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BIM Maintenance System with IoT Integration: Enhancing Building Performance and Facility Management

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Abstract

The rapid growth of technology worldwide in different ways drives the construction sector to take the same path. Smart cities, Digital Twins, Building Information Modeling (BIM), and the Internet of Things (IoT) are the trends in this way today. Also, integrating Building Information Modeling (BIM) and Internet of Things (IoT) technologies has revolutionized how buildings are designed, constructed, maintained, and managed. On the other hand, the complexity, high cost, need for expertise, and other things make the maintenance process and facility management by human inspections, commercial software, and different tools not suitable for the growth of the technology. This paper presents a proposal for a workflow of integration between BIM, and an algorithm of Maintenance System with IoT and highlights its potential to enhance building performance and facility management. The paper explores this innovative system's underlying principles, benefits, challenges, and implementation strategies. Furthermore, it discusses the implications of BIM, and the proposed algorithm of Maintenance System with IoT integration on various stakeholders, including building owners, facility managers, and occupants by using a case study. The findings collected by a questionnaire for some experts emphasize the importance of adopting this integrated approach to optimize building operations, improve maintenance practices, and create sustainable and intelligent built environments.

Keywords: Internet of Things; Decision Support System; Building Information Modeling; Maintenance System; Facility Management.

1. Introduction

Building Information Modeling (BIM) and the Internet of Things (IoT) have emerged as transformative technologies in the construction and facility management industries [1]. Related to Allen [2] BIM is a digital representation of the physical and functional characteristics, integrating various data sources to support decision-making throughout the building lifecycle. On the other side, IoT refers to a network of interconnected devices and sensors that collect and exchange data [3]. The integration of BIM and IoT offers significant potential to enhance building performance and streamline facility management processes. By combining the data-rich environment of BIM with real-time data from IoT devices, building owners and facility managers can gain valuable insights into the operational efficiency, maintenance needs, and overall performance of their buildings. In an era defined by rapid technological advancements, the construction and facility management industries are undergoing a transformative shift. At the forefront of this revolution stand two ground-breaking technologies: Building Information Modeling (BIM) and the Internet of Things (IoT). These powerful tools have emerged as catalysts for innovation, reshaping the way we conceive, construct, and manage the built environment.

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The integration of Building Information Modeling (BIM) and the Internet of Things (IoT) has opened up new possibilities for enhancing building performance and facility management through an innovative BIM Maintenance System. This integration combines the power of BIM's digital representation of building assets and IoT's real-time data collection capabilities from interconnected devices and sensors. By integrating IoT with BIM, facility managers can gain valuable insights into the operational performance of building systems, optimize maintenance practices, and improve overall facility management efficiency. This article explores the benefits and applications of the BIM Maintenance System with IoT integration, highlighting how it enables proactive maintenance, energy optimization, asset performance monitoring, and enhanced occupant comfort.

The integration of BIM and IoT is revolutionizing the way facility managers approach maintenance and management, leading to smarter and more sustainable buildings. So, this research is divided into multiple parts. The first part explains the components of BIM and IoT individually and highlights their significance in the context of facility management. The second part discusses the concept of the BIM Maintenance System and how the integration of BIM and IoT technologies can enhance its functionality. This part also addresses the challenges and considerations associated with implementing the BIM Maintenance System with IoT integration. These challenges include data integration and interoperability, security and privacy concerns, cost implications, and the need for training and skill development. The third one shows the main idea of the research, which is a proposed maintenance workflow with an integration system between BIM and IOT to make a digitalized maintenance system at construction buildings. Additionally, the implications of the integration BIM- proposed Maintenance workflow with IoT integration for various stakeholders, such as building owners, facility managers, occupants, and the construction industry, will be discussed. The paper aims to provide a comprehensive understanding of how this integrated approach can revolutionize building maintenance practices, optimize asset management, and create sustainable and intelligent built environments by providing a proposal workflow for this integration. Furthermore, the paper will address the benefits of this integrated approach, including enhanced asset management, real-time monitoring, improved energy efficiency, and streamlined facility management processes. Finally, the paper will evaluate the proposed integration system based on data collected by a questionnaire from expertise and present conclusions and recommendations for future research and practice, including advancements in BIM and IoT technologies and the importance of industry-wide adoption and standardization. IoT form a dynamic duo, opening doors to enhanced communication, optimized operations, and sustainable practices. In this exploration, we delve into the remarkable impact of BIM and IoT on the construction and facility management sectors, discovering the vast potential they hold for a future where buildings are not just structures, but intelligent ecosystems tailored to meet our ever-evolving needs [4].

