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ARE WE THERE OR DO WE HAVE MORE TO DO? METAVERSE IN FACILITY MANAGEMENT AND FUTURE PROSPECTS

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Abstract. Businesses are eager to adopt new technologies such as augmented reality, blockchain, extended reality, and artificial intelligence, among others, as they see beneficial applications for strategic empowerment. As one of the technological disruptions, metaverse has caught the attention of the larger business community and facility management (FM) sector. In a world where various virtual realities converge, the hyper-connected digital universe known as the metaverse has the potential to fundamentally alter how FM and business interactions are conducted in the future. More people are spending time conducting business online, increasing the metaverse's potential. Businesses are also making significant investments in the development of metaverse techniques. This study reviews the current literature to comprehend how metaverse techniques have shaped the building blocks of FM by looking at 206 papers. There is currently a dearth of functional metaverse research. This article aims to provide a thorough analysis of the integration of metaverse techniques for facility management. The review reveals several opportunities for further research into the FM-metaverse ecosystem, including improving data interoperability, enhancing the precision of point cloud data for as-built models of existing facilities, and producing efficient virtual property database integration.

Keywords: metaverse, facility management, blockchain, virtual reality, extended reality, literature review.

Introduction

The past decade has seen a paradigm shift in the fields of engineering, construction, architecture, and facility management (ECAFM); this has improved the adoption of critical development for its design process management (Alexa et al., 2022; Al-Salman & Salih, 2019). The integration of products and management of operations, however, are still carried out separately, manually, and independently, adding to the complexity of facility management (Wang et al., 2022).

With the primary goal of ensuring the built environment's maximum performance, facility management is an area of expertise that encompasses spaces, people, technology, and processes (Kim et al., 2018). The built property life cycle has historically been separated from engineering, architecture, construction (EAC), and FM. The FM field lags far behind other industries in adopting cutting-edge technological trends (Sanzana et al., 2022; Xie et al., 2020). The management of buildings in their current state of use should be effective throughout their lifespan, with a sustainable approach to taking into account the novel issues of the European Union (EU) of digital transition and resilience. FM is in the forefront to reaching these objectives (Petri et al., 2023). Moreover, up to 86% of the building's total lifespan expenses are covered by FM (K.E.K et al., 2021; Rad et al., 2021). Even though the lifespan of a building costs can and should be managed during the design stage, new tools and technologies are increasingly being adopted to enhance FM in current structures. Future research into cutting-edge technologies such as combining FM with Mixed Reality (MR), Augmented Reality (AR), Virtual Reality (VR), and Extended Reality (XR) has been identified and discussed (Künz et al., 2022). The metaverse is the

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solution that integrates all these pertinent technologies in a global setting. This notion creates a digitally simulated setting that can be accessed as a fully immersive virtual world. By the duality principle, users can communicate with this virtual ecosystem using their digital avatars (Ning et al., 2021). Furthermore, avatars represent users virtually, having the same legal status in the metaverse as they would have in the real world (Mystakidis, 2022). Hence, the avatar is responsible for all transactions made in the virtual world and is not permitted to undo any committed acts. The content is accessible to anyone with a VR/AR-enabled fully immersive gadget, such as glasses or a headset, that satisfies the prerequisites (Ning et al., 2021).

Over the past few years, there has been an increase in interest in disruptive technologies (DT) adoption in FM. Numerous governments, such as Australia and the UK, have emphasized the need to revolutionize the FM field by accelerating DT adoption (Setaki & Van Timmeren, 2022; Xie et al., 2020). The metaverse is the next phase of technological progress and can dramatically expand the use of digital technology and improve FM beyond what is possible with conventional online systems. A brand-new class of social media platforms and internet applications, enabled by metaverse, incorporates several cutting-edge technologies. It offers a fully immersive experience based on XR technology, builds an economic ecosystem based on blockchain technology, generates a mirrored representation of the physical world based on digital twin technology, and seamlessly incorporates the real world and the virtual world into the identity system, the social system, and the economic ecosystem, enabling each user to generate content and adjust the world (Huynh-The et al., 2023; Shi et al., 2023). The concept of the metaverse is undergoing constant change, with various actors adding to its significance in their own unique ways.

The metaverse is suggested as an appealing answer to automation, interplay, and the incorporation of wider surrounding circumstances, where the virtualization process now faces substantial challenges (Oleksy et al., 2023; Vidal-Tomás, 2023). Facility managers, therefore, have historical data and the expertise to establish the basis for innovative approach prototypes. As an example, it can be utilized in FM projects to manage devices, monitor the presence or motion of people, align the primary parts with their corresponding 3D models, or enable the efficient use of all the system's intelligence to carry out the work plan (Sanzana et al., 2022; Shvets & Hanák, 2023). Even though VR and AR technologies provide stand-alone FM solutions, no environment or platform could combine both of these technologies. This digital ecosystem is made available to the world through the metaverse, which greatly expands the range of potential outcomes (Huynh-The et al., 2023). Hence, the recent anxiety regarding a successful digital transition in FM presents a fantastic opportunity to enhance facility data management in current buildings.

Therefore, we look into previous research in the metaverse field through a systematic literature review. Nine eminent literature reviews on the metaverse were discovered during the initial research for this article. The details of these nine literature papers, as well as the gaps that were discovered in them, are presented in Table 1. The relationship between the concept of the metaverse and FM is not discussed in any of the literature reviews listed in Table 1. The majority of the papers discuss the two concepts separately. The absence of connections between FM and metaverse techniques in these articles points to a significant and pertinent research gap; as a result, the goal of this paper's literature review is to present a comprehensive analysis of the incorporation of metaverse techniques for FM. Table 1 serves the purpose of mapping the field and compiling a list of search words relevant to FM and metaverse techniques. By analyzing the literature reviews in Table 1, we gain insights into the existing research landscape and extract keywords that will help in our exploration of the intersection between FM and metaverse techniques.

Table 1. Main review studies on metaverse and facility management

S. No.	Ref.	Article title	Journal	Theme	Articles review	Gaps
1	(Kar & Varsha, 2023)	"Unravelling the techno-functional building blocks of metaverse ecosystems – a review and research agenda"	International Journal of Information Management Data Insights	Investigating how new technologies shape the building blocks of the metaverse environment	70	The only focus was identifying the research on metaverse marketing strategies
2	(Arisekola & Madson, 2023)	"Digital twins for asset management: social network analysis-based review"	Automation in Construction	Identification of digital twin's role in asset management using social network analysis	92	The focus was not on metaverse and facility management
3	(Babalola et al., 2023)	"A systematic review of the application of immersive technologies for safety and health management in the construction sector"	Journal of Safety Research	Exploring the role of the application of various cutting-edge technologies in the construction field	117	The study was much more general and concentrated on the role of immersive technologies in the construction industry

