Special Issue from: Visions for Future Cities: Innovations & Environmental Technologies Conference, (VFC2022), Cairo, Egypt, 24-25 September, 2022

Benefits and Challenges of Integrating IoT, VR & AR in the BIM-based Facility Management Process: Literature and Case-based Analysis

Ahmed Omar M.S. Mostafa[1] **& Ahmed Yasser M. M. Alaqeeli** [2]

[1]College of Arch. And Planning, King Saud University, KSA, ahmedoms@ksu.edu.sa
[2]College of Arch. And Planning, King Saud University, KSA, 439106435@student.ksu.edu.sa

Abstract: **With the emerging technologies of the fourth industrial revolution (4th IR), there are more possibilities to enhance the facility management (FM). Despite the increasing tendencies to integrate new technologies in the process of FM, its potentials in enhancing the BIM-based FM decision making process is not yet totally explored and its application is facing many challenges that should be considered. This paper aims to explore the benefits and challenges of integrating the Internet of Things (IoT), Virtual Reality (VR) and Augmented Reality (AR) in the Facility Management (FM) process to enhance the decision making; and to conclude a framework for integrating of such technologies in the BIM-based FM Process. The paper adopted a descriptive methodology through a comprehensive literature and case-based review to achieve its objectives. The conclusion shows that integrating the IoT, VR & AR in the FM process and handling its related challenges from the early stages could greatly enhance and support the FM team and the FM related parties in making quick, accurate and effective decisions, saving energy & cost and optimizing the use of resources.**

Keywords: **Fourth Industrial Revolution (4IR), Facility management (FM), Operation and Maintenance (O&M), Building information modeling (BIM), Internet of things (IoT), Virtual Reality (VR), Augmented reality (AR).**

I. INTRODUCTION

A. The BIM-based Facility Management Process

Despite the spread of using BIM in the design and construction stages, its use in the FM is still not yet well invested, explored, nor clearly identified. With the increase of complexity of building components and systems, the real benefit of using BIM during the facility O&M phase is then come to the surface. BIM is defined as the shared digital representation of the physical and functional characteristics of any compact object that represents a reliable basis for decision-making [1] and improving the facility submission process [2]. BIM contains building architecture, with a structured database of non-graphical data that provides information about building components [3], and simulates a digitally accurate building model that contains accurate information for building realization at various stages of the project - design, purchase, manufacture, construction, and even operation and maintenance activities [4].

Various strains of BIM have been developed so far as shown in figure 1: the simplest BIM is a three-dimensional 3D model, which includes all semantic, engineering, and topological information [5], and the 3D model can be converted to 4D BIM by integrating time information (construction schedule) into it. By combining cost data, 5D BIM can also provide real-time construction cost analysis [6]. While the term 6D is used for sustainability and 7D for facility management [7]. BIM can use the data to manage the building life cycle and the physical assets involved in it.

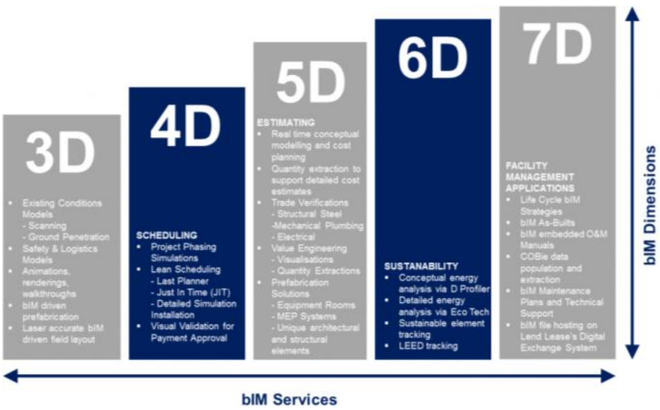

Figure 1. BIM Services and dimensions (Source: [8])

Technology allows the enterprise owner and manager to retrieve accurate information through the virtual facility model. This helps the FM co-individual, who may not normally be trained in graphics and project documentation [3].

BIM Life Cycle is the practice of creating, maintaining, and using building information to manage operations and maintenance of buildings throughout its operational life cycle [9]. The Objective of BIM is to build a dynamic facility model that can be applied throughout the entire project life cycle [10]. Facility Management (FM) is defined as a profession that includes multiple disciplines to ensure the functions of the built environment by integrating people, place, process and technology. The most important objective of facility management is to reduce operating costs, enhance energy efficiency, support sustainability, and improve facility quality [11]. As a result of capabilities, BIM is a powerful tool that can support the achievement of these Objectives and make the process more integrated and efficient [3].

The multidisciplinary nature of facility management requires comprehensive information that is easily accessible through BIM [12]. Therefore, by investing the energy analysis capability in BIM applications, different energy models could be compared to identify the most efficient mode that can be used to achieve energy savings for existing buildings and reduce operational costs. BIM-FM integration could also improve maintenance and reduce equipment failures availability of updated equipment information and maintenance data supporting predictive planning and maintenance.[13].

BIM and integration of BIM management with facility management tools or models can also provide faster and easier analysis to make informed decisions [14]. Finally, building information modeling is a revolutionary technology that has truly transformed the design and construction industry. As BIM-FM applications continue to develop, we can expect further discussions on process changes in this area [15].

- ***Problem Statement*:** There are many problems facing the building manager, including the waste of energy, with its related high cost and the lack of maximum use of resources to achieve the high efficiency of the building, which leads to difficult decision-making. During site maintenance, the facility manager sometimes needs to verbally describe the condition of the site to another manager in the office or to visit the site where the facility's information is stored. The distance from the information storage location impedes the retrieval of information. It is also difficult to find the required information within an extensive database containing a set of specializations, as this takes a long time. In addition, it is difficult to match relevant information with reality, as information is usually represented in a two-dimensional space. So in conclusion, *Despite the spread of applying modern technologies in the design and construction, its use in the BIM-based FM is still not yet well invested and there are many Challenges facing the FM manager, that could be facilitated and overcome by taking advantage of such technologies.*

- ***Objectives*:** *The main objective of the research paper: To explore the capabilities, benefits and challenges of integrating three of the 4th industrial revolution technologies with the BIM-based FM process, namely the Internet of Things (IoT), Virtual Reality (VR) and Augmented Reality (AR); and conclude a framework for integrating such technologies in the BIM-based FM Process to enhance the decision-making and well invest its capabilities.*

- ***Methodology*:** This paper will adopt a *descriptive methodology* to achieve its objectives depending on the authors' experience and a literature-based analysis to explore the capabilities and benefits of using selected modern technologies (VR, AR & IoT) in the BIM-based Facility Management (FM) and its related challenges supported by case-studies to reach the target conclusions and recommendations. The selection of references done in phases started with identifying research resources and engines .Initially the search was conducted in the Saudi Digital Library (SDL) using the following search terms: (Facilities Management FM), Building Information Modeling BIM) provided that they are in the Abstract, and the scope of the research was limited to the last ten years. The total results were 158 results. Then we Abstract quickly reading to choose Some studies to analyze it. In the next step, the trends and challenges mentioned by the researchers in these studies were identified, We also used some of the sources that were repeated in these studies. In the third step, we surveyed recent trends related to the fields of the Fourth Industrial Revolution To focus research terms. Finally, We searched at (Google Scholar) using the following search terms provided that of them were in the title: (Facility Management and Internet of Things) We got 7 results. (Facility Management and Virtual Reality) we got 6 results. (Facility Management and Augmented Reality) got 30 results. We analyzed studies to explore these trends, challenges and case studies.

II. TRENDS OF 4TH IR TECHNOLOGIES TO ENHANCE BIM-BASED FM

The use of new technologies in facilities management contributes in performance enhancement through optimizing resource use, reducing energy and maintenance costs, and visualizing information for the maintenance team. In the context of this paper, and the review of the compiled literature, it was concluded that the Internet of Things (IoT), the Virtual Reality (VR), and Augmented Reality (AR) are three of the major trends that positively affect the performance and process of Facility Management (FM). The following part is a literature and case-based analysis of the three trends.

A. The Internet of Things (IOT) in FM

As the use of the IOT is linked to the initial investments of the facility, the question of benefits arises when discussing this issue. Computers must learn from new technology and interact with their real environment. A digital twin can be achieved by combining the Internet of Things and BIM. For example, an analysis of climatic conditions (temperature, humidity, carbon dioxide, etc.) that are measured in the context of building engineering. This opens new possibilities, which are also referred to as spatial analyzes. In Figure 2. , the measured IoT data is allocated in a building to the BIM model [16]. The selection control can be used to distinguish regions that correspond to the regions of specific parameters. Mostly related to financial aspects the energy consumption control, energy and maintenance costs saving are of high priority for the FM offices.

B. The role of the IOT in Energy control and saving

Energy can be used more efficiently in a variety of scenarios [17]. The alerts / messages received, (from data from IoT devices) about the absence of people in Spaces (i.e. building space information) is a direct result of the combination of information about the building area with live data captured from the IoT, devices, cameras, and sensors. This way, the FM office will receive warnings to turn off the heating / cooling system automatically, if people are not in the Spaces [17] , Figure 3. shows a thermal map based on WLAN data and occupancy data from table sensors [16]. Sensors allow lighting for meeting, ventilation, and heating rooms, depending on occupancy. Instead of regularly cleaning sanitary rooms, water consumption and space use can consume the need for cleaning [18].