The convergence of BIM and IoT represents a paradigm shift in the construction and facility management industries. Together, they form a symbiotic relationship that harnesses the power of data, connectivity, and collaboration. BIM's ability to create a digital twin of a building harmonizes with the IoT's capacity to gather and utilize real-time data, resulting in intelligent, connected structures. This dynamic combination unlocks a multitude of possibilities, ranging from predictive maintenance and energy optimization to personalized occupant experiences and sustainable practices. As these transformative technologies continue to evolve, the construction and facility management industries stand on the cusp of a new era. The integration of BIM and IoT promises to reshape the way we design, construct, and manage buildings, ushering in a future where projects are more efficient, sustainable, and responsive to the needs of occupants and stakeholders. In this exploration, we delve into the profound impact of BIM and IoT, uncovering their potential to revolutionize the construction and facility management landscapes and shape the built environment of tomorrow [5]. All of this contributes to the growing body of knowledge in the field of building maintenance and facility management, providing insights and guidance for organizations seeking to leverage the power of these technologies to enhance building performance and operational efficiency.

2. Literature Review

The big revolution of technology today makes many researchers take this way to improve and introduce new ideas and solutions for different problems. In construction, Machine learning, neural networks, Deep learning, IOT, BIM, Digital Twins, integration between them, and others are the most common and trendy methods in the construction industry. This research focuses on the integration of BIM and IOT to enhance building performance and facility management. So, the main criteria for the literature review are divided into five main titles to give a clear vision, simplicity, and a road map for anyone interested in this direction.

2.1. Overview of BIM (BIM Components and Benefits)

Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of a building or infrastructure project [6]. It encompasses the creation and management of a 3D model that integrates various data sources, including geometric information, spatial relationships, quantities, and properties of building elements [7]. BIM goes beyond traditional 2D drawings by providing a collaborative platform that enables multiple stakeholders, such as architects, engineers, contractors, and facility managers, to work together on a shared model. This shared model serves as a single source of truth, facilitating communication, coordination, and decision-making throughout the entire lifecycle of a building. BIM comprises several key components that contribute to its effectiveness in building design, construction, and facility management [8], as shown in Figure. 1. The summary of BIM benefits is also presented in Figure 2.

