowchart (Figure 5) was prepared according to the PRISMA Statement to summarize the SLR (Page *et al.,* 2021).

Figure 5 – Flow diagram



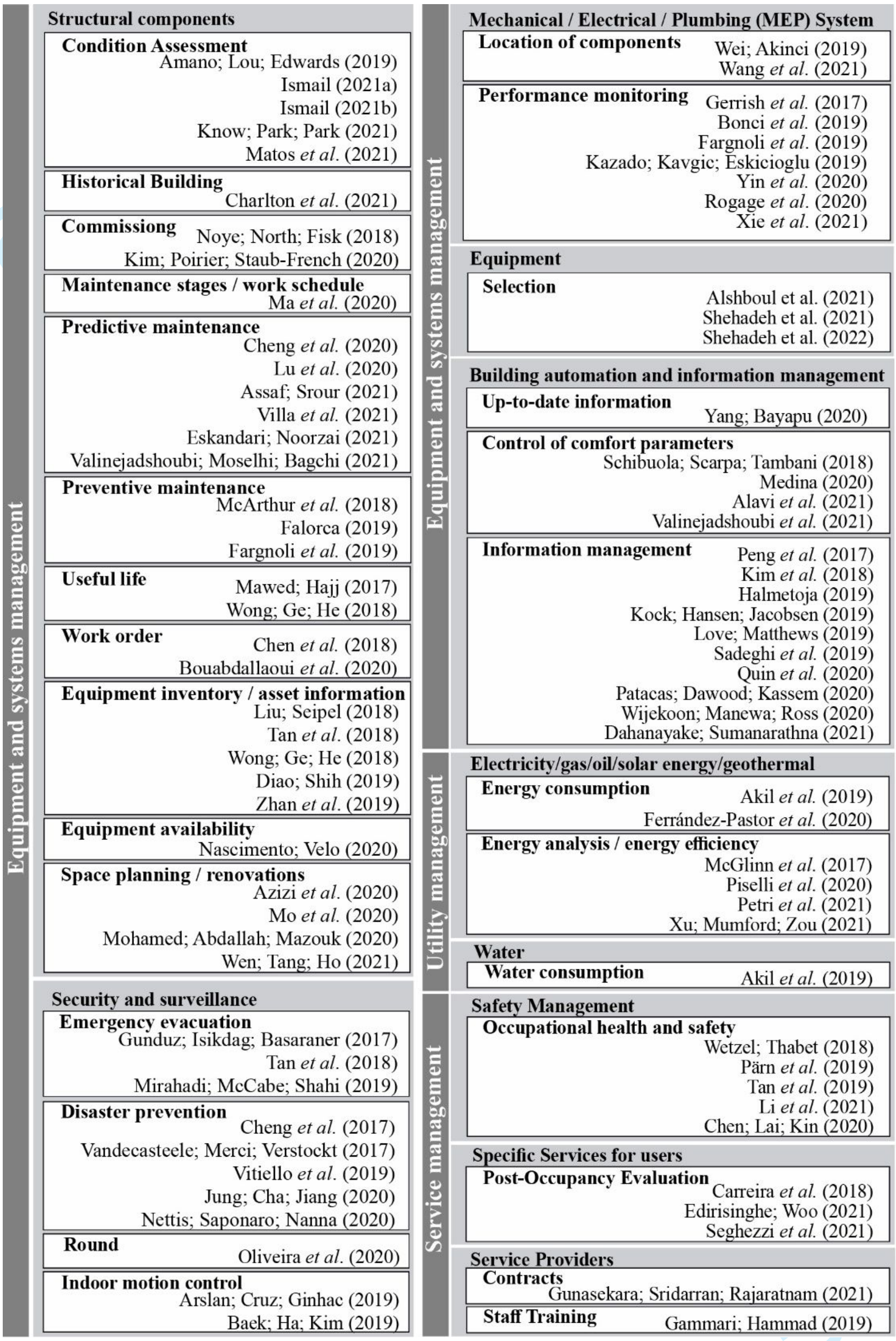
* 2017 does not have information available

**the automation tool START was used and the records were excluded by a human

Source: The Authors

After extracting the data obtained from the SLR, a Theoretical Framework was developed (Figure 6). These data supported the analysis of the details of emerging technologies, and the questions in the online questionnaire (survey), following relevant guidelines presented by Dawson (2020).

Figure 6 – Theoretical Framework

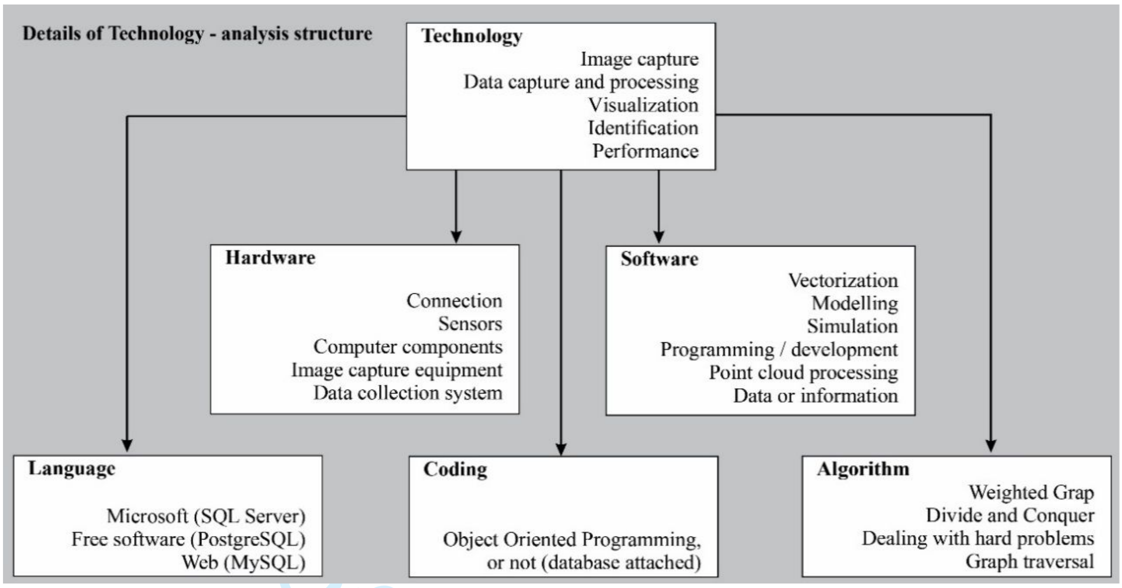


Source: Adapted from Silva (2020).

Analysis structure of the details of technologies

From the included articles, we analyzed the details of the technologies applied to the studies (i.e., hardware, software, language, coding, and algorithm) (Figure 7). Skiena (2020) classification was used for the algorithms.

Figure 7 – Structure of the analysis method of technological details



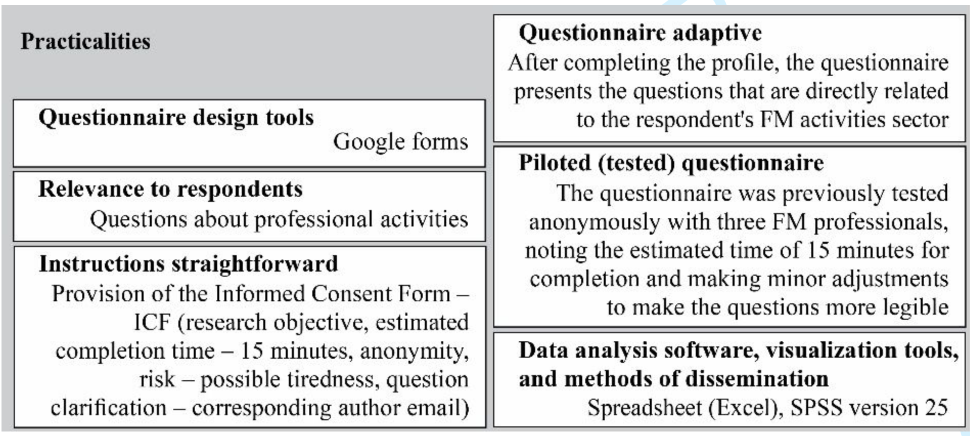
Source: The Authors

Development of an online questionnaire

The technologies applied to FM activities, found from the conduction of the SLR, were fundamental for the development of the online questionnaire, whose questions evidenced the technologies investigated by specific FM activity, according to the theoretical framework (Figure 6). The practical aspects followed the relevant guidelines presented by Dawson (2020) (Figure 8).

This research instrument contains technology options to verify which ones would be more relevant for implementation in different FM activities. The five-point Likert scale was used: '1' - less relevant; and '5' - more relevant. The respondent also had the option I don't know / I don't want to give an opinion'.

Figure 8 – Practicalities



Source: The authors

Brazilian FM professionals

Brazilian FM professionals were invited to participate in the survey via LinkedIn (www.linkedin.com). The Informed Consent Form (ICF) and the link to access the online questionnaire were sent to each. Only the professionals who agreed to participate in the research were computed by complying with the ICF.

Statistical treatment

The statistical treatment consisted of hypothesis tests: 'H_0' - there is no different relevance between the technologies applicable to the specific FM activity, and 'H_1' - There is a difference in the perception of relevance between the technologies presented for each specific FM activity. The non-parametric statistical methods applied were Friedman (1937) and Wilcoxon (1945).

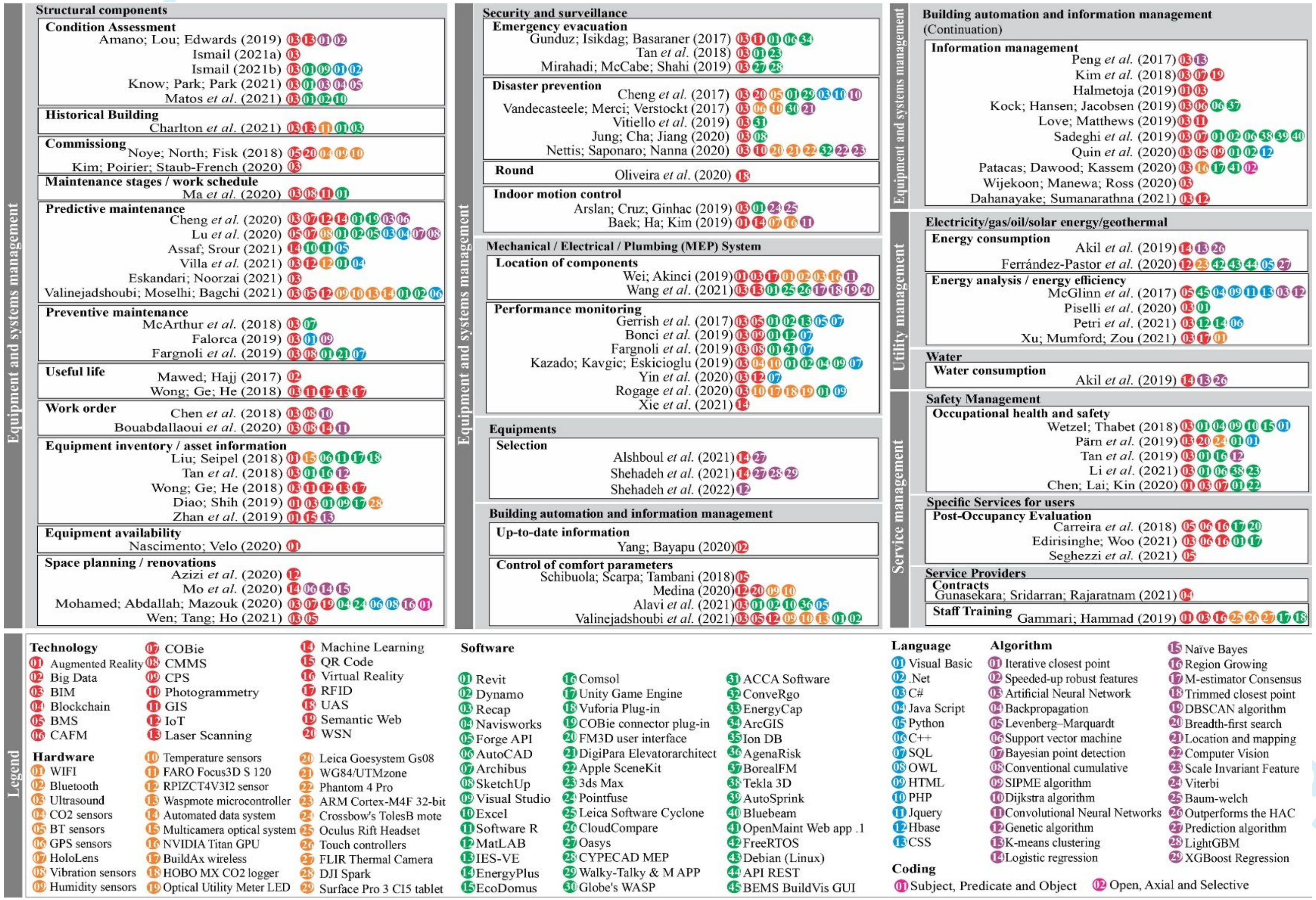
Discussion

The discussion involved the theoretical and practical implications resulting from the survey to corroborate previous research – selected through the SLR and the support for decision-making by FM professionals.