Figure 2. Spatial analysis of room parameters in the BIM model. (Source:[16])

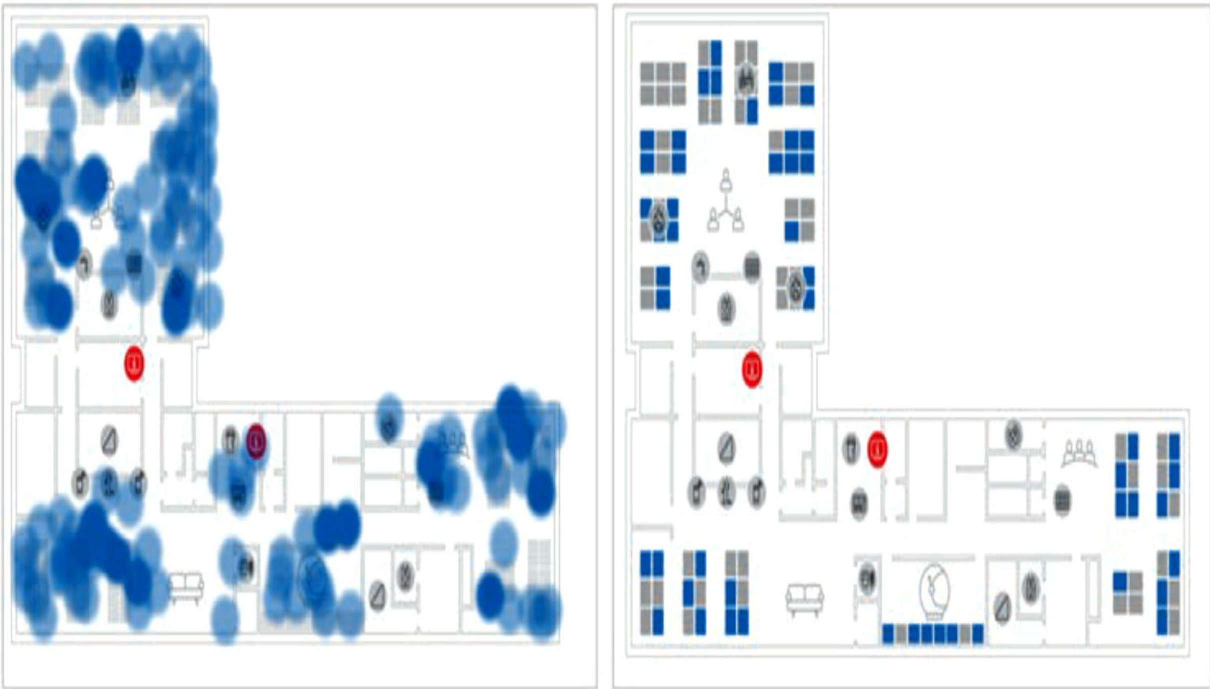

Figure 3. Heat map based on WLAN data (left) and occupancy data from table sensors (right) (Source: [16]).

External parameters such as wind and weather can also be included in the FM planning [16]. A prerequisite for this is a well-considered planning of the use of sensors and actuators [19]. Only by obtaining continuous energy data and the possibility of timely evaluation of savings through the use of smart controls and energy-saving consumers, it will be possible to achieve cost savings throughout the entire life cycle of buildings - from planning, for example with information building models (modeling Building Information) [20]. In addition to direct savings, user interfaces that display results in real-time sensor measurement allow better control over energy consumption [21].

Continuous data monitoring and rapid response help save energy or maintenance costs through the optimal use of resources. Studies estimate savings at 20-30%[22] . The FM Office can provide an estimate of the costs of defective devices for different buildings. Another example of energy management may relate to “open windows and operating radiators”. A message from the facility's management team can inform space users that the heating system is turned off. By doing this, the FM office can enhance energy saving behavior as well [17]. Before implementing an internet based on things-based solution, investment costs should always be fully included in the consumption calculation. This is the only way to assess the overall increase in efficiency [23].

C. The role of IOT in saving maintenance costs:

In the case of maintenance, the absolute costs of maintenance can be reduced, additional costs can be avoided due to reduced efficiency, and staff costs can be reduced.[24] But the increasingly pressing issue of sustainability is also an engine for the IOT. This may be the reason for the public initiatives that are supposed to contribute to the economy by lobbying to use resources more efficiently.

Building automation is really an indispensable part of smart buildings today. Heating and ventilation systems are automatically controlled, elevators and escalators are controlled depending on use, and alarm systems and energy consumers are constantly monitored. Technologies range from simple barcodes via RFIDs to beacon devices that provide timely information.[25] However, the IOT goes even further: if a system presents its state data online, maintenance can also be planned after that [26] . The data that are monitored in the first step must be intelligently evaluated and used. Both the deployment planning of the IOT for FM and reasonable and efficient use of data are prerequisites for successful use [27] . The IOT does not do this alone; it only provides possibilities . [28]

It is necessary to keep in mind that the cost of implementing IoT applications is also included in the actual savings account. With IOT, the smart operating system will have the ability to notify operators of potential problems and automatically submit requests to manufacturers of their components that need to be replaced. The facility's digital dashboard interface will make it easier for its occupants to monitor facility performance, almost locate an asset in a 3D model, and easily access relevant FM information. Future facilities will be more interactive and responsive to the needs of users and their external environment [15]. Figure 4 shows the concept of digital twins with the IoT enabled system to support achieving the discussed benefits.

A Case-Study: IoT to Support Decision in FM:

This study represent the use of a platform to visualize the Internet of Things for an actual case of a research laboratory located in the second engineering building on the campus of Qiao Tong National University, Hsinchu, Taiwan [29], This included creating a platform that can integrate sensor information with BIM and experiment how visualization can help in decision making and energy savings.

Three goals were set for achieving the target integration: (1) Automated integration: It automatically collects data from physical sensors installed in the experiment room (research laboratory) and stores the data in the same room of the BIM model.

(2)Automated Visualization: Automatically calculates the index value based on the collected sensor data and calculates the value mathematically using a color palette chart.

(3) Multiple contexts: Allows the user to switch between different contexts that require different subsets of sensors (e.g. comfort, energy saving).

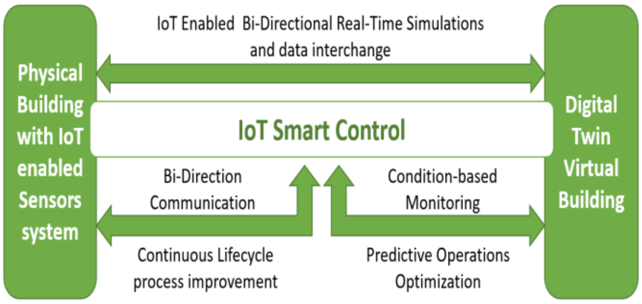

Figure 4. The digital twin concept with the use of IoT to enhance the FM process (by authors)

Figure 5. & 6 show the proposed platform design and the spatial layout of the laboratory and the location of the sensors catching the temperature and humidity information and an accurate controller, to demonstrate how the facility manager can adjust space planning based on values “Predictive Mean Vote” (PMV). Figure 7 & Figure 8 show a sample of temperature and humidity data for each two-minute interval over a two-hour period. Figure 9 shows snapshots of the visual comfort level and suggestions for improvement under various conditions (window is open /close and A/C is on/off).The results show that when the air conditioning was turned on, the temperature and humidity seemed to drop, but according to the PMV value, the room remained comfortable in all three cases. In some large areas with limited number of air conditioning systems, the visual comfort level can have an uneven distribution. This may lead to change in space layout where activity use spaces are allocated in comfortable areas and storage spaces are allocated in least comfortable areas.

The platform suggested by researchers displays integrated values in a three-dimensional color manner as a layer in a three-dimensional space.

This provides the facility manager with a better way to visualize and identify potential facility management problems. This visualization allows the establishment manager to see the distribution of values from the perspective of the desired context, thus supporting decision-making to make the appropriate adjustments.

D. The Virtual Reality (VR) in FM

As per [30], VR is a virtual environment generated as a 3d digital model accessed through multiple hardware platforms to offer an immersive environment. When using BIM for the digital model, that is widely used in the AEC industry to train O&M personnel on different maintenance and repair activities and test their understanding and knowledge of various O&M procedures [15], it could add additional data that support the use of this technology in FM, benefit from its advantage that lies in the integrated FM, where a complete database can be managed in one VR scene [31], help people intuitively understand the environment in a fully immersive way [32]; and to make more accurate decisions.

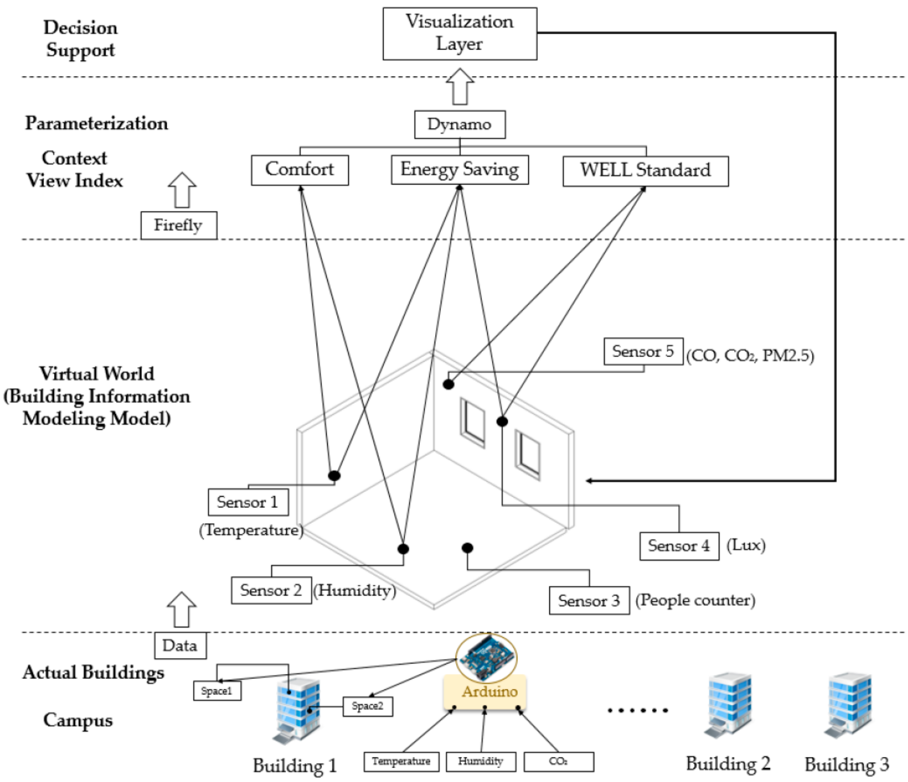

Figure 5. The proposed platform design for a platform that can integrate sensor information with BIM (Source: [29]).