End of Table 1

S. No.	Ref.	Article title	Journal	Theme	Articles review	Gaps
4	(Sanzana et al., 2022)	"Application of deep learning in facility management and maintenance for heating, ventilation, and air conditioning"	Automation in Construction	Employing current deep learning applications in facility management	100	The only goal was to locate deep learning research in the field of facility management
5	(Narin, 2021)	"A content analysis of the metaverse articles"	Journal of Metaverse	Exploring the role of metaverse technology in all fields	40	The focus of the article was on the implementation of the metaverse rather than facility management
6	(Giang Barrera & Shah, 2023)	"Marketing in the metaverse: conceptual understanding, framework, and research agenda"	Journal of Business Research	Adoption of metaverse in marketing	164	The article highlights the growing interest in the metaverse. However, it does not emphasize the part that the metaverse plays in facility management
7	(Lyons, 2022)	"Talent acquisition and management, immersive work environments, and machine vision algorithms in the virtual economy of the metaverse"	Psychosociological Issues in Human Resource Management	Implementation of metaverse in management and talent acquisition	79	The study looked at metaverse in talent management and recruitment. However, there is no discussion about facility management
8	(Onggirawan et al., 2023)	"Systematic literature review: The adaptation of distance learning process during the COVID-19 pandemic using virtual educational spaces in metaverse"	Procedia Computer Science	Implementation of metaverse in the educational field	31	The focus of the article was not facility management, but rather the implementation of the metaverse ecosystem
9	(Mannino et al., 2021)	"Building information modelling and internet of things integration for facility management—literature review and future needs"	Applied Sciences	Providing a thorough analysis of IoT-BIM incorporation for process improvements in facility management	99	The focus was not on metaverse in facility management

To fill this research gap, we carry out a literature review to primarily address the following research questions (RQ).

- *RQ1: How has the literature on metaverse techniques in the FM field developed over time?*
- *RQ2: What are the metaverse techniques used to solve FM optimization issues?*
- *RQ3: What are the primary research questions related to the metaverse – FM integration, which should motivate future research initiatives?*

The remainder of this paper is structured as follows. The background of FM and metaverse techniques, as well as their impact on FM, is presented in Section 1. The research methodology is outlined in Section 2. The results of the research are presented in Section 3. The key findings and future research directions are discussed in Section 4. Finally, we conclude the review in the last section.

1. Background

This section provides a clear definition of the review's scope and boundaries; this is necessary to understand the remaining sections of the paper.

1.1. Evolution of metaverse

The metaverse is the next stage of digital development that has the potential to dramatically increase the adoption of digital technology and expand the range of services available beyond conventional systems with online access (Ning et al., 2021). In essence, it won't bring back the internet or social network; instead it has been created and incrementally transformed into a 3D social network that users can access online with novel and exciting experiences (Oleksy et al., 2023). The term "metaverse" first appeared in Neal Stephenson's fiction book "Snow Crash" in 1992, where

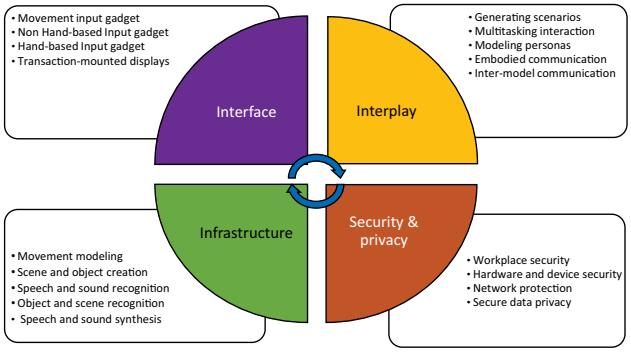

Figure 1. Metaverse classifications

it was defined as a substantial virtual setting linked to the real world where users or customers are able to communicate with avatars (Shi et al., 2023). Accordingly, the first appearance is to a computerized world that defines a variety of concepts such as lifelogging items like physiological sensors that are used to gather data (Vidal-Tomás, 2023), embedded internet, virtual space (Oleksy et al., 2023), mirror planets, and omniverse environments – places of modeling using object interaction (Kara et al., 2023). The concept of the metaverse was then introduced into the context of the most recent iteration of the online realm, which uses web 3.0 electronic device artifacts like VR headsets, electronic ledgers, and avatars with an original combination of the real and virtual worlds to enable social interaction for users (Dincelli & Yayla, 2022).

As shown in Figure 1, we categorize the definitions of the metaverse into four types by summarizing each metaverse attribute: infrastructure, interface, interplay, security, and privacy. An illustrative example of a categorization used for separating the various kinds of metaverse is the similarity to the real world. There are two types of infrastructure: realistic infrastructure that accurately reflects actual constraints and unrealistic infrastructure that allows for a wide range of degrees of autonomy (Huynh-The et al., 2023). The level of involvement (e.g. VR, 3D) in the metaverse is also categorized according to the characteristics of the interface. Although users can experience a great deal of immersion when using VR gadgets in a 3D setting, the metaverse provides more than just the use of VR equipment in 3D environments (Mystakidis, 2022). The focus of metaverse classifications, alongside interfaces and environments, is on interplays between users and non-player characters (NPCs) that go beyond straightforward dialogue (Shi et al., 2023). Instead of just being a copy of real-world community, the metaverse has recently focused on redefining the social significance of the metaverse itself.

1.2. Facility management

Facility management is an interdisciplinary subject that necessitates the cooperation and management of multiple individuals (Li et al., 2019; Pishdad-Bozorgi et al., 2018). FM is described in ISO 41011:2018 as an "organizational function which incorporates place, people, and process within the construction environment to enhance the well-being of people, ergonomics, and the efficiency of the core business" (Babinskė & Apanavičienė, 2020). The International Facility Management Association (IFMA) lists 11 core competencies in FM as follows: operations and maintenance (O&M), occupancy and human factors, sustainability, risk management, project management, finance and business, communication, facility information and technology management, real estate, quality and performance, strategy and leadership (Lee et al., 2021).

Currently, due to obsolete procedures that result in a lack of data, some buildings do not have optimal management (Pishdad-Bozorgi et al., 2018; Wang et al., 2022). In other instances, the data gathered is not fully utilized despite the use of sensors, automated items, and databases (Re Cecconi et al., 2019; Lee et al., 2021). FM computerized systems, such as Automated Maintenance Management Systems (AMMS), Building Automation Systems (BAS), and Energy Management Systems (EMS) are examples of places where data is frequently dispersed and provided manually after the occupancy of the building (Lee et al., 2021). Processes can become time-consuming and inefficient due to dispersion and data scarcity (Kim et al., 2018). Moreover, FM workers frequently use printed materials in their daily tasks, which lengthens the time taken and makes it more challenging to obtain reliable data (Pishdad-Bozorgi et al., 2018). For these reasons, improving FM operations and procedures is a crucial challenge in FM businesses.

1.3. Metaverse integration in facility management

The development of cutting-edge technologies at the beginning of the twenty-first century has made it possible to integrate the real and virtual worlds. Many conventional business practices have evolved as a result of technological developments. For instance, large corporations in the automotive (e.g. Bosch, BMW) and aerospace sectors (e.g. Boeing) have been digitalized to promote revenue, improve operations, and encourage innovation (R&D) (Alexa et al., 2022; Fazal et al., 2022). The worldwide construction field is the least technologically advanced of all sectors, according to Newman et al. (2020). In general, less than 1% of revenue is invested in R&D; this is significantly less than in other industries, such as the aerospace and automotive sectors, where R&D expenditures range from 3.5 to 4.5% of revenue (Papulová et al., 2022).