3. Emerging Technologies

There is a profusion of emerging technologies (ETs) applicable to FM (Figure 9) and investigated by academics worldwide. Behind each technology, there are different components to be acquired and/or manipulated: (1) software; (2) hardware; (3) programming language); (4) algorithms; and (5) coding. The theoretical framework allowed for the disclosure of the scope and complexity of each of these ETs.

Figure 9 - Details of technologies applied to FM



Source: The Authors

Each technology offers different solutions, and the Facility Manager is responsible for analyzing the options for choosing the one that will best meet their needs. Laser Scanning, Photogrammetry, and Unmanned Aircraft System (UAS) have the potential to perform image capture. Whereas Blockchain, Building Management System (BMS) / Building Automation System (BAS), Big Data, Machine Learning, Building Information Modelling (BIM), and Geographic Information System (GIS) were adopted for data capture and processing. Augmented Reality, Virtual Reality, BIM, GIS, Computer-aided facility management (CAFM), and Construction Operations Building Information Exchange (COBie) were used for viewing. In the case of identification, Radio Frequency Identification (RFID), and Quick Response Code (QR Code) were applied. Whereas for performance monitoring and control, BMS/BAS, Cyber-Physical Systems (CPS), Internet of Things (IoT), and Wireless Sensor Network (WSN) were adopted.

Due to the profusion of technologies and specific needs to be met, different hardware was used. For wireless connection of devices, the use of equipment for Wi-Fi and Bluetooth is evidenced. Sensors were also applied, such as CO2, BT, GPS, Vibration, Humidity, Temperature, RPIZCT4V3I2, Crossbow's Toles B motto. Specifically for user interaction, the HoloLens, Oculus Rift Headset + Touch controllers, Surface Pro 3 CI5, Tablet HOBO MX CO2 logger were used as display equipment. Components such as Nvidia Titan GPU, Waspmote microcontroller, BuildAx Wireless, and ARM Cortex-M4F 32-bit were also used to upgrade computers. For image capture, the use of FATO Focus 3D S 120, Multicamera optical system, Phantom 4 PROF, FLIR Thermal Camera, and DJI Spark equipment is evidenced. Finally, the Automated data System, Optical Utility meter LED, Leica Geosystem Gs08, and WG84/UTMzone were adopted as data collection system.

Regarding software, the adoption of AutoCAD for vectorization, and REVIT, ReCap, SkecthUp, MatLAB, IES-VE, COMSOL, CYPECAD MEP, Tekla 3D, AutoSprink, and 3D Max was observed. In computational simulation cases, REVIT, MatLAB, IES-VE, EnergyPLUS, COMSOL, DigiPara Elevatorarchitet, Oasys, CYPECAD MEP, and AgenaRisk were used. Whereas for data/information management, REVIT, Navisworks, Forge API, Excel, Ecodomus, COBie connector plug-in, FM3D user interface, Globe's WASP, ACCA Software, EnergyCap, Bluebeam, OpenMaint, BEMS BuidVis GUI, and ArcGIS were used. Specific software was used for cloud processing points such as Leica Software Cyclone, Pointfuse, and CloudCompare. In cases that required programming and/or application development, Dynamo, Excel, Software R, Visual Studio, MatLAB, Unity Game Engine, Vuforia, Debian, FreeRTOS, API REST, and Apple SceneKit were used.

On the programming language, we found evidence of the use of: Visual Basic, .Net, and C# with the SQL Server database (Microsoft); Java Script, Python, and C++ with the PostgreSQL (free software) database; and HTML, PHP, OWL, Jquery, CSS with the MySQL (Web) database. Regarding coding, object-oriented programming was used with Subject, Predictive and Object, and Open, Axial and Selective. Among the many algorithms that exist to perform tasks, those based on Skiena (2020), Dijkstra's Algorithm – Weighted Grap, Convolution(al) – Divide and Conquer, Genetic algorithm – Dealing with hard problems, and Breadth-First Search – Graph Traversal were evidenced.

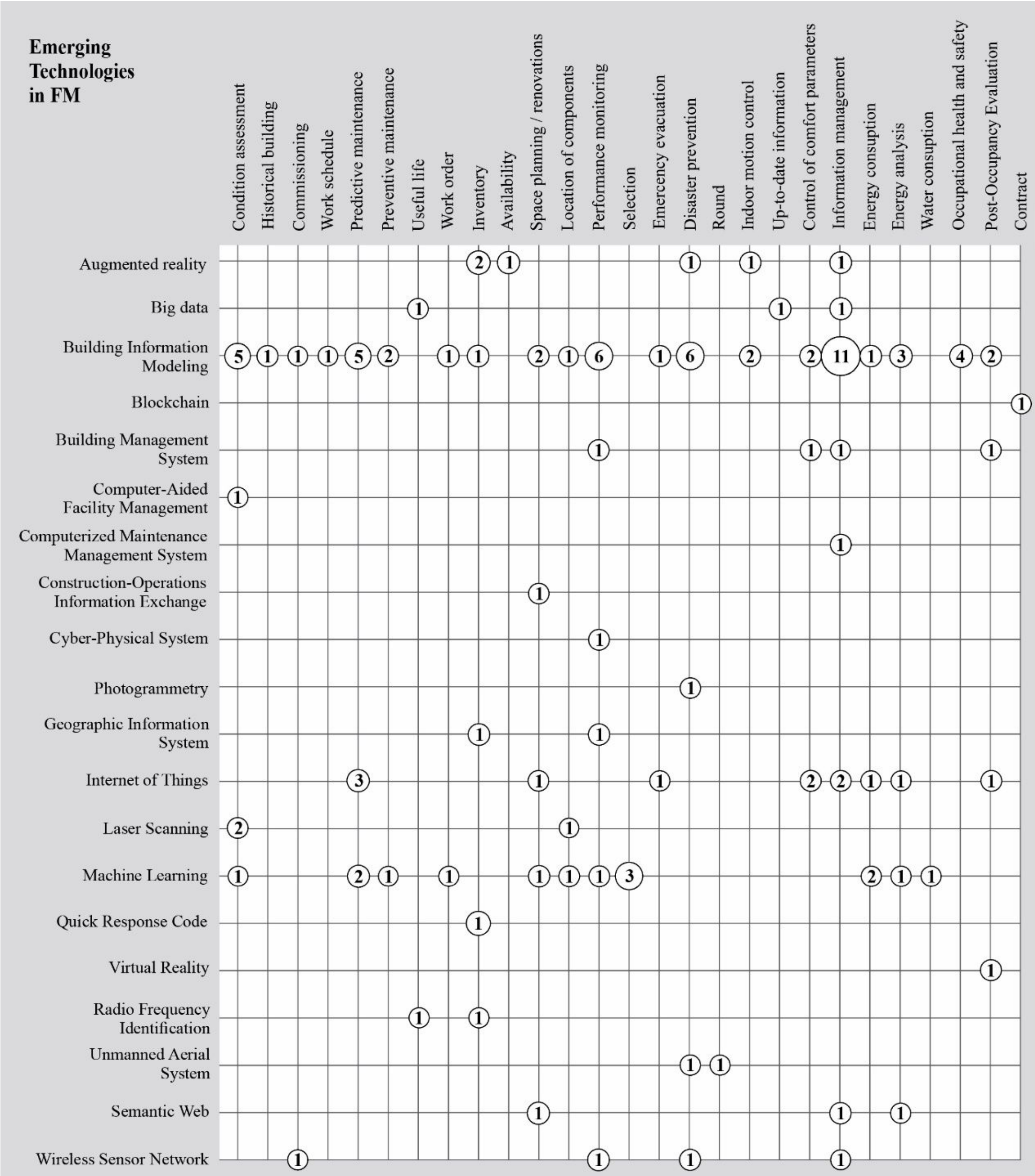
4. Results

4.1. Data description

The theoretical framework, resulting from the conduct of the SLR, was used to prepare questions about the relevance of each technology applicable to different FM activities in the

Brazilian case, as shown in Figure 10. Thus, the respondent focused on evaluating the application previously investigated for each specific activity.

Figure 10 – Summary of technologies applicable to FM activities



Source: The Authors

The online questionnaire, as mentioned above, was sent to FM professionals working in Brazil and registered on LinkedIn.

4.2. Result verification

One hundred professionals working in FM in Brazil (n = 100) answered the online questionnaire. The predominant profile was men with an MBA or a Lato Sensu postgraduate degree, residing in the state of São Paulo and working in the corporate sector (Figure 11).

Figure 11 – General profile of respondents

Profile		Area		State	
Gender		Corporate	n=47	São Paulo	n=53
Male	n=70	Industrial	n=13	Rio de Janeiro	n=33
Female	n=30	Mall/Retail	n=12	Minas Gerais	n= 6
Education attainment		Educational	n= 8	Paraná	n= 3
Lato Sensu / MBA	n=67	Healthcare	n= 7	Espírito Santo	n= 1
Higher education	n=28	Consulting	n= 4	Goiás	n= 1
Master degree	n=5	Technology	n= 3	Bahia	n= 1
		Energy/Oil&Gas	n= 3	Piauí	n= 1
		Banking	n= 2	Amazonas	n= 1
		Hotel	n= 1	Other	n= 0

Source: The Authors

Hypothesis testing was applied to various FM activities. The inclusion criterion was to have at least two technology options for the same activity (identified in the SLR) and at least thirty-two respondents (n <32). Thus, six activities were classified for the inferential statistical test.

Statistical Treatment

The commissioning, preventive maintenance, work order emission/control activities, and monitoring of the useful life of the equipment presented two technology options, while emergency evacuation and equipment inventory/asset information activities presented three or more options. Thus, for a correct application of non-parametric statistics, the Wilcoxon method (1945) was used for activities with two options and the Friedman method (1937) for activities with three or more options (Table I).