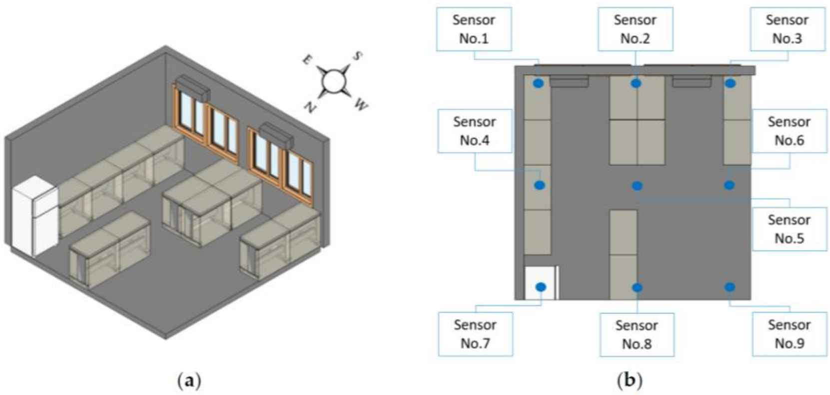

Figure 6. (A) Spatial planning of the research laboratory; (b) Sensing sites. (Source: [29]).

When using virtual reality with traditional graphics, it can provide richer inputs to improve design quality [33]. In addition to all previous benefits, with the use of VR, a real-time site condition could be shared by the FM and cooperative maintenance work can be achieved [34].

A Case-Study: Improved design quality for facility management using virtual reality

This study [33] explored construction professionals' perceptions of using virtual reality to provide design inputs to improve design quality in Point Gray campus at the University of British Columbia in Vancouver, Canada. A total of sixteen industry professionals participants who had little or no experience in using virtual reality, shared in this study to put their input regarding the serviceability of two sample equipment in a mechanical room.

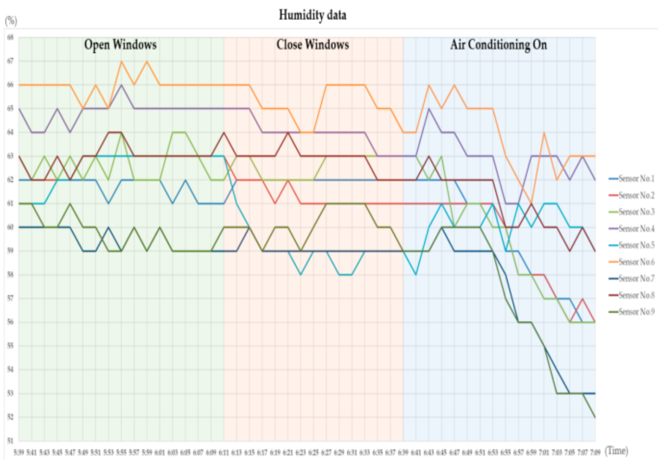

Figure 7. Humidity data for sensors 1-9 (Source: [29]).

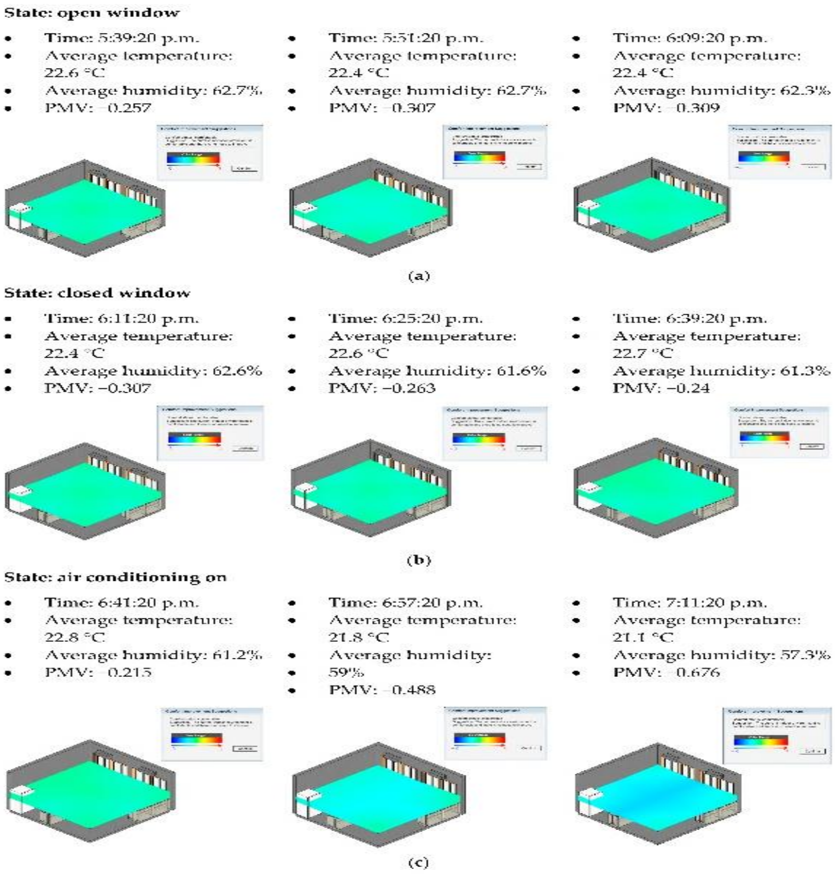

Figure 8. (A) Results of the PMV visualization of the open window condition; (b) the closed window condition; (c) Air conditioning is on. (Source: [29]).

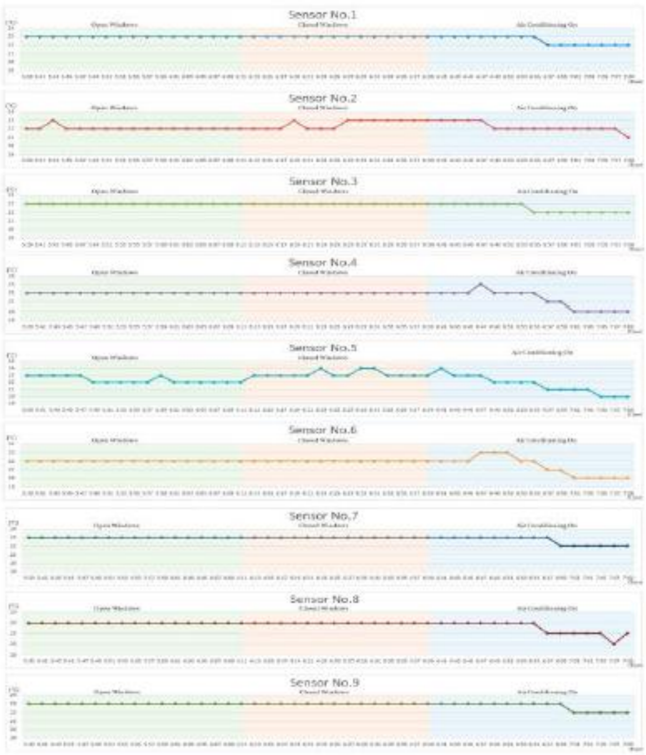

Figure 9. Temperature data for sensors 1-9 (Source: [29])

The equipment encountered maintenance challenges related to access at its original location, and, to set a precedent for working conditions, participants were asked to specify the minimum distance that the equipment should be moved to make it more serviceable, knowing that the sample equipment required maintenance every two weeks and 20-30 minutes of work duration. As shown in **Error! Reference source not found.**Figure 10.

There were two scenarios:

- In the first scenario an expansion tank was set up placed on the ground 6 inches from the wall, and the expansion tank component requiring maintenance was placed 9 inches from the wall.
- In the second scenario, a piece of equipment requiring maintenance was placed 8 feet from the ground. Participants were asked to downgrade equipment to improve its viability under restrictions that work conditions do not allow the use of a ladder or chair to improve accessibility.

The preparation and presentation of the participants' presentation are shown in Figure 11. A virtual environment was created for the BIM model to be viewed in virtual reality with the possibility that participants could apply a change and view it in real time. In the same time researchers have the ability to see the virtual environment that were being changed by the participants.