The contemporary FM setups are unable to gather and analyze the comprehensive data and knowledge resulting from construction activities or repair and maintenance, such as arguments for choosing particular maintenance techniques, failure causes, selection of specialized contractors, and cascading effects on other building components (Shvets & Hanák, 2023; Wang et al., 2022). Building efficiency can be significantly impacted by an effective data management system for operations, which may assist and incorporate data produced by the project management team (Pishdad-Bozorgi et al., 2018; Sanzana et al., 2022). Widespread interest has been generated by the potential for expanding the

application of key metaverse techniques, such as XR (including VR and AR), blockchain, digital twin, and 6G wireless systems, for recording, transmitting, and recording big data throughout the entire construction process, from design and development to maintenance and operation (Dincelli & Yayla, 2022; Maas & Hughes, 2020). Consequently, more innovations have been created in recent years.

2. Methodology

2.1. Database selection

For this systematic review, we search articles using the Scopus database because it offers a variety of scholarly information and helps us develop a more thorough understanding of the research we wish to conduct. Accordingly, we can rely on the research papers indexed in Scopus for academic purposes as they are carefully chosen for inclusion in the database itself (Meyers et al., 2021; Oliveira et al., 2018).

2.2. Search strategy

We search the Scopus database using a set of keywords and article titles to conduct our research. The terms "metaverse", "extended reality", "virtual reality", "augmented reality", and "blockchain" are searched together with Boolean logic (AND/NOT) to retrieve the literature on "metaverse techniques" and "facility management". To locate as many articles on the integration of metaverse techniques in the field of FM as possible, a second search is conducted using the keywords associated with FM core functions (Table 2). Since using metaverse techniques in FM is still a relatively new concept, this review does not have a time frame restriction.

2.3. Data mining and quality assessment

The literature review (LR), a crucial component of all academic research, helps to base the study on the body of existing research on the relevant topic (Lee et al., 2021). The LR aims to add value by reporting original research gaps, findings, and ensuring future directions (Oliveira et al., 2018). The LR offers a thorough overview of the existing literature in a particular field by gathering and synthesizing previous pertinent papers (Denyer & Tranfield, 2009). The need for a systematic methodology to develop a rigorous, exhaustive, and fruitful LR is essential due to the extraordinarily quick pace of generating knowledge in business fields that is fueled by a dispersed interdisciplinary approach (Maas & Hughes, 2020).

For our systematic literature review, we use the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach due to its thorough reviewing strategy. The PRISMA method provides a thorough checklist of all prerequisites for conducting a review that can be reproduced by other researchers and will result in accurate data for future research (Moher et al., 2010). The PRISMA method is made up of several steps that can be useful for conducting research in the fields of physical and medical science, although it is still in its exploratory stage and is being updated for research in computer science. The PRISMA-based method for systematic literature reviews helps to guarantee the integrity of the review, enables readers to assess its strengths and shortcomings, allows for the replicating of review approaches, structure, and format, and serves as a resource for others in the field of research (Liberati et al., 2009).

The papers are designed to be written in English throughout the research process. Reading the titles and abstracts allows us to manually filter the literature that the search turns up. The next step in the filtration process involves roughly searching the articles to make sure they are pertinent to the discussion of metaverse-based facility management solutions. As part of the screening process, the papers that had been recorded are manually reviewed to determine whether they are relevant to the topic. Those that weren't, are excluded. For this systematic review, we do not consult any books, conference reviews, or conference papers. We employ a content analysis strategy to identify the themes in order to guarantee their coherence. We carry out individual keyword searches on Scopus and identify the level of agreement among the data that is returned. To verify the search outcome, relevant database titles and keywords are double-checked. Then, duplicate full-text articles are eliminated after being screened for relevance.

In total, 206 papers from 135 journals that are ranked A or A* (ABDC listing) or 2 or higher (ABS listing) are the result of our research. The quality standards for journals are maintained to guarantee that the articles included undergo thorough peer review before publication. Through a series of readings of the introduction, methods used, discussion, and key findings, we examine the concepts related to our main objectives that are presented in the paper. The relevant articles are collected, then coded into different groups. Furthermore, we provide a comprehensive examination of the key ideas, concepts, and contributions that come to light during the regressive analysis of this systematic review. Further, we have offered a flowchart of our study (see Figure 2).

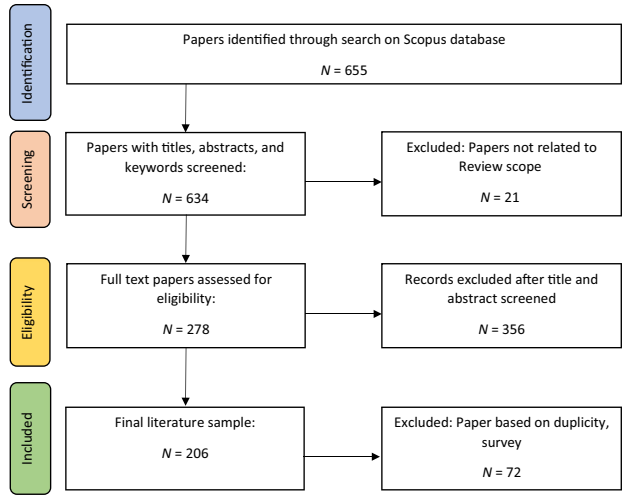

Figure 2. Flowchart on review methodology

Table 2. Research keywords for FM and its core functions

FM core competencies	Keywords
FM	"Facilit* management" or FM
Risk management	"Emergency*" or "Risk*"
O&M	"Facili*maintenance management" or FMM or "maintenance management" or maintenance or "operation*" or "Work management systems" or "physical safety and security"
Performance and quality	KPI or "key performance indicators" or "quality management" or "service level agreements"
Information and technology management	"Automation" or "intelligent building systems" or "data collection" or "information security*" or "information management" or "cyber-security" or "information system"
Sustainability	"Energy*" or Sustainab* or "Water*" or "Waste*" or "Building energy management systems" or BEM*
Communication	Report* or communication* or "communication* strategy"
Human factors	"Workplace environment" or occupancy or "occupant services" or "occupant safety" or "occupant health" or "occupant security"
Finance and business	Budget* or "financial management" or contract* or financial or procurement
Project management	"Project execution" or "project management" or "project monitor" or "project schedule" or "project outcomes"
Property and real estate management	"Property management" or "real estate management" or "Real estate strategies" or "Asset management" or "real estate assessment"
Strategy & leadership	"Team* management" or leadership or "conflict management" or "team* organization"

3. Results

This section explicitly reveals the current state of the relevant literature and the contributing journals by presenting the findings of our initial statistical analysis. The results of the literature review are discussed in relation to the following questions: 1) How many peer-reviewed articles are published year-wise?, 2) How has FM-metaverse nexus evolved, and which journals have published the FM metaverse synergy peer-reviewed publications?, 3) What are the metaverse techniques that contribute to the improvement of FM?, and 4) What are the FM classifications based on metaverse technique applications?