Table I - Summary of statistical treatment

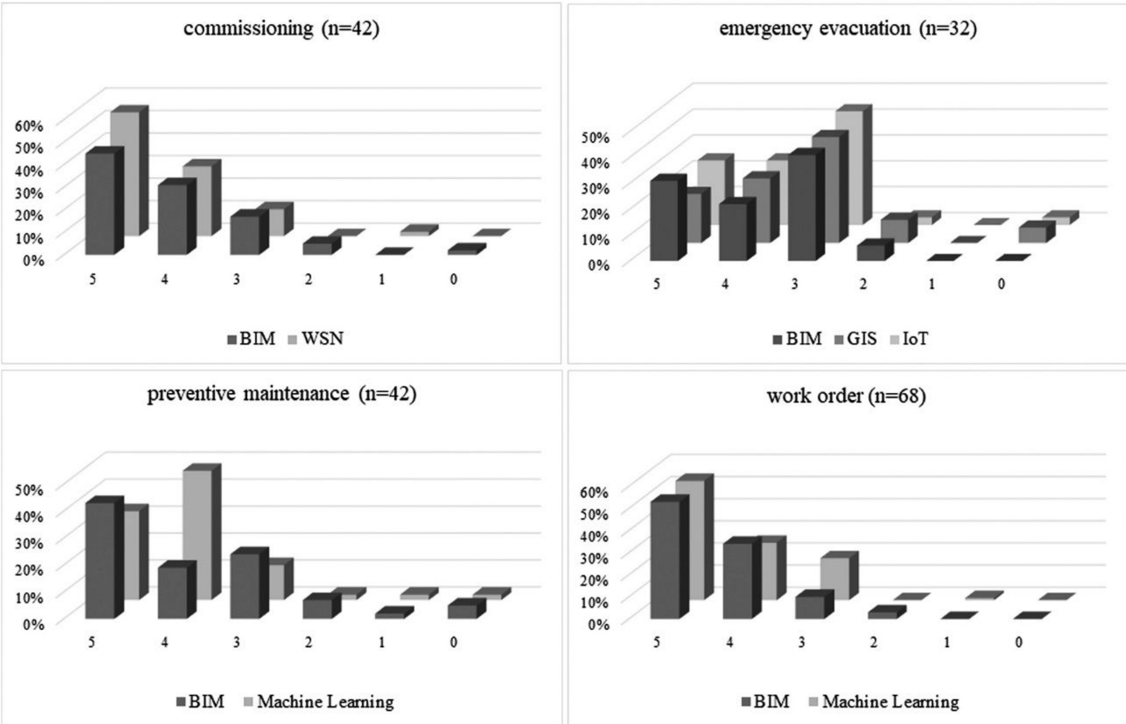
input data				rank			mid-ranks		rank-sum		test			
activity	ample size	ETs	method	-	+	draws	-	+	-	+	z-score	p-value	Chi-square	gl
commissioning	42	BIM	Wilcoxon	WSN<BIM	WSN>BIM	WSN=BIM	10.08	9.21	60.50	110.50	-1.140	0.254	N/A	N/A
		WSN		6	12	24								
emergency evacuation	32	BIM	Friedman	N/A	N/A	N/A	2.11		N/A	N/A	N/A	0.297	2.431	2
		GIS					1.84							
		IoT					2.05							
equipment inventory/asset information	74	BIM	Friedman	N/A	N/A	N/A	3.68		N/A	N/A	N/A	0.000	36.813	4
		GIS					2.55							
		QR					2.91							
		AR					2.82							
		RFID					3.03							
preventive maintenance	42	BIM	Wilcoxon	ML<BIM	ML>BIM	ML=BIM	12.14	13.68	133.50	191.50	-0.812	0.417	N/A	N/A
		ML		11	14	17								
work order	68	BIM	Wilcoxon	ML<BIM	ML>BIM	ML=BIM	8.23	13.68	90.50	62.50	-0.710	0.478	N/A	N/A
		ML		11	6	51								
useful life	42	BD	Wilcoxon	RFID<BD	RFID>BD	RFID=BD	9.06	8.00	145.00	8.00	-3.531	0.000	N/A	N/A
		RFID		16	1	25								

- : Negative, + : Positive; N/A : not apply; z-score : test statistic value; p-value : significance; and gl : degree of freedom
Source: The Authors

The equipment inventory/asset information and useful life activities presented a significance probability equal to zero (p-value = 0.000). In other words, below the maximum value assigned for significance ($p < 0.05$). Thus, the null hypothesis (H_0) is rejected, and one technology is assigned a higher level of relevance than the others. As noted in: (1) BIM (average rating = 3.68) in the activity related to equipment inventory/asset information; and (2) Big Data (BD) (sum of negative position = 145.00) for the activity related to useful life.

For activities with acceptance of the null hypothesis (H_0), an analysis was proposed using descriptive statistics, through the MODE presented in bar graphs (Figure 12): (1) commissioning - BIM and WSN technologies are applicable, with WSN having a higher percentage frequency and MODE in item '5'; (2) emergency evacuation BIM, GIS, and IoT technologies are applicable, and IoT has a higher frequency of percentage and MODE in item '3'; (3) preventive maintenance - BIM and ML technologies are applicable, with BIM having the highest percentage of frequency and MODE in item '4'; and (4) WO - BIM and ML technologies are applicable, with BIM having higher percentage frequency and MODE in item' 5'.

Figure 12 - Bar graphs with technologies applicable to activities



Source: The Authors

Discussion

The organizational function of Facility Management encompasses a complex and diverse set of activities that need process improvements for (1) data collection, analysis, and transfer, (2) the workflow, and (3) prediction and monitoring. Emerging technologies have the potential to support diverse FM activities. However, new knowledge and investment are needed to be implemented appropriately, generating a positive impact on the parties involved (facility managers, owners, users, and service providers).

Conducting the SLR was of paramount importance to identify, with scientific rigor, emerging technologies applicable to different FM activities, allowing the disclosure of their contributions and limitations of the processes of implementation and operation of ETs in FM. This research identified 28 FM activities and 119 technological applications (Figure 10). BIM was investigated in 59 cases (50%), Machine Learning in 15 cases (13%), and IoT in 12 cases (10%). There may even be an integration between them, as investigated by Cheng *et al.* (2020), to predict the future condition of the MEP components.

It is noteworthy that behind each technology, there are different software, hardware, languages, algorithms, and coding necessary to customize the technology to the specific activity. This makes the implementation and operation of ET even more complex.

Mainly in developing countries, such as Brazil, the search for specific solutions demonstrates the initial stage of maturation of technological applications in FM, as can be seen in the awarded professional works: (1) Nascimento and Veloso (2020) – presentation of videos of operation and/or handling of equipment through Augmented Reality; (2) Oliveira *et al.*

(2020) – use of drones for routine inspection; and (3) Medina (2020) - monitoring and control of HVAC equipment by IoT.

This fact motivated performing a survey with Brazilian FM professionals to verify which ETs would meet the latent needs of professional practice. The low participation of respondents allowed us to give statistical treatment to the technological options applicable to only six FM activities identified in the SLR (Figure 13).

Figure 13 – Analysis of the alternatives

Activity	Options	Reference	Type of technology	descriptive: MODE	inferential: p-value	inferential: rank
Commissioning	BIM	Kim; Poirier; Staub-French (2020)	Data capture and processing, and visualization	5 (< 40%)		
	WSN	**Noye; North; Fisk (2018)**	**Performance**	**5 (> 50%)**		
Emergency evacuation	BIM	Mirahadi; McCabe; Shahi (2019)	Data capture and processing, and visualization	3 (>30%)		
	GIS	Gunduz; Isikdag; Basaraner (2017)	Data capture and processing, and visualization	3 (>30%)		
	IoT	**Wong; Ge; He (2018)**	**Performance**	**3 (>40%)**		
Equipment inventory/ asset information	**BIM**	**Diao; Shih (2019)**	**Data capture and processing, and visualization**		**< 0.05**	**3.68**
	GIS	Tan et al. (2018)	Data capture and processing, and visualization		< 0.05	2.55
	QR	Zhan (2019)	Identification		< 0.05	2.91
	AR	Liu; Seipel (2018)	Visualization		< 0.05	2.82
	RFID	Wong; Ge; He (2018)	Identification		< 0.05	3.03
Preventive maintenance	**BIM**	**Falorca (2019)**	**Data capture and processing, and visualization**	**5 (< 40%)**		
	ML	McArthur et al. (2018)	Data capture and processing	4 (> 40%)		
Work Order	BIM	Chen et al. (2018)	Data capture and processing, and visualization	5 (< 50%)		
	ML	**McArthur et al. (2018)**	**Data capture and processing**	**5 (> 50%)**		
Useful Life	**BD**	**Mawed; Hajj (2017)**	**Data capture and processing**		**< 0.05**	**145.00**
	RFID	Wong; Ge; He (2018)	Identification		< 0.05	8.00

Source: The Authors

The related works, developed by Diao; Shih and Mawed (2019); Hajj (2017), are validated by using statistical treatment inferential from the survey applied to Brazilian FM professionals. Thus, they highlight the process of replication and improvement of the proposed methods and instruments. The studies of Wong, Ge, He (2018); Falorca (2019); and McArthur et al. (2018), show more relevant trends than the others since the analysis was only possible by MODE.

BIM is initially perceived as more relevant for preventive maintenance activities, issuance, and control of WOs and equipment inventory/asset information. This corroborates research on the application of BIM as support to (1) improve the management of elevator maintenance operations in a building (Fargnoli et al., 2019), (2) automatically program and generate maintenance WOs (Chen et al., 2018), and (3) troubleshooting and operational efficiency of MEP maintenance (Diao; Shih, 2019).

Big Data is perceived as more relevant to Useful Life activities, corroborating the case study developed to identify operational complexities using a dataset and identify KPIs requiring monitoring in the Balanced Scorecard (Mawed; Hajj, 2017). This shows Big Data and BIM and the need for tools that help in the processing and recording data in the medium and long term.

However, WSN was perceived as more relevant to support commissioning activities. This corroborates the Arduino-based prototype for measurements needed to meet the PO-Cx (Noye; North; Fisk, 2018). For emergency evacuation activities, the application of IoT was more frequent, which is in line with the survey of seven real-time positioning systems (Wong; Ge; He, 2018). Both technological applications have the function of operating the devices in an automated way, demonstrating the need for tools that help immediate response-requiring activities.

The options adopted by FM professionals are directed to the response of performance in use at a specific time (i.e., commissioning and emergency evacuation) and to the monitoring and control of daily activities by using technological solutions that involve data capture and processing (i.e., inventory of equipment/asset information, preventive maintenance, Service Order, and service life).

Note the usefulness of the technological applications investigated in the real world since such implementations would assist Facility Managers in scheduled activities and eventualities. Such technological applications make responses to demands more agile and reliable. The importance of the process of selecting emerging technology(ies) to meet previously identified needs is again worth emphasizing.

In addition, the process of selecting and implementing emerging technologies alongside Facility Management activities can positively impact organizations in the search for competitiveness in the market in which they operate and contribute to meeting the Sustainable Development Goals (SDGs) (UN, 2022), mainly for SDGs 9 – Industry, innovation and infrastructure, SDGs 12 – Responsible consumption and production, and 16 – Peace, justice and strong institutions.

The validation of the applications of technologies in FM activities recommends the following future work focused on the Brazilian context: (1) Maturation of the solution development stage (Fargnoli *et al.,* 2019); (2) Improvement of the solution to allow the generation of Work Orders for several maintenance teams (Chen *et al.,* 2018); (3) Proposing a solution to mitigate application drift (Diao; Shih, *2019*); (4) Instruments to streamline decision-making regarding the assessment of technology by companies (Mawed; Hajj, 2017); (5) Expansion of the use and analysis of data from specific sensors for different building systems (Noye; North; Fisk, 2018); and (6) Exploration of empirical validations and instantiations in case studies to validate findings from text review and mining (Gunduz; Isikdag; Basaraner, 2017).

The limitation of the research focuses on: (1) selecting only two databases for surveying recent publications (methodology); (2) small sample of professionals surveyed (results); (3) non-parametric inferential statistical treatment due to the small sample size (evaluation).