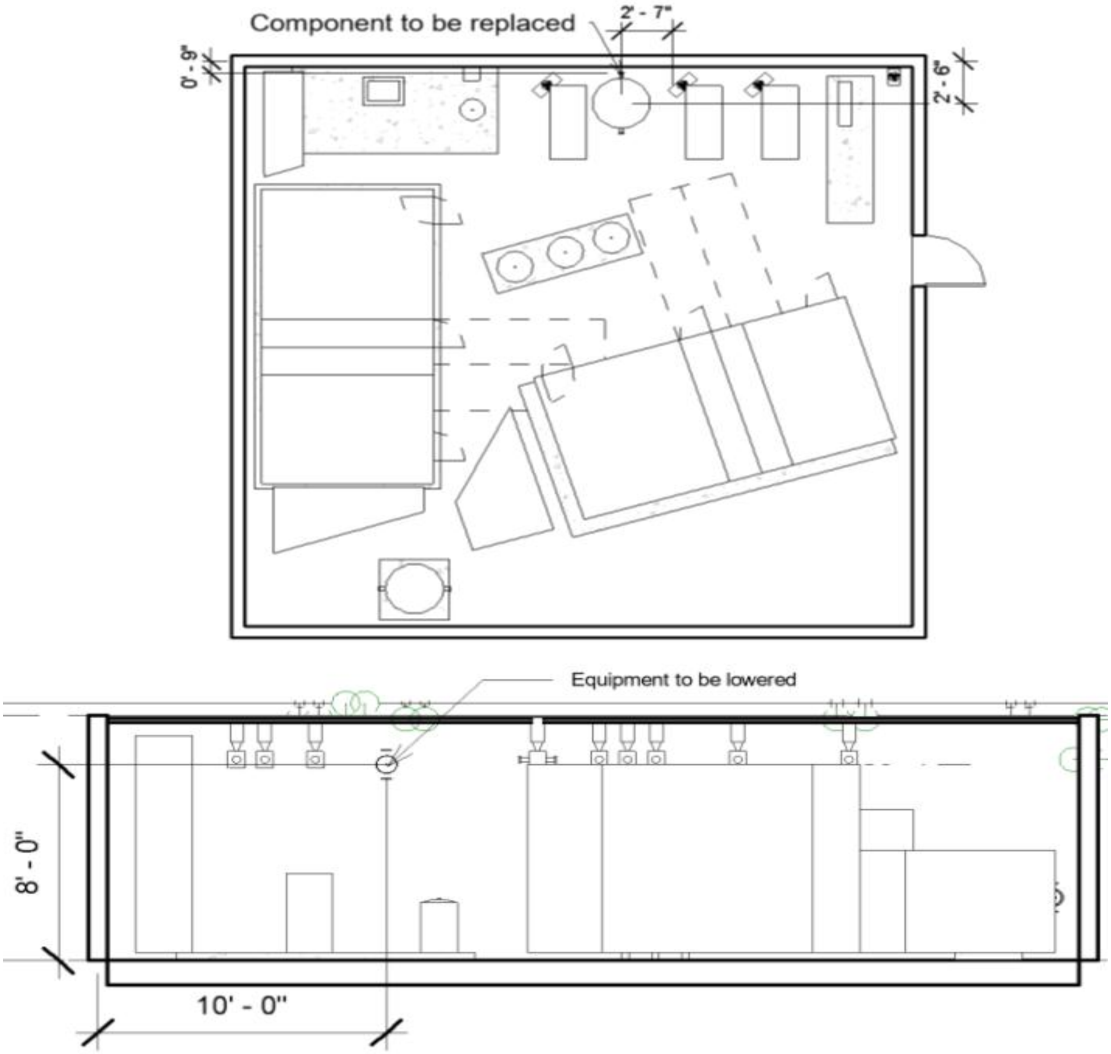

Figure 10. Conventional drawings presented to participants for the first and second scenarios, respectively. (Source: [33])

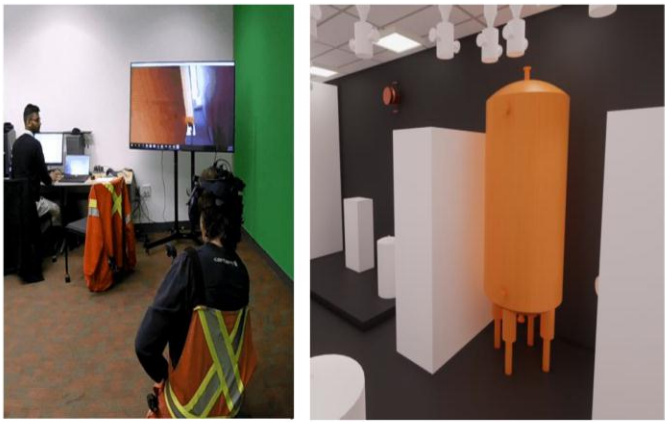

Figure 11. Preparing for VR entries and view a sample view of the participants (Source: [33])

Based on the two scenarios, participants were divided into two groups and each group is also divided into two subgroups: one of which used traditional graphics, and the second used virtual reality. A moderator executed and recorded the changes required by participants.

The result, as shown in Figure 12 & Figure 13 were as follows:

- When using VR to provide input, participants can physically wander around equipment to see available space. Participants used their controllers to check if they had access to the component to be replaced, and then provided inputs for transporting the equipment.

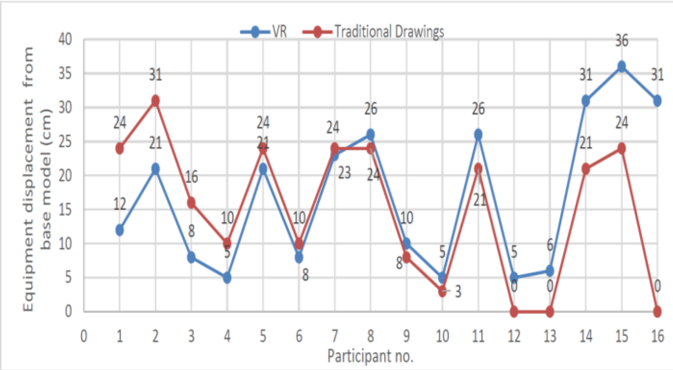

Figure 12. Displacement suggested by participants in the first scenario (UP)

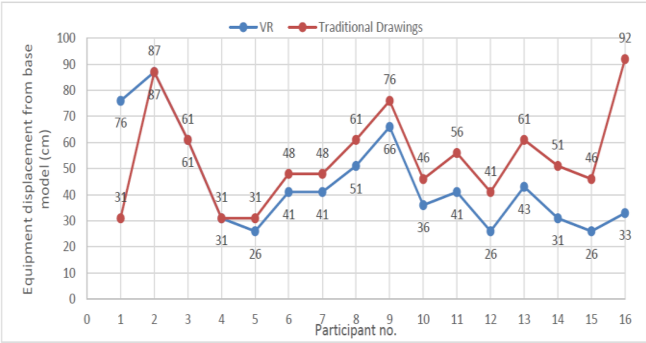

Figure 13. Displacement suggested by participants in the second scenario (down) (Source: [33])

- In the case of traditional drawings, they had to rely on their mental perception of space and their past decision-making experience, but in the same time using can provide more insightful inputs to improve design quality.
- Participants' feedback about the experiment that using virtual reality prove to be easier to provide the suitable design inputs.
- The spatial understanding provided by VR helped the participants to make more accurate decisions.
- The overall results indicate that virtual reality is a viable option to provide design inputs from the end-user perspective.

E. The Augmented Reality (AR) in FM

As per [35], AR is a technology that creates an enhanced environment by synthesizing computer-generated information on a real-life view to users. The use of this technology could be substantial in the field for construction and maintenance when integrated with location-based technologies (such as RFID, GPS and sensors). This technology is also give advantage to carry out maintenance work, follow-up work related to both the inspector and facility manager at one time and to minimize interventions based on individual subjective judgments through real-time site circumstance sharing and collaboration functions [34], thus improving accuracy and reliability of maintenance work results and effectively facilitate communication between the people working on the site [36].

"BIM can be used in conjunction with AR to improve field work efficiency by providing superposed engineering representation over physical space along with related facility-based information, and to provide different types of analysis, Such as equipment fault detection and diagnosis [37].

When integrating BIM with augmented reality, there are five advantages to FM: intelligent error diagnosis, visual operating instructions, state perception, building performance monitoring, and portable path instructions. Figure 14 illustrates the application areas and benefits of BIM + AR in FM [38].

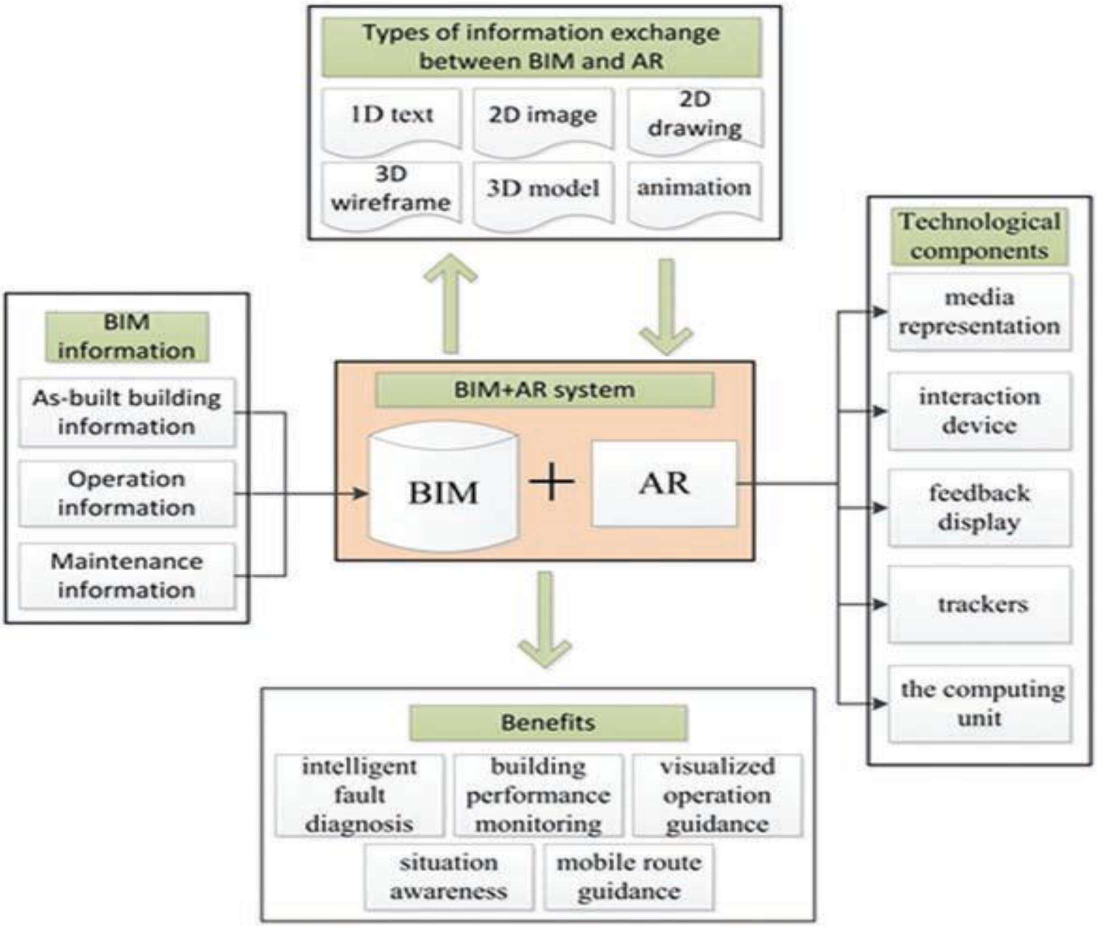

Figure 14. Application areas and benefits of BIM+AR in FM. (Source: [38]