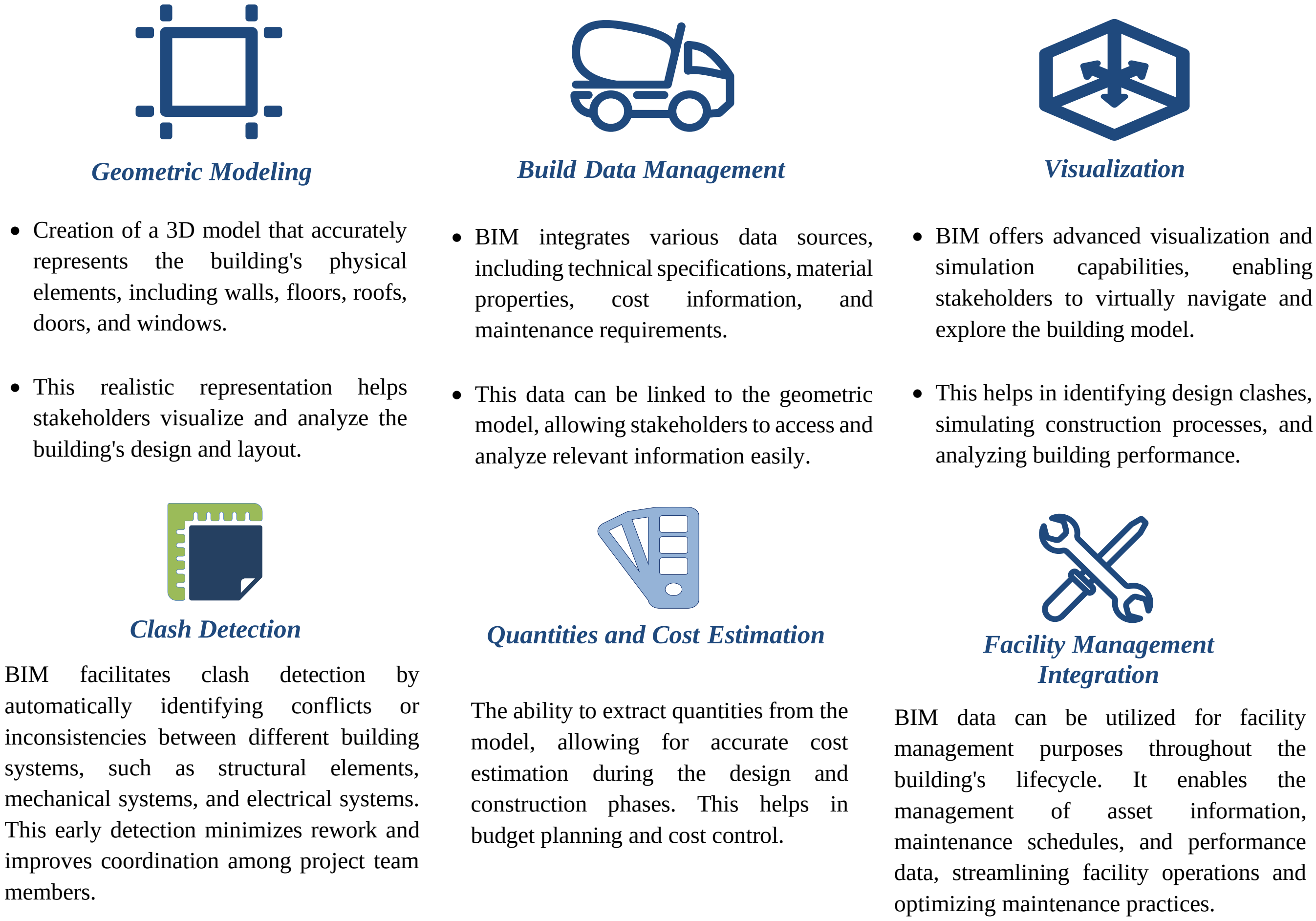


Figure 1. BIM Maintenance System Plugins

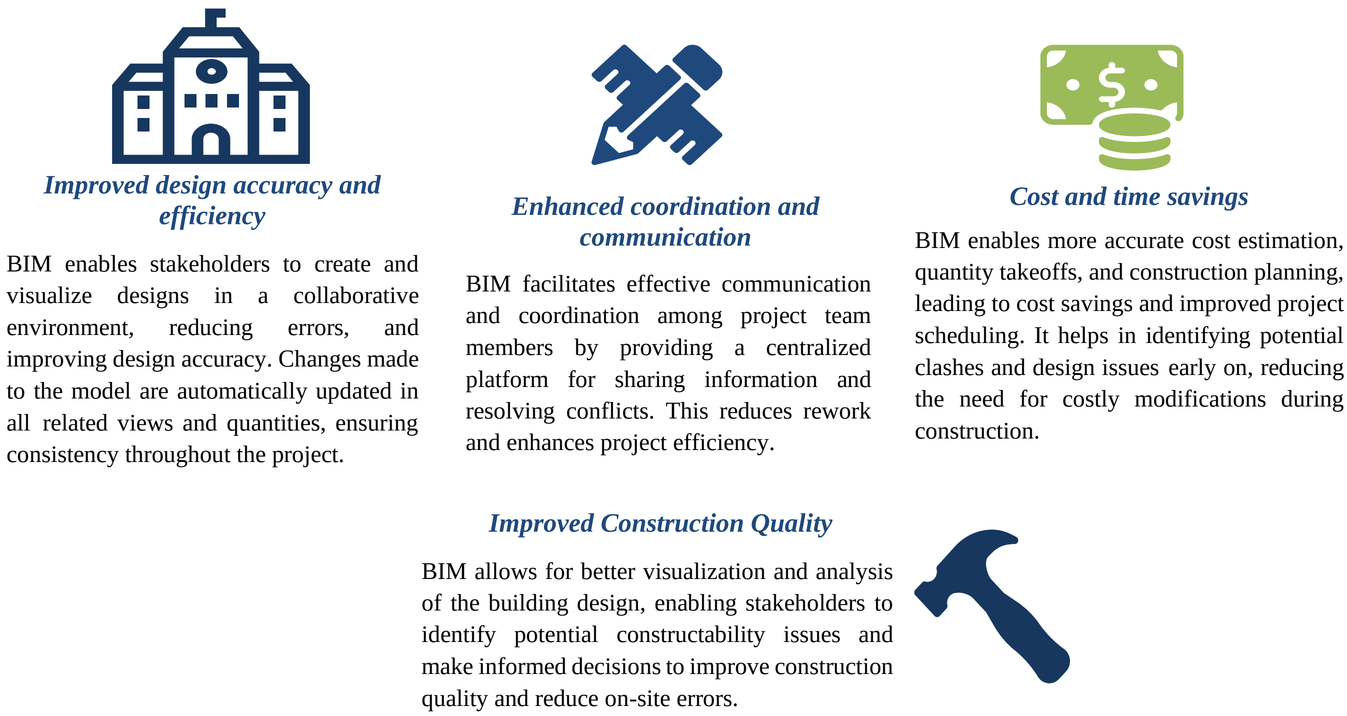


Figure 2. A Summary of BIM Benefits

2.2. BIM in Facility Management

BIM's benefits extend beyond the design and construction phases, as it plays a crucial role in facility management. By integrating BIM with facility management processes, stakeholders can effectively manage and maintain the building throughout its lifecycle [9].

BIM in facility management offers the following advantages, as shown in Figure 3.