5. Conclusion

The application of emerging technologies in the continuous improvement process in FM has excellent potential and impact on the organization and people. However, for a better allocation of human and financial capital, a through study must be carried out to verify the specificities of the activity(ies) and the technological resources (software, hardware, programming language, application/development of algorithms/models, and coding) that will be needed to meet the demands, mainly in developing countries like Brazil.

The WSN, IoT, BIM, and Big Data are the FM ETs with the greatest optimization potential in the performance of FM activities, considering the technological competencies of Brazilian FM professionals that answered the survey, from the exploration of previous studies on technological application in different FM activities.

The suggested framework could support managers in selecting and implementing emerging technologies with FM activities.

Acknowledgements

To Fluminense Federal University (*Universidade Federal Fluminense*) and the Professional Master Program in Management Systems that hosted the author Marcus Vinicius Rosário da Silva for the development of your research on the topic. The author Marcelo Jasmim Meiriño thanks the support of the National Council for Scientific and Technological Development

(*Conselho Nacional de Desenvolvimento Científico e Tecnológico* - CNPq) – Process Number: 430119/2016-0 and the author Sheila Walbe Ornstein thanks the Productivity Grant of the CNPq Process Number 304131/2020-2.

References

Abdelalim, A.; O'Brien, W.; Shi, Z. (2017) "Data visualization and analysis of energy flow on a multi-zone building scale", Automation in Construction, Vol. 84, p. 258-273. doi:10.1016/j.autcon.2017.09.012.

Akil, M.; Tittelein, P.; Defer, D.; Suard, F. (2019) "Statistical indicator for the detection of anomalies in gas, electricity and water consumption: Application of smart monitoring for educational buildings", Energy and Buildings, Vol. 199, p. 512-522, doi: 10.1016/j.enbuild.2019.07.025.

Alavi, H.; Forcada, N.; Bortolini, R.; Edwards, D. J. (2021) "Enhancing occupants' comfort through BIM-based probabilistic approach", Automation in Construction, Vol. 123, doi: 10.1016/j.autcon.2020.103528.

Alshboul, O., Shehadeh, A., Al-Kasasbeh, M., Al Mamlook, R.E., Halalsheh, N. and Alkasasbeh, M. (2021), "Deep and machine learning approaches for forecasting the residual value of heavy construction equipment: a management decision support model", Engineering, Construction and Architectural Management, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/ECAM-08-2020-0614

Alshboul, O.; Shehadeh, A.; Hamedat, O. (2021) "Development of integrated asset management model for highway facilities based on risk evaluation", International Journal of Construction Management, Vol. 1 No. 10, doi: 10.1080/15623599.2021.1972204.

Amano, K.; Lou, E.C.W.; Edwards, R. (2019) "Integration of point cloud data and hyperspectral imaging as a data gathering methodology for refurbishment projects using building information modelling (BIM)", Journal of Facilities Management, Vol. 17 No. 1, pp. 57-75. doi: 10.1108/JFM-11-2017-0064

Ammari, K. E.; Hammad, A. (2019) "Remote interactive collaboration in facilities management using BIM-based mixed reality", Automation in Construction, Vol. 107. doi: 10.1016/j.autcon.2019.102940.

Arslan, M.; Cruz, C.; Ginhac, D. (2019) "Understanding Occupant Behaviors in Dynamic Environments using OBiDE framework", Building and Environment, Vol. 166. doi: 10.1016/j.buildenv.2019.106412.

ARUP. (2019) "FM 20.0: Re-imagining Facility Management for the Digital Age" https://www.arup.com/perspectives/publications/promotional-materials/section/reimagining-facility-management-for-the-digital-age (accessed 13rd April 2022).

Assaf, S.; Srour, I. (2021) "Using a data driven neural network approach to forecast building occupant complaints", Building and Environment, Vol. 200. doi: 10.1016/j.buildenv.2021.107972.

Atkins, B.; Bildsten, L. (2017) "A future for facility management", Construction Innovation, v. 17, n. 2, p. 116-124. doi: 10.1108/CI-11-2016-0059

Azizi, S.; Nair, G.; Rabiee, R.; Olofsson, T. (2020) "Application of Internet of Things in academic buildings for space use efficiency using occupancy and booking data", Building and Environment, Vol. 186. doi: 10.1016/j.buildenv.2020.107355.

Baek, F.; Ha, I.; Kim, H. (2019) "Augmented reality system for facility management using image-based indoor localization", Automation in Construction, Vol. 99. doi: 10.1016/j.autcon.2018.11.034.

Bonci, A.; Carbonari, A.; Cucchiarelli, A.; Messi, L.; Pirani, M; Vaccarini, M. (2019) A cyber-physical system approach for building efficiency monitoring", Automation in Construction, Vol. 102, p. 68-85. doi: 10.1016/j.autcon.2019.02.010.

Bouabdallaoui Y.; Lafhaj Z.; Yim P.; Ducoulombier L.; Bennadji B. (2020) "Natural Language Processing Model for Managing Maintenance Requests in Buildings. Buildings. Vol.10, No. 9:160. doi: 10.3390/buildings10090160

Carreira, P.; Castelo, T.; Gomes, C.C.; Ferreira, A.; Ribeiro, C.; Costa, A.A. (2018) "Virtual reality as integration environments for facilities management: Application and users perception", Engineering, Construction and Architectural Management, Vol. 25 No. 1, pp. 90-112. doi: 10.1108/ECAM-09-2016-0198

Cecconi, F.; Maltese, S; Dejaco, M.C. (2017) "Leveraging BIM for digital built environment asset management", Innov. Infrastruct. Solut., Vol.2, 14. doi: 10.1007/s41062-017-0061-z

Charlton, J.; Kelly, K.; Greenwood, D.; Moreton, L. (2021) "The complexities of managing historic buildings with BIM", Engineering, Construction and Architectural Management, Vol. 28 No. 2, pp. 570-583. doi: 10.1108/ECAM-11-2019-0621

Chen, L.; Shi, P.; Tang, Q.; Liu, W.; Wu, Q. (2020) "Development and application of a specification-compliant highway tunnel facility management system based on BIM", Tunnelling and Underground Space Technology, Vol. 97. doi: 10.1016/j.tust.2019.103262.

Chen, W.; Chen, K.; Cheng, J. C.P.; Wang, Q.; Gan, V. J.L. (2018) "BIM-based framework for automatic scheduling of facility maintenance work orders", Automation in Construction, Vol. 91, p. 15-30. doi: 10.1016/j.autcon.2018.03.007.

Chen, Y. J.; Lai, Y. S.; Lin,Y. H. (2020) "BIM-based augmented reality inspection and maintenance of fire safety equipment", Automation in Construction,NVol. 110. doi: 10.1016/j.autcon.2019.103041.

Cheng, J. C.P.; Chen, W.; Chen, K.; Wang, Q. (2020) "Data-driven predictive maintenance planning framework for MEP components based on BIM and IoT using machine learning algorithms", Automation in Construction, Vol. 112, doi: 10.1016/j.autcon.2020.103087.

Cheng, M. Y.; Chiu, K. C.; Hsieh, Y. M.; Yang, I. T.; Chou, J. S.; Wu, Y. W. (2017) "BIM integrated smart monitoring technique for building fire prevention and disaster relief", Automation in Construction, Vol. 84, p. 14-30. doi: 10.1016/j.autcon.2017.08.027.

Cooper, P.B.; Maraslis, K.; Tryfonas, T.; Oikonomou, G. (2017) "An intelligent hot-desking model harnessing the power of occupancy sensing data", Facilities, Vol. 35 No. 13/14, p. 766-786. doi: 10.1108/F-01-2016-0014

Craveiro, F.; Duarte, J.P.; Bartolo, H.; Bartolo, P.J. (2019) "Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0". Automation in Construction, v. 103, n. xx, p. 251-267. doi: 10.1016/j.autcon.2019.03.011

Dahanayake, K.C.; Sumanarathna, N. (2021) "IoT-BIM-based digital transformation in facilities management: a conceptual model", Journal of Facilities Management, doi: 10.1108/JFM-10-2020-0076

Dawson, C. (2020) "A-Z of Digital Research Methods", New York: Routledge.

Diao, P.-H.; Shih, N.-J. (2019) "BIM-Based AR Maintenance System (BARMS) as an Intelligent Instruction Platform for Complex Plumbing Facilities", Appl. Sci. Vol. 9, 1592. doi:10.3390/app9081592

Edirisinghe, R.; Woo, J. (2021) "BIM-based performance monitoring for smart building management", Facilities, Vol. 39 No. 1/2, p. 19-35. doi: 10.1108/F-11-2019-0120

Eskandari, N.; Noorzai, E. (2021) "Offering a preventive solution to defects in commercial building facility system using BIM", Facilities, doi: 10.1108/F-04-2020-0037

Falorca, J.F. (2019) "Main functions for building maintenance management: an outline application", International Journal of Building Pathology and Adaptation, Vol. 37 No. 5, pp. 490-509. doi: 10.1108/IJBPA-08-2018-0067

Fargnoli M, Lleshaj A, Lombardi M, Sciarretta N, Di Gravio G. (2019) "A BIM-based PSS Approach for the Management of Maintenance Operations of Building Equipment", Buildings. Vol. 9(6):139. doi: 10.3390/buildings9060139

Ferrández-Pastor, F.J.; García-Chamizo, J.M.; Gomez-Trillo, S.; Valdivieso-Sarabia, R.; Nieto-Hidalgo, M. (2020) "Smart Management Consumption in Renewable Energy Fed Ecosystems", Sensors, Vol. 19, 2967. doi: 10.3390/s19132967

Friedman, M. (1937) The use of ranks to avoid the assumptions of normality implicit in the analysis of variance. J. Amer. Statist. Assoc., 32, 675–701.

Gerrish, T.; Ruikar, K.; Cook, M.; Johnson, M.; Phillip, M.; Lowry, C. (2017) “BIM application to building energy performance visualisation and management: Challenges and potential”, Energy and Buildings, Vol. 144, p. 218-228. doi: 10.1016/j.enbuild.2017.03.032.

Gunasekara, H.G.; Sridarran, P.; Rajaratnam, D. (2021) "Effective use of blockchain technology for facilities management procurement process", Journal of Facilities Management, doi: 10.1108/JFM-10-2020-0077

Gunduz, M.; Isikdag, U.; Basaraner, M. (2017) “Trending Technologies for indoor FM: Looking for “Geo” in information”, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. IV-2/W1. doi:10.5194/isprs-annals-IV-2-W1-277-2016.

Halmetoja, E. (2019) "The conditions data model supporting building information models in facility management", Facilities, Vol. 37 No. 7/8, pp. 484-501. doi: 10.1108/F-11-2017-0112

Ismail, Z.-A.B. (2021a) "Towards a BIM-based approach for improving maintenance performance in IBS building projects", Engineering, Construction and Architectural Management, Vol. 28 No. 5, p. 1468-1490. doi: 10.1108/ECAM-07-2020-0508

Ismail, Z.-A. (2021b) "How BIM systems affect maintaining IBS building", Facilities, Vol. 39 No. 3/4, p. 196-214. doi: 10.1108/F-08-2019-0082

ISO. International Standard Organization. (2017) “Facility Management – Scope, Key concepts and benefits”, ISO/TR 41013:2017.