3.1. Publications and journals

For this systematic review, Figure 3 illustrates the publication of research studies by year. The focus on writing

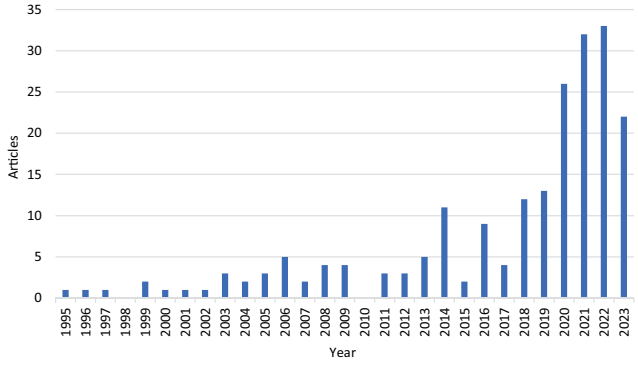

Figure 3. Time distribution

articles about FM related to the metaverse is growing. There are many publications in this field where articles are analyzed for journal-specific trends. Several engineering, management, economics, operations research, and agriculture journals, alongside journals from other industrial fields, are assessed. This is evident from the fact that only one article is published in each of the 107 journals. The diversity of papers that have been published shows the interdisciplinary character of this field and the demand for collaborative efforts from different sectors. The journal-based classification is further described in Table 3.

Table 3. Classification by journals

Journal name	No. of articles
JOURNALS HAVING SINGLE PAPER	107
AUTOMATION IN CONSTRUCTION	17
APPLIED SCIENCES (SWITZERLAND)	9
IEEE ACCESS	8
FACILITIES	7
BUILDINGS	6
ENERGY AND BUILDINGS	4
JOURNAL OF NEUROENGINEERING AND REHABILITATION	4
ENGINEERING, CONSTRUCTION AND ARCHITECTURAL MANAGEMENT	3
JOURNAL OF INFORMATION TECHNOLOGY IN CONSTRUCTION	3
ADVANCES IN ENGINEERING SOFTWARE	2
APPLIED SOFT COMPUTING JOURNAL	2
ARTIFICIAL INTELLIGENCE FOR ENGINEERING DESIGN, ANALYSIS AND MANUFACTURING: AIEDAM	2
CONSTRUCTION INNOVATION	2
ELECTRONICS (SWITZERLAND)	2
ENGINEERING APPLICATIONS OF ARTIFICIAL INTELLIGENCE	2
EXPERT SYSTEMS	2
IEEE TRANSACTIONS ON MULTIMEDIA	2
INFORMATION SCIENCES	2

End of Table 3

Journal name	No. of articles
INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH	2
INTERNATIONAL JOURNAL OF INNOVATIVE TECHNOLOGY AND EXPLORING ENGINEERING	2
ISPRS JOURNAL OF PHOTOGRAMMETRY AND REMOTE SENSING	2
JOURNAL OF BUILDING ENGINEERING	2
JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT	2
JOURNAL OF FACILITIES MANAGEMENT	2
JOURNAL OF MANAGEMENT IN ENGINEERING	2
JOURNAL OF PERFORMANCE OF CONSTRUCTED FACILITIES	2
MATHEMATICS	2
SUSTAINABILITY (SWITZERLAND)	2

3.2. Descriptive analysis

We analyze the existing literature under the following two streams: 1) metaverse techniques applied in FM, and 2) FM core functions classification, in order to effectively respond to the three research questions stated in this study. Under the first stream, we aim to identify the metaverse techniques that scholars prefer to use when conducting their research (see Figure 4). This allows us to answer the second research question (RQ2).

The management of facility processes, improvement of document management and building security, provision of cost-efficient and effective materials, tracking and logistics, building energy controls, and monitoring of building component lifespan, are all FM operations and procedures that these techniques are thought to greatly facilitate. We find that authors primarily use blockchain as a metaverse technique when addressing FM. 42% of the articles used in this research are based on blockchain, which can serve as a distributed, decentralized source of shared reality and store and provide encrypted information access. From work order monitoring to proactive maintenance through life cycle analyses, blockchain has the potential to revolutionize the management of facilities. Furthermore, 38% of articles use extended reality (AR/VR/MR), which can help facility managers produce accurate, accessible, and three-dimensional depictions. Contemporary sophisticated and efficient methods of rendering data in space include VR and AR; these enhance interaction and visualization for FM tasks. Using a virtual 3D model, VR creates a visual representation of a computer-generated replica of a real or imagined environment (Maas & Hughes, 2020). Real-world settings and virtual objects can coexist in the same environment using AR technology (Künz et al., 2022). Moreover, in 24% of the studies, artificial intelligence (AI)

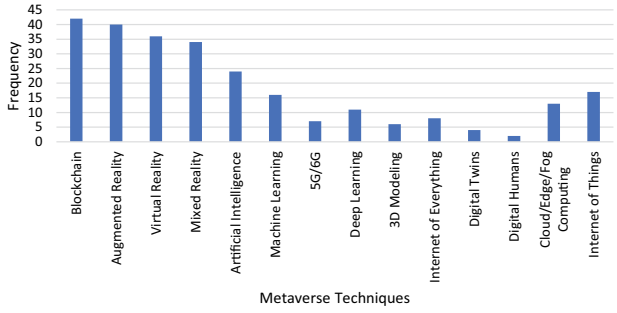

Figure 4. Application of metaverse techniques in FM

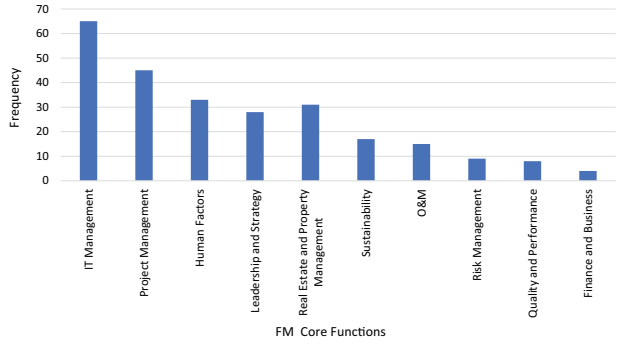

Figure 5. Facilitiy management core functions classification

is used by researchers. AI-enabled FM software can more effectively separate capital and operating costs, enhance accuracy and improve demand forecasting (Acerbi et al., 2021). Machine learning, 5G/6G, deep learning, 3D modeling, the Internet of Things, digital twins, and other technologies are less frequently used metaverse techniques.

To locate as many articles as possible about the incorporation of metaverse techniques in the FM sector, a second search is conducted using the keywords associated with FM core functions (Table 2). We attempt to create a graph of the different FM core operations where metaverse-based techniques are used to enhance FM. In contrast to the other FM core functions, Figure 5 shows that Human Factors, Strategy and Leadership, Property and Real Estate Management, Project Management, and Facility Information and Technology Management use metaverse techniques more frequently. Furthermore, it is obvious from the plot below that the less frequently used metaverse techniques in their practice are those related to finance and business, O&M, quality, sustainability, and risk management. There is no article found on the adoption of metaverse techniques within the communication core function.

3.3. Content analysis

The descriptive analyses shown in this paper's illustrations highlight the key traits of the literature on metaverse techniques, as well as its integration and impact on FM. An overview of the integration of metaverse techniques in the various FM core functions is given in the sub-sections that follow.