A Case Study: Integration of AR in health FM

In this case study [38], the application of AR in facility management was studied to the MRI room in the health care project located in Perth. The model of the room was prepared using BIM Application, then they set the locations of virtual reality visualization equipment on different patches of the room, the hidden tubes model was installed in the shape, the air conditioning units were represented, and the MRI equipment was located in the model, as shown in Figure 15.

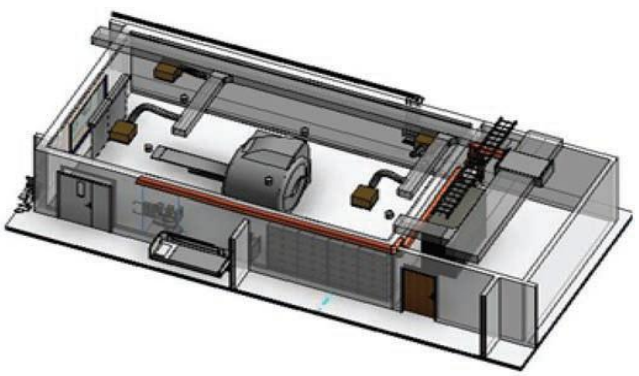

Figure 15. BIM model of an MRI room using Revit software

A number of scenarios were put in place to implement the integrated approach to BIM and AR which includes locating the hidden components, and enabling Perform step-by-step maintenance, arrange equipment planning, and mobile instructions to guide maintenance.

- In the first scenario AR helped the FM to efficiently determine the location of pipes hidden behind the wall as shown in Figure 16).
- In the second scenario, AR helped the FM to show relevant maintenance procedures clearly and intelligently and to give him clear instructions that follow the mobile procedure to guide the process (as shown in Figure 17) Leading to improving the performance of maintenance teams especially inexperienced beginners and develop problem-solving skills.
- In the third scenario, AR helped the FM to arrange the equipment in each room in BIM application, visualize it in real context and immersive environment, and thus to take the right decision to put in place (as shown in Figure 18).

The main conclusions of this case study:

- AR and BIM enables the FM to handle the flow of huge information more effectively and efficiently.
- AR enables FM to navigate the space leading to particularly facilitate the on-site review process.
- There are issues that need more research related to:
  - Implementing a BIM context in real space across AR,

- Visualizing maintenance instructions in step-by-step animation, and
- Creating a path inside a building using a visual system supported by AR and BIM models.

Figure 16. Virtual piping system behind the wall.

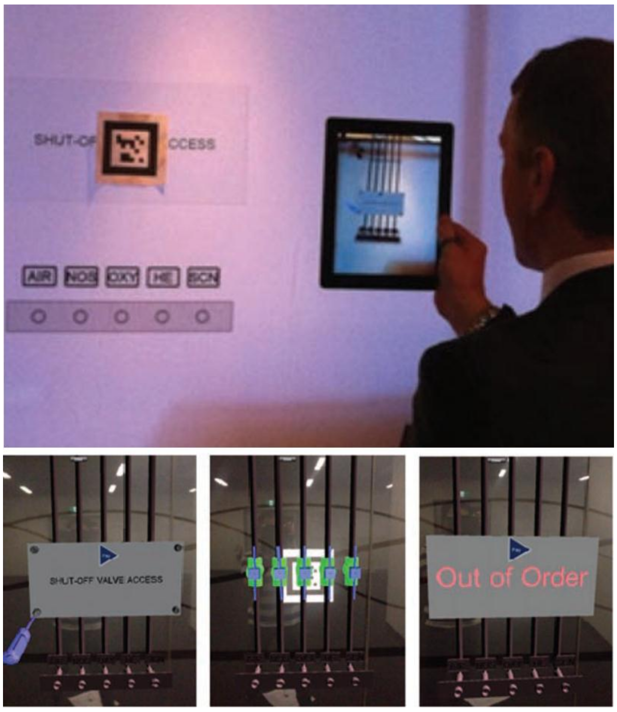

Figure 17. An indicative process for example scenario in augmented reality system.

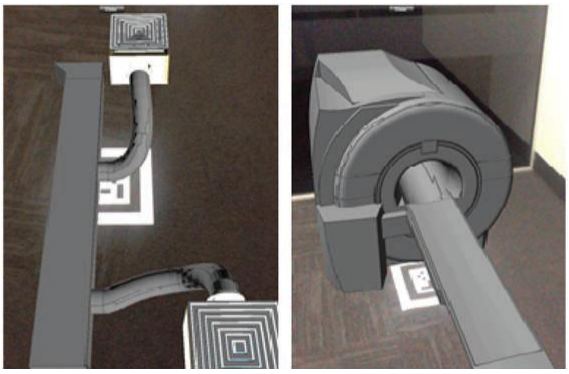

Figure 18. Visualization of virtual equipment in AR. Source of Figures (15, 16, 17 &18: [38])

III. Challenges Facing Integrating IoT, VR & AR with The BIM- Based FM

Using BIM to support FM is becoming more common, but it poses some challenges , By exploring the literary studies on this topic we concluded four categories of challenges facing the application of the discussed technologies in the BIM-based FM: Cost-related challenges, Technical-related challenges, User-related challenges, and Data-related challenges. The next section discusses these categories.

A. Cost-related Challenges

In general, the application of these techniques in the facility management process is always linked to high budgets due to the direct and indirect cost. The direct cost associated with establishing the required infrastructure including networks, hardware and software while the indirect costs is related to many other issues and follow the concept of "ice-berg" as it is not directly realized by many of FM team and decision makers. Maintenance and training Programs are just examples that have a significant role in the efficiency of use and overcoming most of the input and output challenges.

Implementation and training costs are an important challenge in using BIM to support FM. Enough time and human resources should be devoted to training construction professionals in the use of BIM [39]. therefore, the use of BIM is usually associated with additional administrative and training costs [40]. depending on their needs BIM certification in the FM process requires a change to the process and the criteria that will increase the cost [12]. Also, the lack of approval of BIM to provide FM cost is another barrier to adoption [41]. Since building designers do not directly benefit from BIM's use of FM, they fail to motivate the owner to invest in BIM [42]. Due to the owner's failure to invest in BIM, the data is not managed properly [58].

When no BIM workflow structure, building owners pay twice, the first time, to the construction contractor to obtain a set of complete documents and once for utility maintenance contractors to capture the updated conditions by construction [43]. As a result, FM personnel spend a long time verifying, identifying, and isolating useful data from the rest. Costs associated with information management annually, approximately $ 10 billion is lost due to data access and interoperability problems [54]. Although these new costs may be more than offset by efficiency and size gains, they are still a cost borne by a member of the project team. Therefore, before fully using BIM, the risks of its use and allocation should not only be identified, but also the cost of its implementation [44].

From a general perspective of the subject, achieving a balance between the budget for the use of Internet of Things, virtual reality and augmented reality technologies, and the training included in professional practice, and the benefits that can be obtained from this use, undoubtedly requires a study and analysis of the added value resulting from this use against the direct and indirect costs. The application and its solutions to the problems and challenges that are expected to occur [66].

B. Technical-related Challenges

Technologies, in general, is facing many technical limitations that represent a major challenge for both developers and users. The required sense of realism [64], and other studies pointed to the challenges resulting from the incompatibility between virtual and real models, from simulating the building models to solve related engineering challenges, or from the requirements of compatibility with the different systems and devices used for virtual reality [65]. Some virtual reality applications are compatible with specific devices or specific operating systems, and this makes it a special challenge due to the multiplicity of types of devices that are needed in such systems. For example, users may own Portable devices, but not all of them are compatible with the application used for IoT, VR, or AR. This requires the provision of special software or changing the application to achieve the required compatibility [66].

The easy Interface is also one of the technical challenges that could be taken care by developer to encourage all levels of users and support them when using such applications.

C. User-related Challenges

- ***Lack of knowledge of BIM implementation guidance***

The lack of the knowledge background and required skills of using new technologies is one of the most important challenges that may cause delays in the application of such technologies. Studies show that there are three regulatory factors influencing BIM-based team coordination: number Participants, heterogeneity, and the highest decision maker involved [45]. Despite the important role of asset owners in BIM accreditation for FM, many of them still lack the technical competency and knowledge required to fully operate, manage and fully manage BIM operations during the operational and maintenance phases to use, and most of them do not have a thorough knowledge of BIM related implementation guidelines in facility management practice [46].&[47].This is due to unclear roles, unlimited responsibilities, non-standard BIM workflow structure, and frequency In sharing information with other teams, the lack of guidance for controlling or verifying BIM data leads to building overworked individuals [48].