Jung, S.; Cha, H.S.; Jiang, S. (2020) “Developing a Building Fire Information Management System Based on 3D Object Visualization”, Appl. Sci., Vol. 10, 772. doi: 10.3390/app10030772

Kang, T.; Patil, S.; Kang, K.; Koo, D.; Kim, J. (2020) “Rule-Based Scan-to-BIM Mapping Pipeline in the Plumbing System”, Appl. Sci., Vol. 10, 7422. 10.3390/app10217422

Kazado, D.; Kavgic M.; Eskicioglu, R. (2019) “Integrating Building Information Modeling (BIM) and sensor technology for Facility Management”, ITcon Vol. 24, p. 440-458. https://www.itcon.org/2019/23

Kim, K.; Kim, H.; Kim, W.; Kim, C.; Kim, J.; Yu, J. (2018) “Integration of ifc objects and facility management work information using Semantic Web”, Automation in Construction, Vol. 87, p. 173-187. doi: 10.1016/j.autcon.2017.12.019.

Kim, S., Poirier, E.A. and Staub-French, S. (2020), "Information commissioning: bridging the gap between digital and physical built assets", Journal of Facilities Management, Vol. 18 No. 3, pp. 231-245. doi: 10.1108/JFM-04-2020-0024

Koch, C.; Hansen, G.K.; Jacobsen, K. (2019) "Missed opportunities: two case studies of digitalization of FM in hospitals", Facilities, Vol. 37 No. 7/8, p. 381-394. doi: 10.1108/F-01-2018-0014

Kwon, T.; Park, S.; Park, S. (2021) “Building information modeling-based bridge health monitoring for anomaly detection under complex loading conditions using artificial neural networks”, J Civil Struct Health Monit. doi: 10.1007/s13349-021-00508-6

Li, S.; Xu, Y.; Cai, J.; Hu, D.; He, Q. (2021) “Integrated environment-occupant-pathogen information modeling to assess and communicate room-level outbreak risks of infectious diseases”, Building and Environment, Vol. 187. doi: 10.1016/j.buildenv.2020.107394.

Liu, F.; Seipel, S. (2018) “Precision study on augmented reality-based visual guidance for facility management tasks”, Automation in Construction, Vol. 90, p. 79-90. doi: 10.1016/j.autcon.2018.02.020.

Love, P.E.D.; Matthews, J. (2019) “The ‘how’ of benefits management for digital technology: From engineering to asset management”, Automation in Construction, Vol. 107. doi: 10.1016/j.autcon.2019.102930.

Lu, Q.; Xie, X.; Parlikad, A. K.; Schooling, J. M. (2020) “Digital twin-enabled anomaly detection for built asset monitoring in operation and maintenance”, Automation in Construction, Vol. 118. doi: 10.1016/j.autcon.2020.103277.

Ma, Z.; Ren, Y.; Xiang, X.; Turk, Z. (2020) “Data-driven decision-making for equipment maintenance”, Automation in Construction, Vol. 112, doi: 10.1016/j.autcon.2020.103103.

Matos, R.; Rodrigues, F.; Rodrigues, H.; Costa, A. (2021) “Building condition assessment supported by Building Information Modelling”. Journal of Building Engineering, Vol. 38. doi: 10.1016/j.jobe.2021.102186.

Mawed, M.; Hajj, A.A. (2017) “Using big data to improve the performance management: a case study from the UAE FM industry”, Facilities, v. 35, n. 13/14, p.746-765. doi: 10.1108/F-01-2016-0006

Mawson, V. J.; Hughes, B. R. (2020) “Deep learning techniques for energy forecasting and condition monitoring in the manufacturing sector”, Energy and Buildings, Vol. 217. doi: 10.1016/j.enbuild.2020.109966.

McArthur, J.J.; Shahbazi, N.; Fok, R.; Raghubar, C.; Bortoluzzi, B.; An, A. (2018) “Machine learning and BIM visualization for maintenance issue classification and enhanced data collection”, Advanced Engineering Informatics, Vol. 38, p. 101-112. Doi: 10.1016/j.aei.2018.06.007

McGlinn, K.; Yuce, B.; Wicaksono, H.; Howell, S.; Rezgui, Y. (2017) “Usability evaluation of a web-based tool for supporting holistic building energy management”, Automation in Construction, Vol. 84, p. 154-165. doi: 10.1016/j.autcon.2017.08.033.

Medina, B. E. (2020) “[IoT para aparelhos de ar condicionado: uma solução para a gestão centralizada de múltiplos equipamentos]”. Prêmio ABRAFAC.

Mirahadi, F.; McCabe, B.; Shahi, A. (2019) “IFC-centric performance-based evaluation of building evacuations using fire dynamics simulation and agent-based modeling”, Automation in Construction, Vol. 101, p. 1-16, doi: 10.1016/j.autcon.2019.01.007.

Mo, Y.; Zhao, D.; Du, J.; Syal, M.; Aziz, A.; Li, H. (2020) “Automated staff assignment for building maintenance using natural language processing”, Automation in Construction, Vol. 113. doi: 10.1016/j.autcon.2020.103150.

Mohamed, A. G.; Abdallah, M. R.; Marzouk, M. (2020) “BIM and semantic web-based maintenance information for existing buildings”, Automation in Construction, Vol. 116. doi: 10.1016/j.autcon.2020.103209.

Nascimento, G. N.; Velo, I. (2020) “[Realidade Aumentada RA – Aplicada nas Operações Prediais]”. Prêmio ABRAFAC.

Nettis, A.; Saponaro, M.; Nanna, M. (2020) “RPAS-Based Framework for Simplified Seismic Risk Assessment of Italian RC-Bridges”. Buildings. Vol. 10(9):150. doi: 10.3390/buildings10090150

Nguyen, C. H. P.; Choi, Y. (2018) “Comparison of point cloud data and 3D CAD data for on-site dimensional inspection of industrial plant piping systems”, Automation in Construction, Vol. 91, p. 44-52. doi: 10.1016/j.autcon.2018.03.008.

Noye, S.; North, R.; Fisk, D. (2018) “A wireless sensor network prototype for post-occupancy troubleshooting of building systems”, Automation in Construction, Vol.89, p.225-234. doi: 10.1016/j.autcon.2017.12.025

Oliveira, G. P.; França, R. A.; Calabro, C. M.; Lima, E. A. (2020) “[O uso de drone no gerenciamento de propriedades]”. Prêmio ABRAFAC.

Page, M. J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; et al. (2021) “The PRISMA 2020 statement: an updated guideline for reporting systematic reviews”. BMJ, Vol. 372:n71. doi: 10.1136/bmj.n71

Parn, E.A.; Edwards, D.; Riaz, Z.; Mehmood, F.; Lai, J. (2019) "Engineering-out hazards: digitising the management working safety in confined spaces", Facilities, Vol. 37 No. 3/4, p. 196-215. doi: 10.1108/F-03-2018-0039

Patacas, J.; Dawood, N.; Kassem, M. (2020) “BIM for facilities management: A framework and a common data environment using open standards”, Automation in Construction, Vol. 120. doi: 10.1016/j.autcon.2020.103366.

Peng, Y.; Lin, J. R.; Zhang, J. P.; Hu, Z. Z. (2017) “A hybrid data mining approach on BIM-based building operation and maintenance”, Building and Environment, Vol. 126, p. 483-495, doi: 10.1016/j.buildenv.2017.09.030.

Petri, I.; Rana, O.; Rezgui, Y.; Fadli, F. (2021) “Edge HVAC Analytics”, Energies, Vol. 14, 5464. 10.3390/en14175464

Piselli, C.; Guastaveglia, A.; Romanelli, J.; Cotana, F.; Pisello, A.L. (2020) “Facility Energy Management Application of HBIM for Historical Low-Carbon Communities: Design, Modelling and Operation Control of Geothermal Energy Retrofit in a Real Italian Case Study”, Energies 2020, Vol. 13, 6338. doi: 10.3390/en13236338

Quinn, C.; Shabestari, A. Z.; Misic, T.; Gilani, S.; Litoiu, M.; McArthur, J.J. (2020) “Building automation system - BIM integration using a linked data structure”, Automation in Construction, Vol. 118. doi: 10.1016/j.autcon.2020.103257.

Rogage, K.; Clear, A.; Alwan, Z.; Lawrence, T.; Kelly, G. (2020) "Assessing building performance in residential buildings using BIM and sensor data", International Journal of Building Pathology and Adaptation, Vol. 38 No. 1, p. 176-191. doi: 10.1108/IJBPA-01-2019-0012

Roper, K.O. (2017) "Facility management maturity and research", Journal of Facilities Management, Vol. 15 No. 3, pp.235-243. doi: 10.1108/JFM-04-2016-0011

Sadeghi, M.; Elliott, J.W.; Porro, N.; Strong, K. (2019) "Developing building information models (BIM) for building handover, operation and maintenance", Journal of Facilities Management, Vol. 17 No. 3, p. 301-316. doi: 10.1108/JFM-04-2018-0029

Schibuola, L.; Scarpa, M.; Tambani, C. (2018) “Performance optimization of a demand controlled ventilation system by long term monitoring”, Energy and Buildings, Vol. 169, p. 48-57. doi: 10.1016/j.enbuild.2018.03.059.

Seghezzi, E.; Locatelli, M.; Pellegrini, L.; Pattini, G.; Di Giuda, G.M.; Tagliabue, L.C.; Boella, G. (2021) Towards an Occupancy-Oriented Digital Twin for Facility Management: Test Campaign and Sensors Assessment”, Appl. Sci., Vol. 11, 3108. doi: 10.3390/app11073108

Shehadeh, A.; Alshboul, O.; Al Mamlook, R.E.; Hamedat, O. (2021) “Machine learning models for predicting the residual value of heavy construction equipment: An evaluation of modified decision tree, LightGBM, and XGBoost regression”, Automation in Construction, Vol. 129, doi: 10.1016/j.autcon.2021.103827

Shehadeh, A.; O. Alshboul, O.; Tatari, M. A.; Alzubaidi, Salama; A. H. E. S. (2022) "Selection of heavy machinery for earthwork activities: A multiobjective optimization approach using a genetic algorithm", Alexandria Engineering Journal, Vol. 61 No.10, pp. 7555-7569, doi: 10.1016/j.aej.2022.01.010

Skiena, S. S. (2020) “The Algorithm Design Manual” Third Edition, Switzerland: Springer Nature.

Silva, M. V. R. (2020) “[Tecnologias emergentes como recurso para criação de valor agregado junto as atividades de Facility Management: uma análise quali-quantitativa]”. Master Thesis presented to Fluminense Federal University.

Silva, C.; Zamboni, A.; Hernandes, E.; Thomazzo, A. D.; Belgamo, A.; Fabrri, S. (2021) “StArt – State of the Art though Systematic Review (version 3.3)”. Laboratory of Research on Software Engineering (LaPES) belongs to the Computing Department of the Federal University of São Carlos (DC/UFSCar).

Tan, Y.; Song, Y.; Zhu, J.; Long, Q.; Wang, X.; Cheng, J. C P. (2018) “Optimizing lift operations and vessel transport schedules for disassembly of multiple offshore platforms using BIM and GIS”, Automation in Construction, Vol. 94, p. 328-339. doi: 10.1016/j.autcon.2018.07.012

Tan, Y.; Fang, Y.; Zhou, T.; Gan, V. J.L.; Cheng, J. C.P. (2019) “BIM-supported 4D acoustics simulation approach to mitigating noise impact on maintenance workers on offshore oil and gas platforms”, Automation in Construction, Vol. 100, p.1-10. doi: 10.1016/j.autcon.2018.12.019.

UN. United Nations. (2022) “The 17 goals” https://sdgs.un.org/goals (accessed 18th April 2022).

Valinejadshoubi, M.; Moselhi, O.; Bagchi, A. (2021) "Integrating BIM into sensor-based facilities management operations", Journal of Facilities Management. doi: 10.1108/JFM-08-2020-0055

Valinejadshoubi, M.; Moselhi, O.; Bagchi, A.; Salem, A. (2021) "Development of an IoT and BIM-based automated alert system for thermal comfort monitoring in buildings", Sustainable Cities and Society, Vol. 66. doi: 10.1016/j.scs.2020.102602.