3.3.1. FM core function: risk management

Since risk management is essential to FM, it should come as no surprise that researchers from all over the world are most interested in this core competency. Many pertinent studies have been undertaken in this area. The studies of Klaine et al. (2020) and Lemos et al. (2022), which are quite similar, suggest an approach utilizing a wireless bluetooth sensor network to (a) identify escape routes, direct traffic in an emergency, (b) make early detection of a fire, (c) maximize evacuation/rescue efforts through reciprocal interactions between men and machines, and (d) make complex 3D visualizations of fire incidents. The suggested systems could lessen casualties, aid in evacuations and rescue efforts, and lessen public panic in the event of a fire.

Choi and Jun (2020) carry out another intriguing research study on "fire risk management". Their research suggests a method for planning a flexible approach in response to a fire's rapid environmental shifts. Using real-time videos from deep learning algorithms and closed circuit television (CCTV) sensors, the network can determine how many people are present in a given building space. Furthermore, Peng et al. (2017) provide an IoT-based model to forecast dangerous areas. During an evacuation, the IoT model includes a floorplan detail, sensor locations, and a condensed visualization paradigm. Eventually, research points to the possibility of using AR devices to move people away from dangerous and crowded areas while taking the shortest route possible.

3.3.2. FM core function: operations and maintenance

Managing facility operations and maintenance is a crucial aspect of FM. To make sure systems are efficient, secure, and compliant with rules and standards, it is necessary to have a solid understanding of structures and building systems.

Oleksy et al. (2023) make the initial attempt to connect the metaverse to real-time data. The AR model used in their research stores sensor data. This tactic, however, might backfire because the model might become overburdened with too much data from various kinds of sensors. A framework for information modeling is proposed by Entezami et al. (2022) to support structural health monitoring (SHM); this includes an external database to make it easier to store, share, and use the data that is collected. Arunmozhi et al. (2022) suggest methods that enable dynamic visualization of some important fundamental performance metrics within the blockchain model while promoting long-term data management and constant updating.

These tools are designed to make maintenance and risk management decision-making easier while reducing manual errors brought on by visual inspection of the buildings. Moreover, Küntzer et al. (2022) introduce the idea of XR and provide a metamodel for describing the characteristics and behavior of XR used for SHM communication. Specific system components that pertain to maintenance operations are listed.

3.3.3. FM core function: quality and performance

One of the less studied core functions is quality. It addresses requirements and expectations for the facility and its services to raise the efficiency of facility organizations and service providers. The quality of building materials and construction work is discussed (Coronado et al., 2022; De Giovanni, 2021) to ensure that the project's specifications are followed. Information can be detected through digitization if it has been poorly designed or performed. To ensure FM quality, the majority of research studies incorporate AI validation tools.

3.3.4. FM core function: information and technology management

Information technology is one of the many academic fields where metaverse research has started (Dincelli & Yayla, 2022). While Koo et al. (2009) examine the display, monitoring, and server features of creating a system using AR based on wireless technology at building sites and suggest a VR system prototype for the inspection of steel pole buildings, Hammad et al. (2012) propose the viability of AR technology for on-site assignments about infrastructures.

Several articles under review do not offer a general strategy to help with developing applications and software services to integrate metaverse models with sensor data. The engineering challenges of integrating sensor data with blockchain to handle operational performance data in real-time and enable proactive maintenance and operational decisions are discussed by Arunmozhi et al. (2022). The creation of collaborative blockchain-based MR, AR, and VR techniques is covered in Kral et al. (2022). Naticchia et al. (2020) conduct interesting research by creating an MR-based FM framework with two distinct modules: an office module for Immersive Augmented Virtuality (IAV) and a field AR module. These modules can be used separately or in combination to increase the effectiveness of field tasks through interactive visual cooperation.

Another interesting study is conducted by Sadhu et al. (2023), who provide three methods for integrating AI sensors to enable the visualization and analysis of both current and past data. The majority of studies emphasize the danger of losing competitiveness in both domestic and global markets if building industry participants delay implementing emerging technologies. However, the articles claim that investors are hesitant, particularly about expensive technologically advanced items. As a result, numerous researchers strive to reduce the initial expenditure while proposing creative approaches that enhance FM processes.

Studies on MR authoring tools focus on the creation of a 3D modeling program called Tinmith, which enables real-time exterior structure capture and rendering for MR modeling and direct user interaction (Piekarski & Thomas, 2003). Itoh et al. (2021) conduct a study on MR-CAD, which overlays 3D CAD models on top of real background images via a head-mounted display

(HMD), permitting the identification of spatial interference on blueprints throughout the design stage. In their research, Chen et al. (2021) present a VR prototype to decide where to install tower cranes at high-rise building locations and conduct testing procedures using a real building blueprint.

Recently, there has also been active research into using digital twins for FM. Through autonomous access to the most recent project information with digital twins, the study of Jiang et al. (2022) suggests an innovative approach to support site construction and FM activities by enabling site workers to visually record building problems or status updates. Tarek and Marzouk (2022) suggest an integrated AR and cloud computing approach for infrastructure utilities maintenance that can assist facility managers digitally when looking for FM items or when carrying out actual repairs and maintenance tasks. In addition, May et al. (2022) develop and evaluate an on-site BIM-based AR defect management (BIM-ARDM) system for construction inspections. A smart FM system is proposed by Casini (2022) that enhances current maintenance procedures and investigates a brand-new maintenance work process along with strategies for the use of extended reality technology.

The study by Lu (2021) suggests an AR-based cooperation assistance system for working-level FM process stakeholders, in which AR is used not only as a tool for maintenance data visualization, but also as a tool to exchange information and signals; this facilitates showing other coordination-related features to the entire team. BIM-based big data analytics with cloud-based storage capacities are created, verified, and assessed in Demirdöğen et al. (2023) to integrate BDA-based BIM systems to enhance information retrieval and operational effectiveness during the building process. A BIM-based MR framework is suggested by El Ammari and Hammad (2019) to assist with facility field tasks. In order to retrieve information based on time, the suggested framework incorporates BIM models, multisource facilities information, and feature-based monitoring in an MR-based setting. Further research to develop categories for fire protection equipment inspections using AI is conducted, and systems that can configure compiled data for AR visualization are developed and validated (Huang et al., 2022; Marzouk & Zaher, 2020; Xu et al., 2023).

The use of metaverse techniques in FM work is found to allow effective construction management by enabling the user to automatically access the paper documents or architecture blueprint, according to the analysis of the results of the preceding research. However, it is crucial to specify the data needed for FM and to connect with the data from the building information modeling, along with good visualization. The utility and worth of metaverse techniques with reduced cognitive resistance when used for FM are anticipated to be essential regarding enhanced productivity since 4D BIM based on a current virtual environment does not effectively reflect actual building site circumstances.

3.3.5. FM core function: sustainability

Sustainability can also be seen as an ethical responsibility that frequently benefits asset owners financially. The actions of facility managers are intended to support organizational effectiveness, preserve the environment, support the users of their facilities, and reduce risks and liabilities. Zhong et al. (2022) propose a blockchain-based IoT model to offer a variety of static data about building sustainability. The IoT system assumes responsibility for on-site data collection from building sensors. Building energy management can benefit from the synergy between these two ecosystems (IoT-blockchain), particularly through user participation. Banfi et al. (2022) process and display all data necessary for FM and energy simulations using XR and interoperability. Kuliga et al. (2015) demonstrate the value of using VR to manage and share information regarding a building's various aspects. Data on the environment and energy consumption are visualized in their study using VR. Hence, facility managers can better control building equipment and manage energy consumption.