The lack of spatial understanding and proper communication of problems with proposed solutions among project stakeholders on design issues is a major impediment to assessing buildability [49]. For example, the current BIM workflow structure does not include FM employees until the operation and maintenance stage, this workflow structure suddenly exposes FM members to large amounts of data that overwhelm them. The owner's FM team typically does not have the software and expertise to extract asset information when supplied with the existing BIM form, resulting in them not filling out manned data [57]. Efficiently handling BIM in 3D environments therefore seems to be a difficult endeavor for management practitioners (FM). They often lack the resources or expertise to benefit from FM models in the operational phase [50].

D. Data-related Challenges

- ***Inefficiency of the BIM model information and data:***

All over the stages of the life cycle of the facility (start-up, planning, design, construction, closure, operation and maintenance), the volume of the facility information gradually increases in an accumulative manner. When comes to construction information manufacturing data, specifications, operational instructions, procedures, and warranty information types are included [51].& [52]. Unfortunately, Most of BIM models are inaccurate, incomplete, or have unnecessary information [53]. This challenge put the FM in the corner as the core of its process and work is the facility information.

When the project is delivered, one of the difficult responsibilities of owners is to assess the quality of BIM model information to be delivered to the FM company. In some cases the owner outsource this responsibility to external service providers [54]. These inefficiency of information leads to delaying data processing, information loss, data fragmentation, and segmentation during the building's life cycle [55] and /or Decreasing the ability of the facility management team and owners to manage information [56].
If there is no specific procedure determined by the design and construction team at the beginning of the project, it is difficult to control the quality of the final delivery that is delivered to the owner [57]. As a result, BIM models are not managed or maintained throughout the building life cycle [58].

- ***Inefficiency of information and data:***

- Large volume of information and data.
- Inaccuracy or incomplete BIM documents contain unnecessary information.
- Low quality of information and incomplete information about mechanical, electrical and plumbing systems (MEP).
- The limited ability of the facility management team and owners to manage information.
- Possibility of losing control of the quality of information delivery to the owner if the required information has not been identified in the operational phase.
- Failure to manage or maintain BIM models throughout the building life cycle.

- ***The dilemma of dealing with the (Big Data):***

- Large volume of information and data lead to challenges related to data handling, processing and integration.
- The nature of the raw data increases the challenge of converting it to valuable information for operators and users.

- The diverse and unstructured data come from different devices connected to the central system make the situation more difficult.

- ***The constant need for updating data***
- Having accurate and up-to-date information of the facility as constructed is essential for FM [59]. This put a financial burden on the FM companies to keep the facility data up to date. In some cases, FM companies invest a large amount of money and time to build the facility model for further use. Even though, if such models are not continuously updated to its current state, it becomes useless. This challenge increases with the fact that The manual data entry into the BIM model is a time-consuming process [60], and may cause inaccuracies in updating BIM information which causes, with the limited ability of mobile devices to update necessary information, delays and errors in Performing major FM tasks [61]. Consequently, The cost of the model is related to "creating" as well as "updating" [13].

In addition, updating data human-related behavior plays an important role to create, update and get the correct information in the model [13]. FM employees lack the motivation to provide ongoing feedback to the owner using an updated BIM [55], Whether the information is in a folder or on a form that someone must update when changes occur.

- ***Different naming conventions***

The BIM model information is accumulated by both the design and construction teams related to different participants. At present, there are no specific guidelines, naming, numbering style, linguistic meanings, grammar and scheme to use while collecting this information [52]. Multiple sources of information in different formats cost the owner's staff a long time to determine the information they are looking for. Without general guidelines, each team use different terms, naming conventions and specialized applications that may lead to the problem of the "interoperability" [57]. This challenge, in turn, leads to semantic interoperability, blind data heterogeneity and delay in handling the data or considering it useless [62].

IV. A Summary of BIM-based FM enhancement when integrated with IOT, VR and AR

Through the previous literature and case-based analysis, the following is a summary of the Enhancement of BIM-based FM when integrated with IOT, VR and AR:

A. *Enhancement of BIM-based FM when integrated with IOT:*

- ***Optimize the use of resources to achieve Energy and cost saving throughout the entire building life cycle:***
- Optimize the internal spaces environmental conditions: Analyze climatic and weather conditions such as wind, temperature, humidity, and carbon dioxide; and use it to optimize space environment as per user preferences.
- Rationalizing the consumption of water such as the water intended for cleaning the toilets according to use.
- Automatic control of space lighting, ventilation and heating according to occupancy.
- Good power control via a user interface that displays sensor results in real time.
- Promote user behavior in saving energy, through direct communication with space users and requesting the shutdown of a system when it is not needed by relying on the sensors.
- ***Enhance Maintenance provisions and save costs:***
- Continuous monitoring of building objects, systems and spaces and inform the maintenance team of any possible problems for a rapid response, or to automatically send requests to manufacturers of components that must be replaced
- Optimize maintenance staff related cost and avoid the extra costs due to the lower efficiency.
- Easily accessing equipment information and monitor the performance of the facility through the digital dashboard interface.

B. *Enhancement of BIM-based FM when integrated with VR:*

- <u>Facility Database Management:</u> Full database management in a virtual reality scene with an easy access through multiple device platforms.
- <u>Visualizing for understanding and decision making:</u> VR offers a visualization method to help people understand the environment intuitively in a completely immersive way and make more accurate decisions and provide insightful inputs to improve design quality.
- <u>Cooperative Maintenance:</u> accessing the virtual environment from any location support achieving cooperative maintenance work between the facility manager and the facility management company.
- <u>Training of FM team members:</u> Create serious games to train operation and maintenance personnel and test their understanding of various procedures.

C. *Enhancement of BIM-based FM when integrated with AR*

- <u>Improving the efficiency of fieldwork:</u> by providing superposed engineering representation over the physical space along with relevant information.
- Review the facility manager's inspection work plan, so inspector registry information and verification work can be performed at one time.
- <u>More accurate decisions:</u> and reduce interventions based on individual personal judgment
- .Intelligent error diagnosis and dealing with the flow of huge information more effectively and efficiently.
- <u>Visual operating instructions:</u> visualizes maintenance instructions in the animation step-by-step.
- <u>Portable path instructions:</u> via the "Navigation" function, which can particularly facilitate on-site review process.

D. *Challenges*

- ***Cost-related challenges***
- Using new technologies in facility management process is always linked to high budget due to direct and indirect cost.

- The costs of training the facilities management team in using BIM.
- Team recruitment criteria differ to require a BIM certificate in the FM process which will increase the cost.
- Owner's lack of approval for BIM accreditation in FM results in no budget being provided.
- Building owners pay twice because there is no BIM workflow structure at the beginning of the project.
- It is important to achieve the balance between the budget related to the use of IoT, VR & AR technologies, and the benefits that can be obtained from this use.

- ***Technical-related challenges***
- The main challenges in this category is related to the preparation of the required networks, hardware and software for applying the new technologies.
- It is important to achieve the compatibility and interoperability of the used systems, hardware, and software.
- The easy Interface is also one of the technical challenges that could be taken care by developer to encourage all levels of users and support them when using such applications.

- ***User-related challenges:***
- Some FM employees lack the competence and technical knowledge necessary to fully operate, manage and exploit BIM operations during the operation and maintenance stages.
- Lack of comprehensive knowledge of BIM implementation guidance and available standards and processes in facility management practice.
- unclear roles, unlimited responsibilities, lack of spatial understanding and appropriate communication of issues with proposed solutions among project participants.
- The owner's FM team usually does not have the software and expertise to extract facility information when it is delivered using the BIM form.

- ***Data-related challenges***

– ***Inefficiency of information and data:***
  - Large volume of information and data such as manufacturing data, specifications, instructions, operational procedures and warranty information.
  - Inaccuracy or incomplete BIM documents contain unnecessary information.
  - The need to assess the quality of information and ensure the completion of mechanical, electrical and plumbing systems (MEP).
  - The limited ability of the facility management team and owners to manage information.
  - Difficulty in controlling the quality of information delivery to the owner if the required information has not been identified in the operational phase.
  - Failure to manage or maintain BIM models throughout the building life cycle.

– ***The dilemma of dealing with the (Big Data):***
  - Large volume of information and data lead to challenges related to data handling, processing and integration.
  - The nature of the raw data increases the challenge of converting it to valuable information for operators and users.
  - The diverse and unstructured data come from different devices connected to the central system make the situation more difficult.

– ***Difficulty in updating data continuously:***
  - Relying on manual entry to update data takes a long time.
  - Inaccuracy of updating data resulting from duplication or alteration of data.
  - The limited ability of mobile devices to update necessary information in BIM forms.
  - FM employees lack the motivation to provide ongoing owner feedback with updated BIM.

– ***Various naming conventions:***
  - Insufficient data integrity due to differences in syntax, graph, or indications.
  - Lack of specific guidelines, naming, numbering style, linguistic meanings and rules for using information.
  - When searching for information, multiple sources of information in different formats cost a long time to locate information.
  - The Facilities Management Team creates a set of their information.

V. Discussion

Studies have shown that with BIM data that can replace existing two-dimensional drawings, the IoT, VR & AR can increase the efficiency of the Facility Management. In addition, since BIM datasets created in the construction phase are utilized, it has the advantage of requiring little resource input for technical application. It is important to make an optimization decision during the operation and maintenance phase to control the accuracy, appropriateness and quality of the information flow .so early participation of FM staff in the design phases and construction will be very useful for developing accurate and complete BIM as they were built.