Vandecasteele, F.; Merci, B.; Verstockt, S. (2017) "Fireground location understanding by semantic linking of visual objects and building information models", Fire Safety Journal, Vol. 91, p. 1026-1034. doi: 10.1016/j.firesaf.2017.03.083.

Villa, V.; Naticchia, B.; Bruno, G.; Aliev, K.; Piantanida, P.; Antonelli, D. (20210 "IoT Open-Source Architecture for the Maintenance of Building Facilities". Appl. Sci. 2021, 11, 5374. 10.3390/app11125374

Vitiello, U.; Ciotta, V.; Salzano, A.; Asprone, D.; Manfredi, G.; Cosenza, E. (2019) "BIM-based approach for the cost-optimization of seismic retrofit strategies on existing buildings", Automation in Construction, Vol. 98, p. 90-101, doi: 10.1016/j.autcon.2018.10.023.

Wang, B.; Yin, C.; Luo, H.; Cheng, J. C.P.; Wang, Q. (2021) "Fully automated generation of parametric BIM for MEP scenes based on terrestrial laser scanning data", Automation in Construction, Vol. 125. doi: 10.1016/j.autcon.2021.103615.

Wei, Y.; Akinci, B. (2019) "A vision and learning-based indoor localization and semantic mapping framework for facility operations and management", Automation in Construction, Vol. 107. doi: 10.1016/j.autcon.2019.102915.

Wen, Y.; Tang, L.C.M.; Ho, D.C.W. (2021) "A BIM-based space-oriented solution for hospital facilities management", Facilities, Vol. 39 No. 11/12, p. 689-702. doi: 10.1108/F-10-2019-0105

Wetzel, E. M.; Thabet, W.Y. (2018) "A case study towards transferring relevant safety information for facilities maintenance using BIM", ITcon Vol. 23, p. 53-74, doi: https://www.itcon.org/2018/3

Wijekoon, C.; Manewa, A.;Ross, A.D. (2020), "Enhancing the value of facilities information management (FIM) through BIM integration", Engineering, Construction and Architectural Management, Vol. 27 No. 4, pp. 809-824. doi: 10.1108/ECAM-02-2016-0041

Wilcoxon, F. (1945) "Individual comparisons by ranking methods". Biometrics, 1, 80–83.

Xie, X.; Lu, Q.; Herrera, M. Yu, Q.; Parlikad, A. K.; Schooling, J. M. (2021) "Does historical data still count? Exploring the applicability of smart building applications in the post-pandemic period", Sustainable Cities and Society, Vol. 69. doi: 10.1016/j.scs.2021.102804.

Xie, X.; Lu, Q.; Rodenas-Herraiz, D.; Parlikad, A.K.; Schooling, J.M. (2020) "Visualised inspection system for monitoring environmental anomalies during daily operation and maintenance", Engineering, Construction and Architectural Management, Vol. 27 No. 8, p. 1835-1852. doi: 10.1108/ECAM-11-2019-0640

Xu, X.; Mumford, T.; Zou, P. X. W. (2021) "Life-cycle building information modelling (BIM) engaged framework for improving building energy performance", Energy and Buildings, Vol. 231. doi:10.1016/j.enbuild.2020.110496.

Xu, Y.; Turkan, Y. (2020) "BrIM and UAS for bridge inspections and management", Engineering, Construction and Architectural Management, Vol. 27 No. 3, p. 785-807. doi: 10.1108/ECAM-12-2018-0556

Yan, Y.; Hajjar, J. F. (2021) "Automated extraction of structural elements in steel girder bridges from laser point clouds", Automation in Construction, Vol. 125. doi: 10.1016/j.autcon.2021.103582.

Yang, E.; Bayapu, I. (2020) "Big Data analytics and facilities management: a case study", Facilities, Vol. 38 No. 3/4, p. 268-281. doi: 10.1108/F-01-2019-0007

Yin, X.; Liu, H.; Chen, Y.; Wang, Y.; Al-Hussein, M. (2020) "A BIM-based framework for operation and maintenance of utility tunnels", Tunnelling and Underground Space Technology, Vol. 97. doi: 10.1016/j.tust.2019.103252.

Zhan, J.; Ge, X.J.; Huang, S.; Zhao, L.; Wong, J.K.W.; He, S.X. (2019) "Improvement of the inspection-repair process with building information modelling and image classification", Facilities, Vol. 37 No. 7/8, p. 395-414. doi: 10.1108/F-01-2018-0005

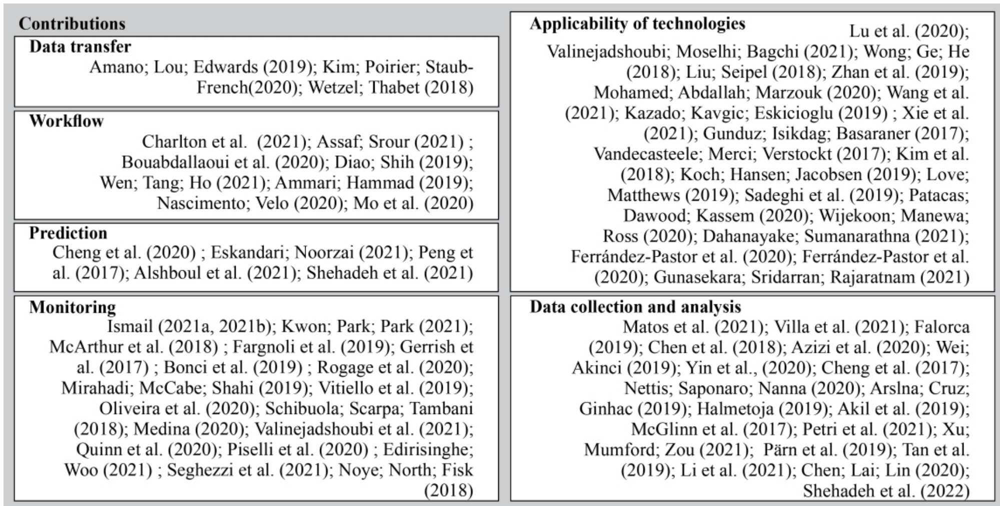


Figure 1 – Summary of main contributions from previous research

297x150mm (300 x 300 DPI)

Limitations

Small sample
Ismail (2021a, 2021b); Lu et al. (2020) ; Rogage et al. (2020); McGlinn et al. (2017) ; Medina (2020); Nascimento; Velo (2020)

Tests/cases
Cheng et al. (2017) ; Kim et al. (2018); Koch; Hansen; Jacobsen (2019)

Visualization
Amano; Lou; Edwards (2019); Liu; Seipel (2018); Zhan et al. (2019); Wang et al. (2021); Ammari; Hammad (2019)

Literature
Gunduz; Isikdag; Basaraner (2017); Vandecasteele; Merci; Verstockt (2017); Mohamed; Abdallah; Marzouk (2020); Dahanayake; Sumanarathna (2021)

Validation lack
Villa et al. (2021); Falorca (2019); Mawed; Hajj (2017); Yang; Bayapu (2020); Love; Matthews (2019); Patacas; Dawood; Kassem (2020); Piselli et al. (2020) ; Xu ;Mumford; Zou (2021) ; Wetzel; Thabet (2018) ; Seghezzi et al. (2021); Fargnoli et al. (2019)

Software
Matos et al. (2021); Diao; Shih (2019); Bonci et al. (2019) ; Kazado; Kavgic; Eskicioglu (2019) ; Mirahadi; McCabe; Shahi (2019); Edirisinghe; Woo (2021) ; Mo et al. (2020)

Model/algorithm
Kwon; Park; Park (2021); Cheng et al. (2020) ; Assaf; Srour (2021) ; Chen et al. (2018) ; Bouabdallaoui et al. (2020); Jung; Cha; Jiang (2020); Alavi et al. (2021); Peng et al. (2017) ; Quinn et al. (2020); Akil et al. (2019) ; Ferrández-Pastor et al. (2020); Tan et al. (2019) ; Carreira et al. (2018) ; McArthur et al. (2018) ; Wei; Akinci (2019); Shehadeh et al (2021); Shehadeh et al. (2022)

Hardware
Noye; North; Fisk (2018); Valinejadshoubi; Moselhi; Bagchi (2021); Nettis; Saponaro; Nanna. (2020); Oliveira et al. (2020); Alshboul et al. (2021)

Use / FM specifics
Charlton et al. (2021; Wen; Tang; Ho (2021); Halmetoja (2019); Sadeghi et al. (2019)

Skills and competencies
Wong; Ge; He (2018); Baek; Ha; Kim (2019); Chen; Lai; Lin (2020); Gunasekara; Sridarran; Rajaratnam (2021)

Data
Kim; Poirier; Staub-French (2020); Ma et al. (2020); Eskandari; Noorzai (2021); Azizi et al. (2020) ; Xie et al. (2021); Wijekoon; Manewa; Ross (2020); Petri et al. (2021) ; Li et al. (2021); Arslan; Cruz; Ginhac (2019); Vitiello et al. (2019); Yin et al. (2020)

Figure 2 - Summary of the main limitations of the research

297x177mm (300 x 300 DPI)

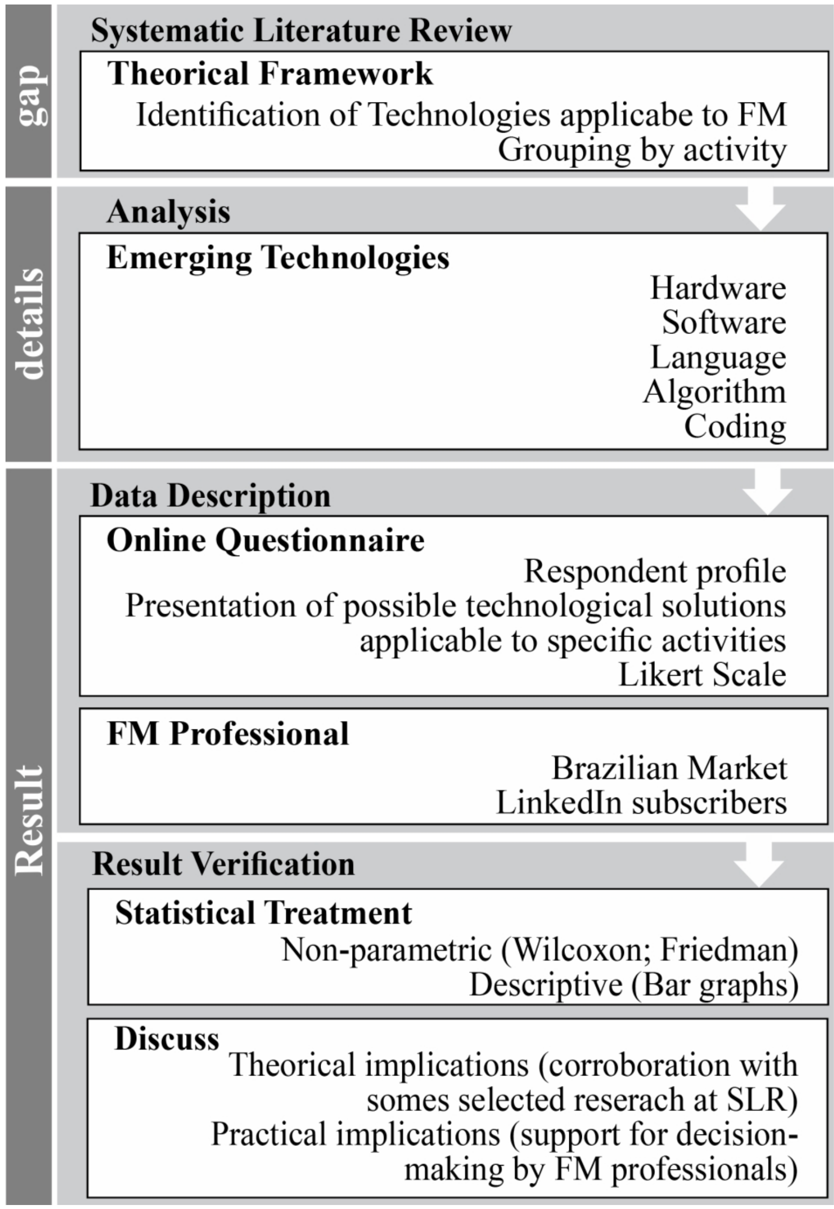


Figure 3 – Step-by-step methodology

153x209mm (300 x 300 DPI)

Protocol

Objective
Identify emerging Technologies in Facility Management and their practical and theoretical implications.