3.3.6. FM core function: human factor

This fundamental parameter emphasizes minimizing risks and liabilities while positively affecting all stakeholders. The topics covered by all of the articles in this competency are indoor environmental tracking. The surveillance systems developed throughout different research projects have a lot to gain from the integration of blockchain and VR. Visualizing a variety of environmental monitoring data is made possible by this integration, linked to various objects and areas. Following this incorporation and the development of the database containing all environmental information (such as humidity, temperature, noise, and light), it is now possible to monitor quality issues to guarantee user convenience as well as to identify the necessity of building element maintenance.

In a study by Nguyen and Bednarz (2020), the researchers look at how extended reality affects communication and cooperation between people. The study demonstrates how virtual environments promote immersive and interactive communication, allowing users to participate more successfully in group projects. According to the results, extended reality encourages improved teamwork, knowledge sharing, and individual engagement, which ultimately produces better results in collaborative work settings. Similar to this, Xia et al. (2021) investigate how VR affects human cognition and decision-making. According to their study, the immersive qualities of a virtual environment stimulate cognitive functions like memory, attention, and problem-solving skills. According to the study's findings, VR could improve decision-making precision, creativity, and general cognitive performance.

3.3.7. FM core function: finance and business

The economic aspects of the finance and business core function are covered, along with both significant operational

expenses and financial investment. Hamledari and Fischer (2021) suggest a framework that integrates blockchain technology, automated sensors, smart contracts, and AI. The proposed framework is intended to serve as a roadmap for IT developers as they create and implement a computerized payment system to address payment security issues. From both the managerial and technical standpoints, this simultaneous use of several sophisticated technologies and the associated workflow has not previously been explored in the field of knowledge. In the same vein, Mathis et al. (2021) automatically update a VR model with location and status information. A substitute system to enable computerized payment of accomplished agreements and address issues with late or unpaid payments is also made possible by the storage of smart sensor data on the blockchain network.

3.3.8. FM core function: project management

The ability to manage projects is another crucial FM core function. Projects can range in size, duration, complexity, and financial risk. The IFMA defines design and planning, execution and shipment, and monitoring as sub-functions of project management (PM) (Babinskė & Apanavičienė, 2020).

The majority of articles about PM focus on the continuous monitoring of staff, materials, and equipment to enhance safety, logistics, quality assurance, security, and efficiency tracking (Conforto & Amaral, 2016; López-Robles et al., 2020). The most popular technologies for implementing the localization of objects and people are IoT and AI (Barnawi et al., 2021; Kinelski, 2020). The suggested mechanisms have an excellent precision rate, and applications for AI positioning systems in the real world are very promising and could increase the effectiveness of distributing resources while reducing human errors. In contrast, Natarajan et al. (2022) create a tracking system using the fusion of motion sensors, bluetooth low energy (BLE) technology, and IoT. The goal of this integration is to increase tracking accuracy while lowering and offsetting sensor errors.

Chadalavada et al. (2020) look at the application of AR in project collaboration and communication in their study. They discover that virtual environments make it possible for remote project teams to collaborate in real-time, improving communication, knowledge sharing, and team cohesion. The study shows that using AR technology improves project coordination and decreases communication barriers, leading to better project results. Similar research is conducted by Mandičák et al. (2021) to determine how big data analytics visualization affect project planning and design. Improved visualization helps decision-makers make better choices, increases stakeholder engagement, and reduces design errors, again leading to better project outcomes. Yigitcanlar et al. (2020) investigate the use of AI simulations for project risk evaluation and control in a different setting. Their study shows that virtual simulations in AI environments offer a realistic platform for project risk assessment, scenario simulation, and assessment of potential mitigation techniques.

The success and resilience of projects are increased as a result of a project manager's use of these techniques to proactively identify and manage risks. A study on the effects of deep learning-based visual data analytics for project oversight and management is also carried out by Pal and Hsieh (2021). They discover that deep learning makes it possible to track project progress, resource distribution, and task dependencies in real-time. To ensure that a project's goals are achieved, project managers can access project information, monitor key performance indicators, and make quick decisions. The study emphasizes the potential of deep learning to strengthen project oversight and management, ultimately enhancing project effectiveness and results.

3.3.9. FM core function: property and real estate management

This core function focuses on the management of tangible assets to meet asset shareholders' goals, improve user experience, and maximize real estate value. Bartram et al. (2020) discuss the use of AI to define the proper IoT-generated data ownership, a component of asset value. When taking into account the proper legal rights and obligations, there are no specific guidelines or laws that define the collection and usage of IoT data. By utilizing the metaverse environment, it may be possible to more clearly define the rights, obligations, and limitations associated with the use of IoT data in multiple-owned buildings.

Miljkovic et al. (2023) investigate the use of AI and VR in property visualization and marketing in their study. The study shows that realistic and collaborative immersive virtual environments allow prospective buyers or owners to tour properties virtually. According to the study, VR enhances real estate marketing initiatives by generating more qualified leads, minimizing the need for in-person visits, and enabling more informed buying or renting decisions. Khan et al. (2022) also look at how machine learning-centric resource management in cloud computing affects property management activities. The study shows that cloud computing platforms provide effective methods for managing and keeping track of real estate assets, enabling immediate access to information, documentation, and maintenance logs. According to the study's findings, cloud computing simplifies property upkeep, increases tenant satisfaction, and enhances resource allocation for property managers.

3.3.10. FM core function: strategy and leadership

This core competency is concerned with matching the facility portfolio to the organization's objectives and resources. The majority of the studies discuss "decision-making" from two different angles. For instance, Qiu et al. (2020) discuss several scenarios involving the use of smart construction items and their enhanced sensing, computing, processing, reacting capabilities, and networking to mitigate human decision-making limitations. These items

are represented in a virtual environment using the Industry Foundation Classes (IFC) format. Smart construction items may be beneficial to information processing, data collection, and autonomous decision-making due to their cutting-edge features, which also reduce human error and save time. Despite the undeniable benefits of smart construction items, there are still several obstacles that must be overcome before they can reach their full potential; these include societal changes, increased costs, adoption of AI, and organizational readiness.

Berg and Vance (2017) look into the application of VR in the strategic planning and decision-making processes. This study shows that virtual environments allow leaders to evaluate strategic options, simulate various scenarios, and acquire a comprehensive understanding of intricate business environments. Furthermore, the research shows that VR promoted creative problem-solving and enhanced strategic thinking enable more informed and data-driven decision-making. Boland (2023) also investigates how XR affects teamwork and leadership development. This study shows that XR platforms offer realistic and engaging settings for teamwork and leadership development.