According to [13], Companies must have a budget to create the data and to keep it updated, otherwise the form itself becomes old and useless: part of the cost should be allocated to create a template and another part should be allocated to continue updating the template. During the first phase of FM, the data and information must be updated immediately, to enable FM team to easily access the database and carry out daily operational work. Stated that the building information modeling workflow is unclear, the successful implementation of BIM requires the exchange of information between different stakeholders.

Therefore, according to, Failure to know the capabilities of BIM in FM practice will reduce the interest of FM companies and customers in investing money, time, and effort to implement them, thereby losing opportunities and future benefits and impeding BIM adoption in FM practice. He explained that increased transparency between stakeholder building and the development of a standard protocol for capturing information during the design and construction phases would enhance decision-making. Therefore, according to , hiring a BIM coordinator to assign responsibilities to individuals working on a team that may significantly affect BIM use and how efficient the organization of the team is to improve the use of BIM. Efficiency of the organization / owner is a traditional building management. As mentioned that will help training and skill Facility management personnel learn to recognize the BIM 3D environment and contribute to all stages of the building and understand what can be accomplished using BIM models and how it can be beneficial to accomplish facility management company goals.

VI. CONCLUSION

Many useful digital technologies emerged or developed during the 4th digital revolution. The IoT, VR and AR are examples of such digital technologies that, when integrated with Facility Management Process, could enhance most of its process activities by providing visual assistance information and support the process of making quick and accurate decisions. From the previous sections, we could conclude the target framework, shown in Figure 19, to reach an enhanced FM process.

- The fundamental task in this framework before applying the discussed technologies is to prepare required plans that mainly deal with challenges and barriers facing the application of IoT, VR and AR in the BIM-based FM and try to overcome, eliminate or mitigate its negative effects on the process. There are form main plans: the cost-related plans, the technical-related plans, the human related plans and the data-related plans. As per the approved budget, the decision to apply whatever suit the FM company and fit with its conditions as the application of such technologies in the framework is not dependent, but related to the approved budget and the approved specification of the suitable infrastructure of such application.
- Using the Internet of Things provides activate the concept of a partial or whole “digital twins” by which the facility manager and his team could get benefit from the real-time simulation of building spaces, component, objects and systems and easily visualize and identify potential problems in facility management, and thus support decision-making for appropriate adjustments.
- Using virtual reality give the user the advantage of managing the building full database, access it from multiple platforms and give him more insightful input to improve design quality. Spatial understanding of virtual reality helps in taking more accurate decisions.
- Displaying real-size models in the augmented reality scene provides the user with a virtual augmented environment in which the user has a navigation tools, a situation awareness notification, and visualized maintenance instructions for all systems. In addition, the user can monitor the building performance and use the capability of intelligent fault diagnosis
- Through the early involvement of FM employees in the design and construction stages, many challenges can be overcome.
- The continuous updating of information and data during the design, construction, operation and maintenance stages is essential for an accurate and solid decision-making process and problem solving.

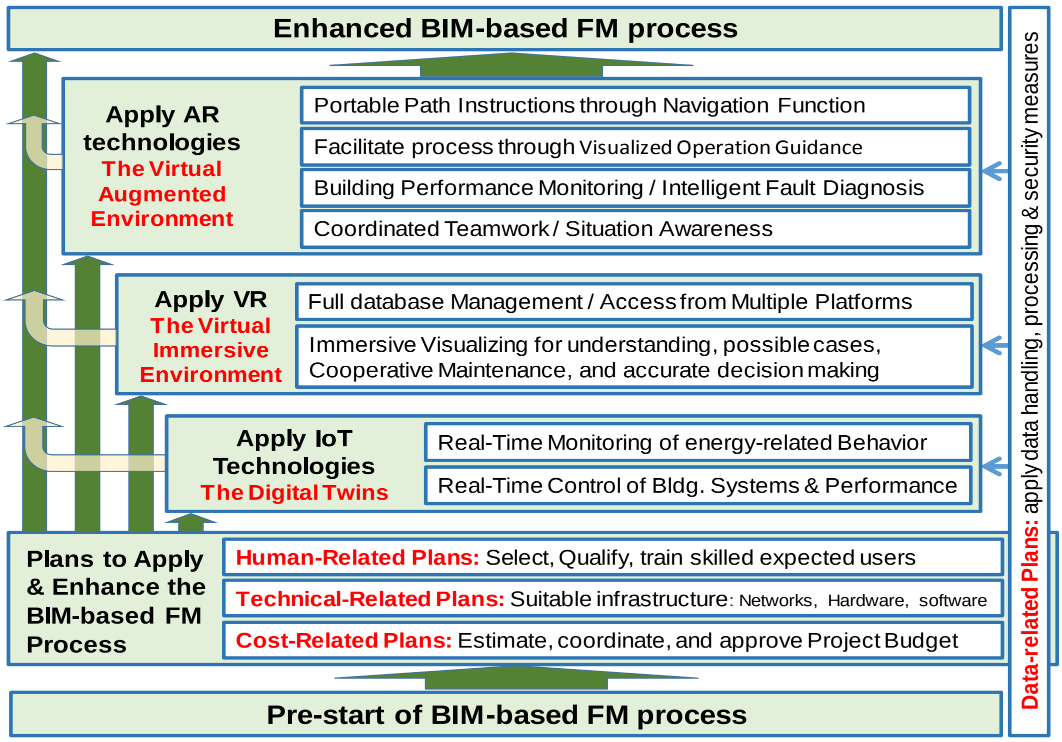

Figure 19. A proposed Framework for integrating IoT, VR & AR with the BIM-Based Facility Management Proces Considering main Benefits and related Challenges (by Authors)

VII. RECOMMENDATION FOR FUTURE RESEARCH DIRECTIONS

A. *Recommendations*

- **Regulators:** to include BIM in Saudi Code and prepare related guidelines to eliminate data-related challenges.
- **Project related parties:**
  - To adopt using BIM in their projects to facilitate the using of the all discussed new technologies in a BIM-based FM process.
  - To invest in training programs for its users to get the utmost benefits of such technologies.
  - To take all required measures to secure Project data from all types of cybercrimes
- **Legal Entities**
  - To study international successful cases for facing cybercrime cases and put related regulations.
- **System Developers**
  - To resolve the problem of complex Interface to encourage all levels of users and support them when using such applications.

B. *Suggested Future research:*

More research efforts are needed to

- Develop a collaborative data exchange system in which all project related parties share their input from the early stages of the project and all over the project life cycle
- Use artificial intelligence technologies to overcome different types of challenges facing the BIM-based Facility Management process.
- Invest the safe virtual training environments to well qualify technology users of the FM team.

REFERENCES

[1]Thamilselvi, P., Siva, A., & Abubakkar, S. A. (2017). BIM – Evolution and Emerging Research Trends. International Journal of Advanced in Management, Technology and Engineering Sciences, pp. Volume 7, Issue 11,

[2]Associated General Contractors of America. (2005). The Contractor's Guide to BIM, 1st ed. AGC Research Foundation, Las Vegas, NV.

[3]Paul Teicholz, 2013. BIM for Facility Managers. 1st ed. s.l.:John Wiley & Sons, Inc..

[4]Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), 241-252

[5]Wong, K. D. A., Wong, F. K., & Nadeem, A. (2011). Building information modelling for tertiary construction education in Hong Kong. Journal of information technology in construction.

[6]Arnett, M. K. P., & Quadrato, C. E. (2012). Building Information Modeling: Design instruction by integration into an undergraduate curriculum. In American Society for Engineering Education. American Society for Engineering Education.

[7]Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. Journal of Building Engineering, 19, 242-257.

[8] First In Architecture. 2022. The Advantages of BIM and its Future. [online] Available at: <https://www.firstinarchitecture.co.uk/the-advantages-of-bim-and-its-future/> [Accessed 27 August 2022].

[9]Haines, B., (2016). The Benefits of Lifecycle BIM for Facility Management. Available: https://fmsystems.com/blog/the-benefits-of-lifecycle-bim-for-facility-management/

[10]Pniewski, V., (2011). "Building Information Modeling (BIM), Interoperability Issues in Light of Interdisciplinary Collaboration," Collaborative Modeling Ltd, Third Edition, London, UK.

[11]Ghosh, A. D. Chasey, and M. Mergenschroer. (2015) in Building information modeling: applications and practices, R. R. A. Issa and S. Olbina, Eds., ed: American Society of Civil Engineers.

[12]Becerik-Gerber, B., F. Jazizadeh, N. Li, and G. Calis. (2011). "Application areas and data requirements for BIM-enabled facilities management." J. Constr. Eng. Manage. 138 (3): 431–442.

[13]MOHAMMAD, S., & SYED, S. A. (2018). BIM for Existing Buildings and its effects on Facility Management (Master's thesis).

[14]Gheisari, M., S. Goodman, J. Schmidt, G. Williams, and J. Irizarry. (2014). "Exploring BIM and mobile augmented reality use in facilities management." In Proc., Construction Research Congress, 1941–1950. Reston,VA: ASCE.

[15]Pishdad-Bozorgi, P. (2017). Future smart facilities: State-of-the-art BIM-enabled facility management. Journal of Construction Engineering and Management, 143(9), 02517006.

[16]Jaspers, E., Härtig, M., Hofmann, M., May, M., & Turianskyj, N. (2018). IoT im FM. In CAFM-Handbuch (pp. 337-375). Springer Vieweg, Wiesbaden.

[17] Pourzolfaghar, Z., McDonnell, P., & Helfert, M. (2017). Barriers to benefit from integration of building information with live data from IOT devices during the facility management phase.

[18]Spain, C. (2016): Data-enabled Water Management. Facility Management Journal March/April 2016, 90-92.