Main question
What are the emerging Technologies in Facility Management (last 5 years)?

Secondary questions
What methodologies are used?
What are the manegerial implications?
What are the knowledge gaps?

String
TS= (((Facility* AND Management) AND ((Emerging AND Technology*) OR Big Data OR BIM OR Blockchain OR Photogrammetry OR GIS OR IoT OR Laser Scanning OR Machine Learning OR QR Code OR Augmented Reality OR Virtual Reality OR RFID OR Unmanned Aerial System OR Semantic Web OR WSN)))

Source selection criteria definition
Digital availability of the article
Indexed database
Journal articles

Studies language
English

Source search methods
PRISMA: Page *et al.* (2021)
START: Silva *et al.* (2021)

Source
Web of Science: Elsevier, Mdpi, Springer Nature, IEEE, Emerald Group Publising
Scopus

Categories
Civil Engineering; Management; Construction Building Technology
Engineering; Business, Management and Accouting

Date range searched
2017 to 2021

Study selection criteria (inclusion)
Technology applied to FM
General usage example
Case example
Theoretical background

Study selection criteria (exclusion)
Technology applied to core business
Keywords do not match the topic
Metadata na/or full document not accessible
Restricted publication (Total or Partial)

Definition of study types
Qualitative and Quantitative

Initial selection of studies
Silva (2020), ISO (2017); Noye; North; Fisk (2018); McArthur et al. (2018); Mawed; Hajj (2017); Tan et al. (2018); Zhan et al. (2019); Gunduz; Isikdag; Basaraner (2017).

Quality assessment of studies
papers will be rated: 'very low' (0-2); 'low' (3-4); 'high' (5-6); and 'very high' (7-8). Papers classified as 'very low' and 'low' will be excluded.

Quality form fields * (yes=1; no=0) I **('yes=2; partially=1; no=0)
Is the introduction to the problem clear?*
- Is the goal/purpose clear?*
- Is the methodology/design clear?*
- Are the results clear?*
- Does the methodology/design match the purpose?**
- Are the findings consistent with the methodology?**

Data extraction of form fields
Author(s) and year
Technologies
Algorithm
Software
Hardware
Language
Coding
FM Activity
Practical implications
Research implications
Limitations

Results summary
Theoretical Framework

Figure 4 – Protocol

228x209mm (300 x 300 DPI)

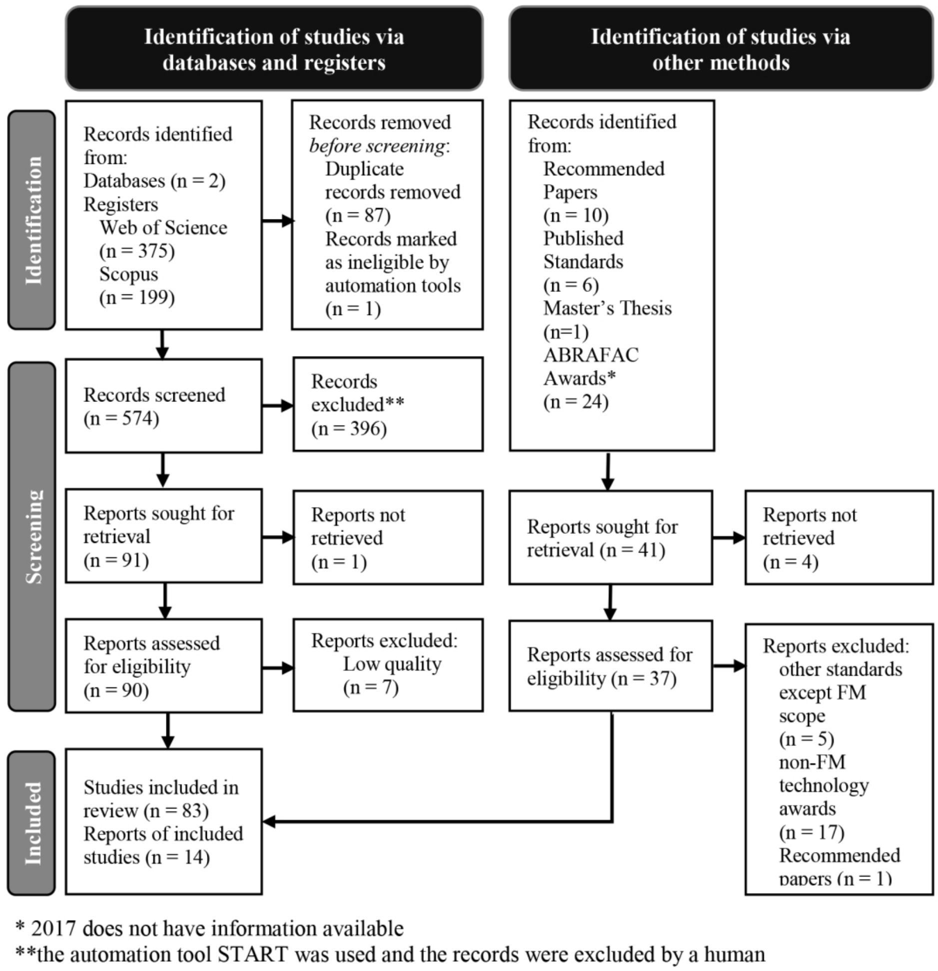


Figure 5 – Flow diagram

156x159mm (300 x 300 DPI)

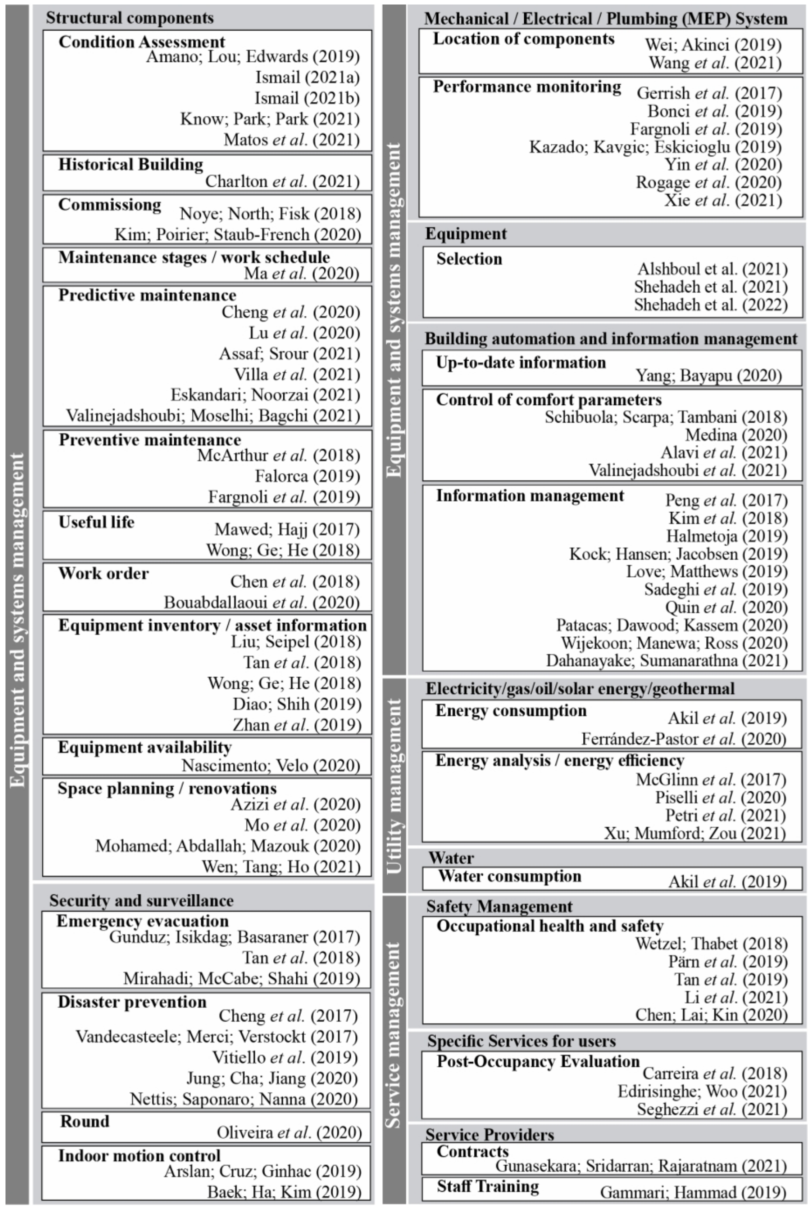


Figure 6 – Theoretical Framework

145x209mm (300 x 300 DPI)

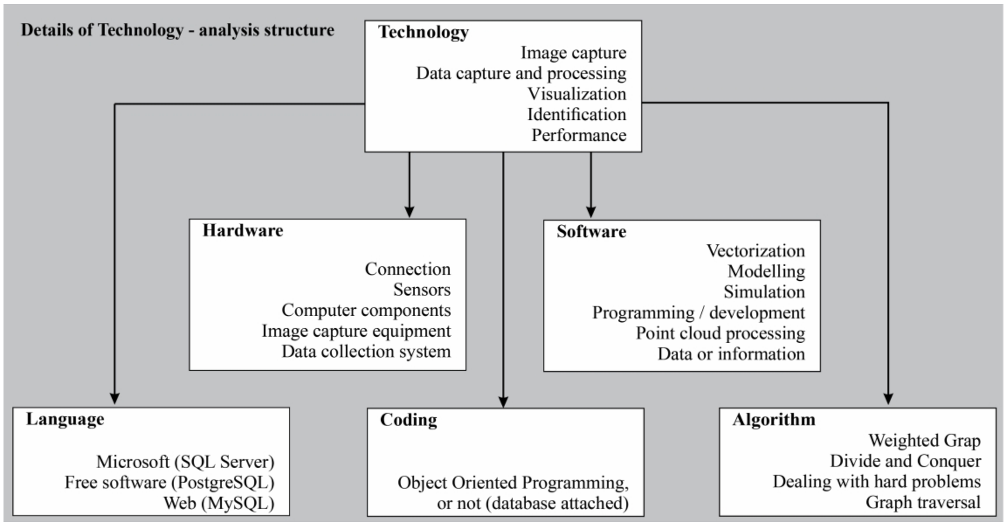


Figure 7 – Structure of the analysis method of technological details

297x154mm (300 x 300 DPI)