4. Discussion and future directions

A thorough literature review has led to the development of the following framework. The proposed metaverse techniques-based FM framework provides an answer to the second RQ and serves as a supporting tool for businesses that want to use metaverse techniques but are unsure of the FM benefits that the various technologies may provide. A comprehensive framework is used to categorize metaverse techniques that affect FM. The framework in Figure 6 provides a summary of metaverse techniques that can be used to enhance various FM functions, including operations and maintenance (O&M), human factors, sustainability, risk management, finance and business, facility information and technology management, project management, quality, real estate, strategy and leadership. This allows practitioners to better determine which metaverse techniques to prioritize during implementation.

Regardless of the industry, collaboration between the various FM core functions is crucial. When each function is virtualized and digitalized through metaverse techniques, they are transformed into a metaverse ecosystem. Our review reveals that XR, blockchain, and AI are widely used technologies to enhance different FM pillars (see Figure 5). For instance, according to Küntzer et al. (2022), XR may encompass a project's architecture, construction, engineering, and FM. They give a practical example of how to create and manage a project's schedule using 4D visualization and XR. Bányai et al. (2019) claim that an XR simulates all building components and represents VR.

By applying metaverse techniques, it is feasible to encounter real-world scenarios including the offer of valuable "as-built" data (Chengoden et al., 2023), details of

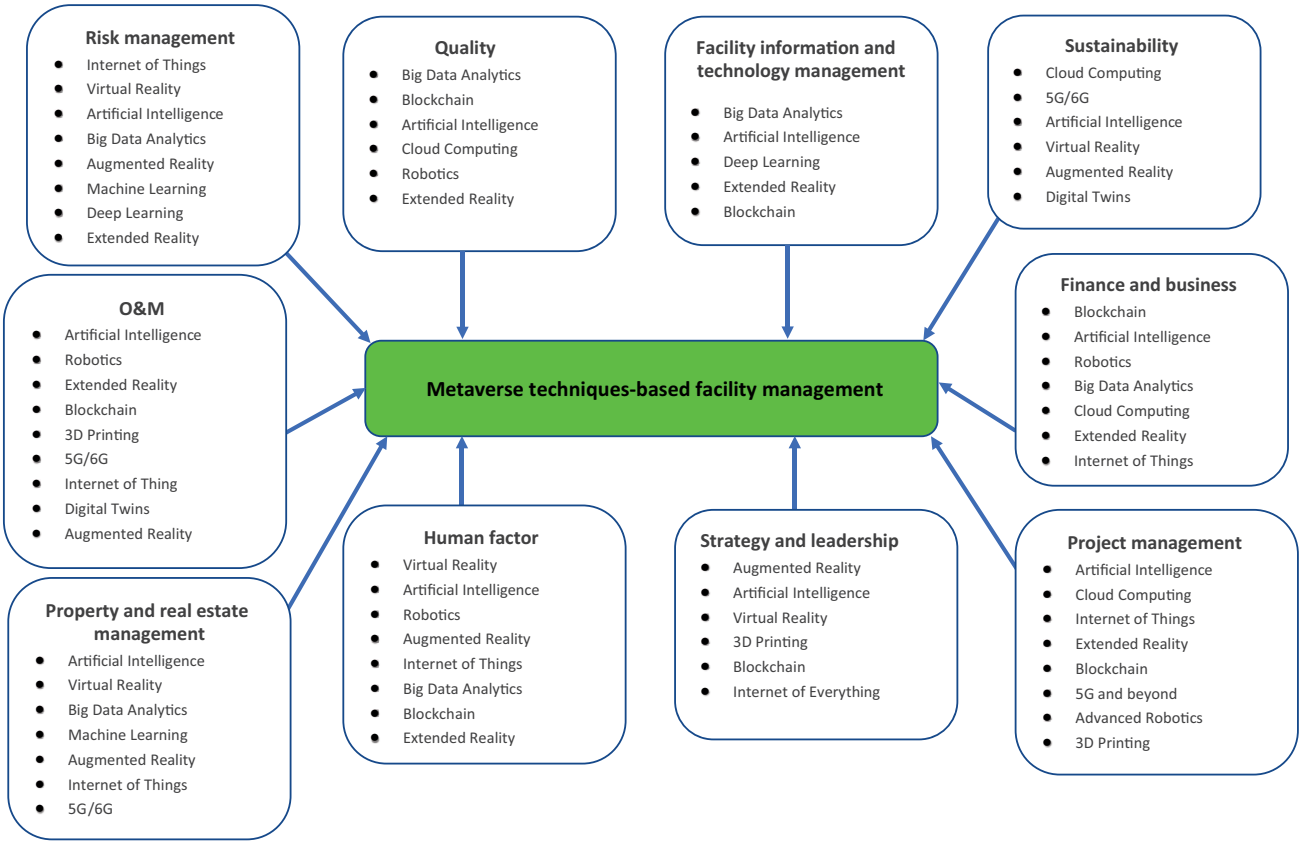

Figure 6. Metaverse techniques-based facility management framework

warranty and service (Hackl et al., 2022), records of maintenance, quality measurement, space making and energy monitoring (Kara et al., 2023), assessment and monitoring, retrofit planning, emergency procedures, accelerated project delivery time, reduced error, decreased execution expenses, and the provision of fee-based services (Mystakidis, 2022). Facility managers don't need to sift through a large body of data because they have access to essential data in an exclusive electronic file (Oleksy et al., 2023). For FM data management, object-based 3D visualization data is provided by metaverse. With the support of the metaverse, data identification and acquisition are quicker and more effective for object-based FM systems (Vidal-Tomás, 2023). Improvements in cooperation, smooth lifecycle integration, holistic strategic planning, the incorporation of requirements into contract documents, greater knowledge regarding FM specifications for construction and design, autonomous model updates, enhanced interoperability, simpler data retrieval, quicker response times in operations, and improvements in employee engagement are just a few of the advantages of integrating FM with metaverse techniques that are highlighted in previous studies.

FM-related scenarios can be better visualized and simulated thanks to the metaverse. The metaverse immersive environment offers a more accurate and user-friendly replication of the positioning and state of facilities elements. For instance, in an XR-based design process, Tromp et al. (2020) create a dual-way data transferring channel into an operation engine that enables several stakeholders to work simultaneously.

The fact that facility managers spend a great deal of time on useless tasks like displaying models, searching, and confirming various pieces of data is one of the biggest obstacles to implementing metaverse techniques in FM. This is largely because there isn't enough information assistance. Thus, the adoption of new procedures, integration of disruptive technologies, and an obvious emphasis on effective management throughout the building life cycle are all indicated by the worldwide technological trends for the field of FM. Due to the adoption of new technologies, notions, and methods, this industry is currently experiencing a digital expansion. However, businesses in the FM field have an insufficient degree of technological maturity.

With the appearance of smart properties, including integration of smart objects into the majority of locations, builders now have new opportunities to improve the quality of these structures for a lower price and in less time by facilitating information sharing among the various stakeholders (Abdelouahid et al., 2021). The holistic method of smart management, based on information and integrated functions, needs to be incorporated into traditional FM practice.

4.1. Directions for future research

This section offers future researchers a variety of avenues that could be pursued in light of the study's findings. Ten themes have been assigned to the future scope (FM core functions) as mentioned earlier in the proposed metaverse techniques-based FM framework. A thorough future research agenda, along with the challenges identified in each FM core function, is provided in Table 4 for the use of researchers working in FM, metaverse, and related topics.