[19]Lauzi, M. & Jörg, Ch. (2017): Ein weitreichendes funkbasiertes Sensor-Aktor-Netzwerk für die Zukunft smarter Städte. Tagungsband InservFM, Messe und Kongress für Facility Management und Industrieservice, Stuttgart, Verlag Wissenschaftliche Skripten. 667-673.

[20]Brad, B.S. & Murar, M.M. (2014): Smart Buildings Using IoT Technologies. Construction of Unique Buildings and Structures 5 (20), 15-27.

[21]Karlgen, J., Fahlen, I.E., Wallberg, A., Hansson, P., Stahl, O., Soderberg, J. & Akesson, K. (2008): Socially Intelligent Interfaces for Increased Energy Awareness in the Home. Proceedings of the First International Conference, IOT 2008, Zürich (Schweiz), 263-275.

[22]Roth, K., Westphalen, D., Feng, M., Llana, P., Quartararo, L. (2005): Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential, Cambridge (MA). TIAX LLC Report für das U.S. Department of Energy.

[23]King, J. & Perry, C. (2017): Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings. Washington D.C. (USA). American Council for an Energy-Efficient Economy. 46 Seiten.

[24]Yoshikawa, H., Tsubokura, T., Toida, S., Kawai, Y. & Hatori F. (2015): Cloud-based Equipment Maintenance and Facility Management Service Platform. Hitachi Review 64(4), 229-233

[25]Mukati A. & Mukati, R. (2016). A Survey on Growing Trends in Automatic Identification and Data Capture Techniques based on Assigned Properties. International Journal of Computer Science and Information Security 14(11), 580-589.

[26]Coster, M. & Liu, Q. (2015): An Imperfect Preventive Maintenance Policy Considering Reliability Limit. Int. Journal of Engineering Research and Applications 5(12-2), 49-56.

[27]Markowitz, D. (2016): Software is Eating the FM World, Facility Management Journal March/April 2016, 36-39.

[28]Emonts-Holley, R. (2017): Smart Maintenance – Softwareunterstützung für ein bedarfsorientiertes Instandhaltungsmanagement in Produktionsumgebungen. Tagungsband InservFM, Messe und Kongress für Facility Management und Industrieservice, Stuttgart, Verlag Wissenschaftliche Skripten. 385-393.

[29]Chang, K. M., Dzeng, R. J., & Wu, Y. J. (2018). An automated IoT visualization BIM platform for decision support in facilities management. Applied Sciences, 8(7), 1086.

[30]Brouchoud, J. 2016. VR Device Options for Architects, [online] Available at http://www. hyperg rid business.com/2016/06/vr-device-option s-for-arch itects/.

[31]Yang, Z., & Kensek, K. 2018. Building Information Modeling and Virtual Reality. 2018 In Architectural Research Centers Consortium Conference Repository.

[32]Donalek, C., Djorgovski, S. G., Cioc, A., Wang, A., Zhang, J., Lawler, E., Yeh, S., Mahabal, A., Graham, M., Drake, A., Davidoff, S., Norris, J. S., and Longo, G. 2014. lmmersive and Collaborative Data Visualization Using Virtual Reality Platforms, 2014 IEEE International Conference on Big Data.

[33]Bhonde, D., Zadeh, P., & Staub-French, S. (2019). Investigating The Use Of Virtual Reality In Improving The Quality Of Design Bim For Facility Management.

[34]Chung, S. W., Kwon, S. W., Moon, D. Y., & Ko, T. K. (2018). Smart Facility Management Systems Utilizing Open BIM and Augmented/Virtual Reality. In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction (Vol. 35, pp. 1-8). IAARC Publications.

[35]Chi, H. L., Kang, S. C., and Wang, X. (2013). "Research trends and opportunities of augmented reality applications in architecture, engineering, and construction." J. Automation in Construction, 33, 116–122.

[36]Baek, F., Ha, I., & Kim, H. (2019). Augmented reality system for facility management using image-based indoor localization. Automation in Construction, 99, 18-26.

[37]Golabchi, A., Akula, M., and Kamat, V. (2016). "Automated building information modeling for fault detection and diagnostics in commercial HVAC systems." Facilities, 34(3/4), 233–246.

[38]Wang, J., Hou, L., Wang, Y., Wang, X., & Simpson, I. (2015). Integrating augmented reality into building information modeling for facility management case studies. In Building Information Modeling: Applications and Practices (pp. 279-304). Building Information Modeling: Applications and Practices.

[39]Mishra, S. and Mishra, A.K. (2014), Benefits and Barriers of Building Information Modelling.

[40]Eadie, R., Browne, M., Odeyinka, H., McKeown, C. and McNiff, S. (2013), "BIM implementation throughout the UK construction project life cycle: an analysis", Automation in Construction, Vol. 36, pp. 145-151.

[41] Williams, R., Shayesteh, H., & Marjanovic-Halburd, L. (2014). Utilizing building information modeling for facilities management. International Journal of Facility Management, 5(1).

[42]Dixit, M. K., Venkatraj, V., Ostadalimakhmalbaf, M., Pariafsai, F., & Lavy, S. (2019). Integration of facility management and building information modeling (BIM). Facilities.

[43]East, W.E. and Brodt, W. (2007), "BIM for construction handover", Journal of Building Information Modeling, pp. 28-35.

[44]Ibrahim, K. F., Abanda, F. H., Vidalakis, C., and Woods, G. (2016). "BIM for FM: Input versus output data." Proc., 33rd CIB W78 Conf., CIB W78, Brisbane, Australia

[45]Jang, S.; Lee, G. 2018. Impact of organizational factors on delays in BIM-based coordination from a decision-making view: A case study, Journal of Civil Engineering and Management 24(1): 19–30.

[46]Giel, B. and Issa, R. (2014). Framework for evaluating the BIM competencies of building owners. Computing in Civil and Building Engineering, 1(3):552–559.

[47]Carbonari, G., Ashworth, S. and Stravoravdis, S. (2015), "How facility management can use building information modelling (BIM) to improve the decision-making process", 15th EuroFM Research Symposium, Milan.

[48]McAuley, B. (2016), Identification of Key Performance Tasks to Demonstrate the Benefit of Introducing the Facilities Manager at an Early Stage in the Building Information Modelling process on Public Sector Projects in Ireland.

[49]Alalawi, M., Ali, M., Johnson, S., Han, S. and Mohamed, Y. 2015. Constructability: Capabilities, Implementation, and Barriers. International Construction Specialty Conference of the Canadian Society for Civil Engineering (ICSC), CSCE, Vancouver, BC, Canada.

[50] Cavka, H B Staub-French, S and Poirier, E A (2017) Developing owner information requirements for BIM-enabled project delivery and asset management. Automation in Construction, 83, 169-183.

[51]Naghshbandi, S.N. (2017), "BIM for facility management: challenges and research gaps", Civil Engineering Journal, Vol. 2 No. 12, pp. 679-684

[52]Liu, R. and Issa, R.A. (2013), "Issues in BIM for facility management from industry practitioners' perspectives", Computing in Civil Engineering (2013), p. 411

[53]Zadeh, P. A., Staub-French, S., & Pottinger, R. (2015, June). Review of BIM quality assessment approaches for facility management. In ICSC15: The Canadian Society for Civil Engineering 5th International/11th Construction Specialty Conference, University of British Columbia, Vancouver, Canada (pp. 1887-1896).

[54]Beach, T., Petri, I., Rezgui, Y. and Rana, O. (2017), "Management of collaborative BIM data by federating distributed BIM models", Journal of Computing in Civil Engineering, Vol. 31 No. 4, p. 04017009.

[55]Liu, R., & Zettersten, G. (2016). Facility sustainment management system automated population from building information models. In Construction Research Congress 2016 (pp. 2403-2410).

[56]Kasprzak, C., Ramesh, A., & Dubler, C. (2013). Developing standards to assess the quality of BIM criteria for facilities management. In AEI 2013: Building Solutions for Architectural Engineering (pp. 680-690).

[57]Wang, Z. (2019). BIM-Based Turnover Documentation and Information System for Facility Management (Doctoral dissertation, Virginia Polytechnic Institute and State University).

[58]Elmualim, A. and Gilder, J. (2014), "BIM: innovation in design management, influence and challenges of implementation", Architectural Engineering and Design Management, Vol. 10 Nos 3/4, pp. 183-199.

[59]Ahmed, M. F., Haas, C. T., & Haas, R. (2014). Automatic detection of cylindrical objects in built facilities. Journal of Computing in Civil Engineering,28(3).

[60]Miettinen, R., Kerosuo, H., Metsälä, T. and Paavola, S. (2018), "Bridging the life cycle: a case study on facility management infrastructures and uses of BIM", Journal of Facilities Management, Vol. 16 No. 1, pp. 2-16

[61]Kang, T.W. and Hong, C.H. (2015), "A study on software architecture for effective BIM/GIS-based facility management data integration", Automation in Construction, Vol. 54, pp. 25-38.

[62]Chen, W., Chen, K., & Cheng, J. C. (2018). Towards an ontology-based approach for information interoperability between BIM and facility management. In Workshop of the European Group for Intelligent Computing in Engineering (pp. 447-469). Springer, Cham.

[64] Velev, D., and Zlateva, P., 2017, "Virtual Reality Challenges in Education and Training", International Journal of Learning and Teaching Vol.(3), No (1).

[65] Williams, J., Orooji, F., Aly, SH. 2019. "Integration of Virtual Reality (VR) in Architectural Design Education: Exploring Student experience". American Society for Engineering Education. Paper ID #27354.

[66] Al-Kebsi, Shaima and Mostafa, Ahmed, 2021, Trends and Challenges of Virtual Reality in Architectural Design Education, Journal of Architecture and Planning, King Saud University, 33 (2)