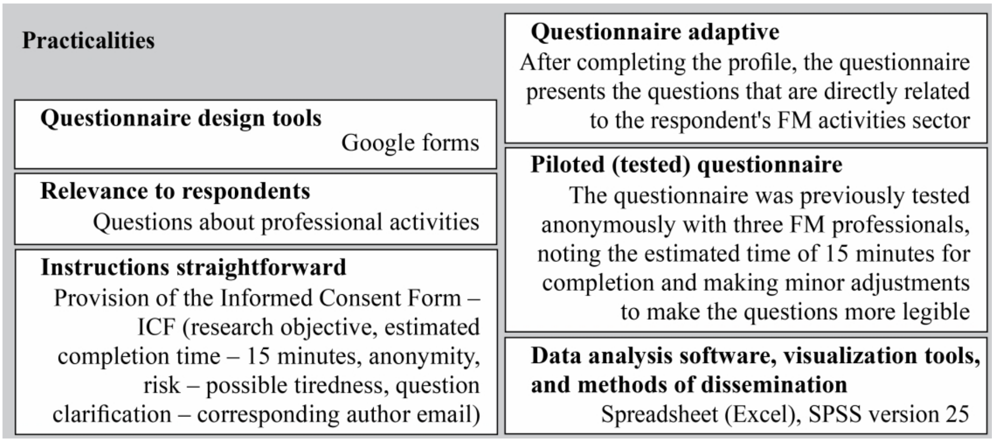


Figure 8 – Practicalities

297x129mm (300 x 300 DPI)

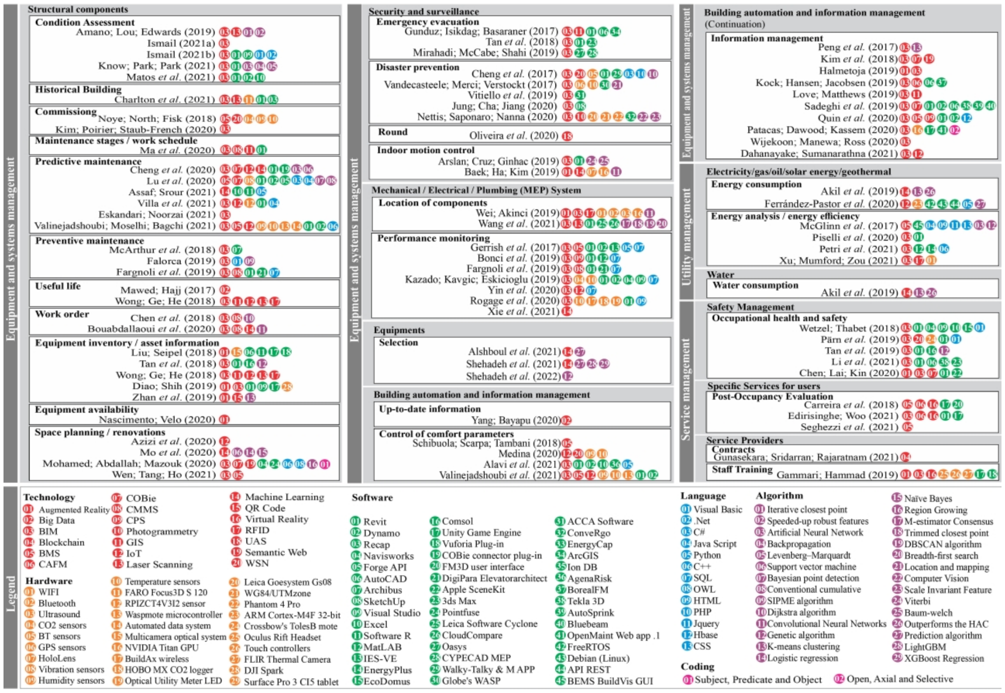


Figure 9 - Details of technologies applied to FM

399x274mm (300 x 300 DPI)

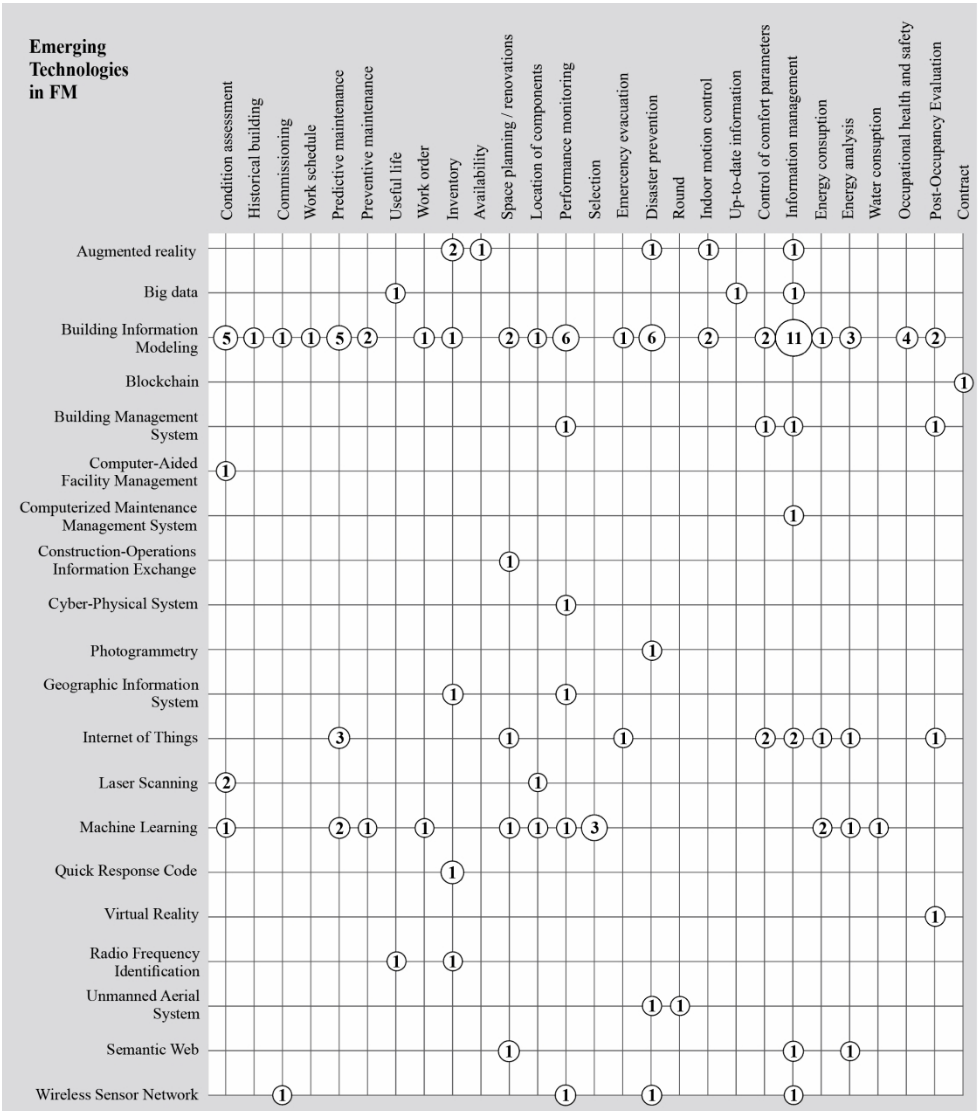


Figure 10 – Summary of technologies applicable to FM activities

189x209mm (300 x 300 DPI)

Profile

Gender	
Male	n=70
Female	n=30

Education attainment	
Lato Sensu / MBA	n=67
Higher education	n=28
Master degree	n=5

Area	
Corporate	n=47
Industrial	n=13
Mall/Retail	n=12
Educational	n= 8
Healthcare	n= 7
Consulting	n= 4
Technology	n= 3
Energy/Oil&Gas	n= 3
Banking	n= 2
Hotel	n= 1

State	
São Paulo	n=53
Rio de Janeiro	n=33
Minas Gerais	n= 6
Paraná	n= 3
Espírito Santo	n= 1
Goiás	n= 1
Bahia	n= 1
Piauí	n= 1
Amazonas	n= 1
Other	n= 0

Figure 11 – General profile of respondents

297x108mm (300 x 300 DPI)

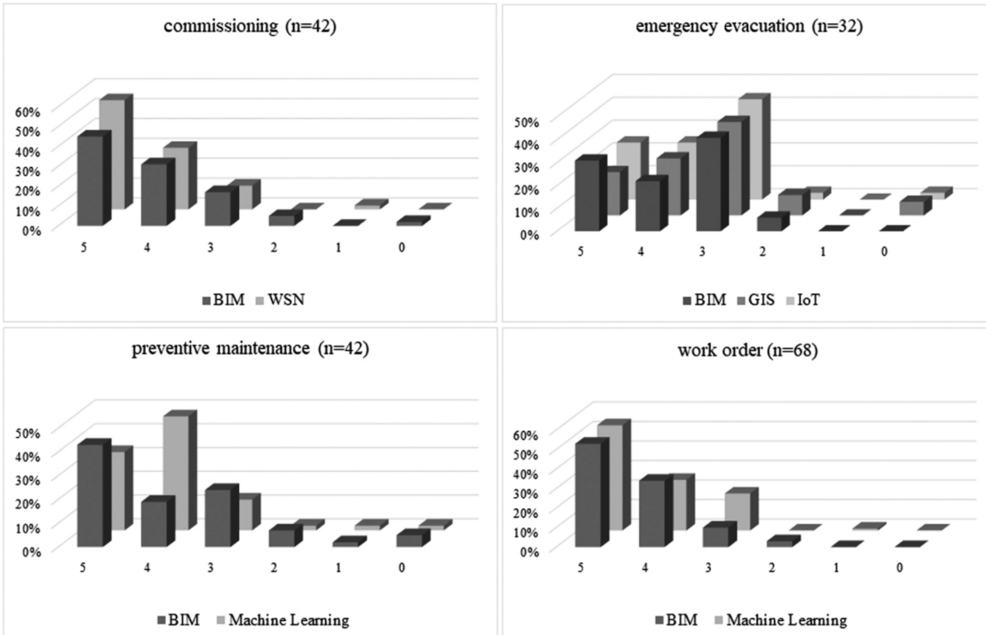


Figure 12 - Bar graphs with technologies applicable to activities

150x99mm (300 x 300 DPI)

	Options	Reference	Type of technology	descriptive	inferential	
				MODE	p-value	rank
Commissioning	BIM	Kim; Poirier; Staub-French (2020)	Data capture and processing, and visualization	5 (< 40%)		
	WSN	**Noye; North; Fisk (2018)**	**Performance**	**5 (> 50%)**		
Emergency evacuation	BIM	Mirahadi; McCabe; Shahi (2019)	Data capture and processing, and visualization	3 (>30%)		
	GIS	Gunduz; Isikdag; Basaraner (2017)	Data capture and processing, and visualization	3 (>30%)		
	IoT	**Wong; Ge; He (2018)**	**Performance**	**3 (>40%)**		
Equipment inventory/ asset information	**BIM**	**Diao; Shih (2019)**	**Data capture and processing, and visualization**		**< 0.05**	**3.68**
	GIS	Tan et al. (2018)	Data capture and processing, and visualization		< 0.05	2.55
	QR	Zhan (2019)	Identification		< 0.05	2.91
	AR	Liu; Seipel (2018)	Visualization		< 0.05	2.82
	RFID	Wong; Ge; He (2018)	Identification		< 0.05	3.03
Preventive maintenance	**BIM**	**Falorca (2019)**	**Data capture and processing, and visualization**	**5 (< 40%)**		
	ML	McArthur et al. (2018)	Data capture and processing	4 (> 40%)		
Work Order	BIM	Chen et al. (2018)	Data capture and processing, and visualization	5 (< 50%)		
	ML	**McArthur et al. (2018)**	**Data capture and processing**	**5 (> 50%)**		
Useful Life	**BD**	**Mawed; Hajj (2017)**	**Data capture and processing**		**< 0.05**	**145.00**
	RFID	Wong; Ge; He (2018)	Identification		< 0.05	8.00

Figure 13 – Analysis of the alternatives

297x163mm (300 x 300 DPI)