Table 4. Thematic challenges and research questions for future studies

FM core function	Challenges identified	Open questions
Operations and maintenance (O&M)	– The majority of O&M work is based on the suggested optimization technique and simulations – Change-averse internal resistance – Budgetary restrictions	OQ1: How can metaverse techniques for FM optimization effectively assess a root cause analysis? OQ2: What is the role of an "AR" or "VR" of a process or product, and how might it enhance flexible O&M to achieve extremely accurate prediction using data from the real world? OQ3: How might effective interaction among various streams of O&M using metaverse techniques increase the efficiency of a highly accurate prediction culture?
Human factors	– Lack of a strategy for managing organizational change – Lack of knowledge – Constant modification of customer requirements	OQ4: What effects do the metaverse-human factor nexus and its key metrics have on an organization's overall efficiency? OQ5: What training and educational initiatives are available to help eliminate doubts about applying metaverse techniques to FM? OQ6: How can metaverse initiatives promote ergonomics and well-being?
Sustainability	– In concept-based research or simulation-based research, sustainability goals are primarily met – The fact that so few implementations are actually in use prevents any wide generalization from taking place at the moment – For the implementation of the metaverse to be successful and long-lasting, the overall FM needs to be revised	OQ7: What are the difficulties and opportunities presented by metaverse techniques in achieving sustainability, even with the agreement of various essential inclusions? OQ8: What functions do metaverse techniques have in terms of sustainability in relation to climate change issues? OQ9: What environmental safeguards can be taken into account when putting the metaverse into practice? OQ10: How might the emphasis on using metaverse techniques to achieve sustainability lead to a shift toward the global FM as a whole rather than the various discrete FM segments?

End of Table 4

FM core function	Challenges identified	Open questions
Risk management	– Organizations with a culture of risk aversion – Unavailability of infrastructure alterations – Lack of security, flexibility, and reliability in concept assurance	OQ11: How could risk management optimization process inefficiencies be predicted using metaverse techniques? OQ12: How can a process be effectively optimized through virtualization while avoiding risk management inefficiencies? OQ13: How can using metaverse techniques effectively reduce risk management uncertainty?
Finance and business	– Security issues – Entangled in the structure of the current financial system – The overabundance of monitoring and transformation operations throughout the metaverse is to blame for the disruption in the synchronization of physical and virtual flows	OQ14: What improvements in business, finance, and related contracts could be made using metaverse techniques? OQ15: With the focus on virtual reality parameters under the metaverse ecosystem, how should current financial operations be re-evaluated? OQ16: How could metaverse initiatives be more adaptable and cost-effective in their implementation?
Facility information and technology management	– Less comprehension of business models focused on metaverse techniques – Many stakeholders are unclear about the concepts of digital FM and virtual FM – Communication lag is completely random – Since all metaverse techniques rely on digitization and the computational environment, gathering data is essential to many of them – Recording and retrieving this data poses certain issues – Difficulties encountered when attempting to draw meaning and significance from the data collection	OQ17: What function do real-time metaverse data techniques play in facility information and technology management? OQ18: How can the various operational parameters and efficiency of FM be ranked in order to apply metaverse techniques to facility information and technology management? OQ19: What initiatives and actions are required to keep the physical and virtual flows in sync?
Project management	– Improper data management – Ineffective business procedures – A failure to acknowledge and reward the sharing of trustworthy data – Lack of a viable business model – Despite the fact that numerous novel metaverse techniques have already been adopted by businesses, their impact on project management is still not fully recognized	OQ20: Which existing business strategies could be utilized to quickly alter the accessibility of metaverse techniques in project management? OQ21: What effects do metaverse techniques have on project management? OQ22: How should project management measures be prioritized while utilizing metaverse techniques?
Quality	– Lack of resources, funding, and technological capacity to integrate the metaverse into the current quality system – Instead of considering total quality costs, endeavors are primarily made in consideration of the FM costs	OQ23: What role, beyond conventional quality systems, do metaverse techniques play in quality performance? OQ24: What functions do metaverse techniques play in predictive analytics to eliminate under- and over- quality by ensuring that decisions are of high quality? OQ25: How can metaverse techniques provide a setting devoid of competition for total quality management?
Real estate and property management	– Poor real estate and property management decision-making – Insufficient optimization model – Complexity of decision-making in property management and real estate supported by the metaverse	OQ26: What metaverse techniques are most effective for comprehending and enhancing the cross-functional relationships between real estate and property management? OQ27: How can the adaptability and application of metaverse techniques in real estate and property management be influenced by the perspectives of various stakeholders? OQ28: What other strategies should be incorporated into metaverse techniques to achieve quick and effective property management performance?
Strategy and leadership	– Lack of a viable business model to adopt and apply metaverse techniques – The viewpoints of stakeholders and policymakers are disregarded – Using the most recent technologies has resulted in a lack of reliability and leadership problems – Lack of benefits perceived and readiness for the organization – Lack of metaverse perception development among various stakeholders	OQ29: What part do metaverse techniques play in increasing stakeholders' and policymakers' ability and flexibility when it comes to strategy and leadership? OQ30: How can metaverse connectivity and agility be enhanced for the best possible strategy and decision-making? OQ31: How can EX effectively contribute to the growth of leadership and trust in the metaverse-enabled FM?

Conclusions

Many businesses continue to use time-consuming paper processes and outdated, divided databases despite the interrelated nature and complexity of FM. Consequently, during the Covid-19 pandemic, they were unable to recognize and react to unforeseen strategic and climate-related challenges. The immersive capabilities of the metaverse have a lot of potential uses in dealing with these kinds of complicated and dynamic situations. The goal of this research is to provide a summary of the current use of metaverse techniques in the field of FM based on a thorough literature review. A total of 206 articles have been identified and analyzed.

Blockchain was the primary metaverse technique addressed regarding FM articles. Researchers have investigated the use of blockchain for different FM-related goals, such as proactive management, daily property management, and asset management. The study has addressed the applications of metaverse techniques in the main FM core functions such as Human Factors, Strategy and Leadership, Property and Real Estate Management, Information and Technology Management, and Project Management.

The review of current literature reveals that the metaverse and FM integration research is still in its infancy. Even though some research efforts are quite in-depth and suggest solutions that have been tried in real-world situations, the majority of research studies remain in the conceptual phase. The primary barriers preventing the adoption of this new technology are (1) most often, the lack of a metaverse strategy that meets the information requirements and makes the most of the potential of a digital strategy; (2) the fragmentation of the FM field; (3) the lack of concrete examples of potential benefits.

The limitations of this study may open new avenues for future investigation. Firstly, this review only took research articles and review papers into account, which ultimately decreased the total number of papers under review. As a result, researchers may in future consider more diverse papers. Secondly, mapping all the dimensions of metaverse techniques in FM cannot be done with a single qualitative-based review. Thirdly, researchers can broaden their Scopus word search to include FM and metaverse techniques.

Finally, the authors suggest a number of possible research directions and stress the urgent need for metaverse-related policy development. The study is restricted to secondary data-based research that can act as a basis for FM scholars and academicians to comprehend the emerging trend of the metaverse and its use in various FM components, leading to FM and an overall organizational growth strategy.

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