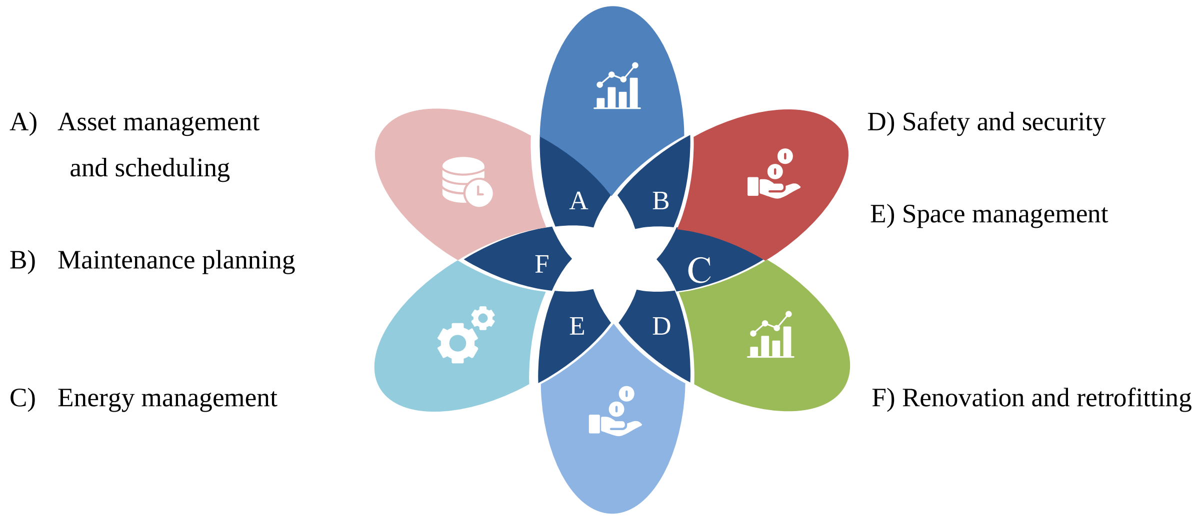


Figure 3. Main Advantages of BIM in FM

a) Asset management [10]: BIM provides a detailed and up-to-date record of the building's components, equipment, and systems. This information helps facility managers in asset tracking, maintenance planning, and lifecycle analysis, ensuring efficient asset management.

b) Maintenance planning and scheduling [11]: BIM enables the integration of maintenance schedules and requirements into the model. Facility managers can access maintenance information, such as equipment manuals, warranties, and service histories, to plan and schedule maintenance activities more effectively.

c) Energy management [12]: BIM can be integrated with energy modeling and simulation tools to analyze and optimize the building's energy performance. Facility managers can identify energy-saving opportunities, monitor energy consumption, and implement energy-efficient strategies.

d) Space management [13]: BIM allows for accurate space management by providing information on room dimensions, occupancy, and utilization. Facility managers can optimize space allocation, track occupancy rates, and plan for future space needs.

e) Safety and security [14]: BIM can be utilized to enhance safety and security management by incorporating information on fire safety systems, emergency exits, and security measures. Facility managers can access this information to develop and implement effective safety protocols.

f) Renovation and retrofitting [15]: BIM supports renovation and retrofitting projects by providing an accurate representation of the existing building and its systems. Facility managers can assess the impact of proposed changes, plan renovations, and evaluate the feasibility of retrofitting initiatives. By leveraging BIM in facility management, stakeholders can streamline operations, improve maintenance practices, and optimize building performance throughout its lifecycle. The integration of BIM with IoT technologies further enhances these capabilities by providing real-time data for monitoring and analysis, which will be discussed in subsequent sections. In summary, BIM in facility management provides comprehensive information about building assets, supports efficient maintenance practices, enables energy management, enhances safety measures, streamlines renovation projects, facilitates collaboration, and assists in long-term planning. It enhances the overall efficiency, effectiveness, and sustainability of facility management processes [12].

2.3. IoT and its Applications in Buildings

The Internet of Things (IoT) refers to Dave et al. [15] a network of interconnected devices embedded with sensors, software, and connectivity capabilities that enable them to collect and exchange data. These devices, often referred to as "smart" or "connected" devices, can range from sensors and actuators to everyday objects such as appliances, lighting systems, HVAC systems, and security systems. IoT technology has gained significant traction in various industries, including buildings and construction. By connecting devices and systems within buildings, IoT enables the capture and analysis of real-time data, facilitating improved decision-making, automation, and optimization of building operations. The Internet of Things (IoT) refers to the network of interconnected devices and sensors that collect and exchange data through the internet. In the context of buildings, IoT technology has numerous applications that enhance functionality, efficiency, and occupant experience [16, 17]. IoT offers a wide range of applications in buildings, revolutionizing the way they are managed and operated. Some key applications of IoT in buildings include the following, also summarized in Figure 4.

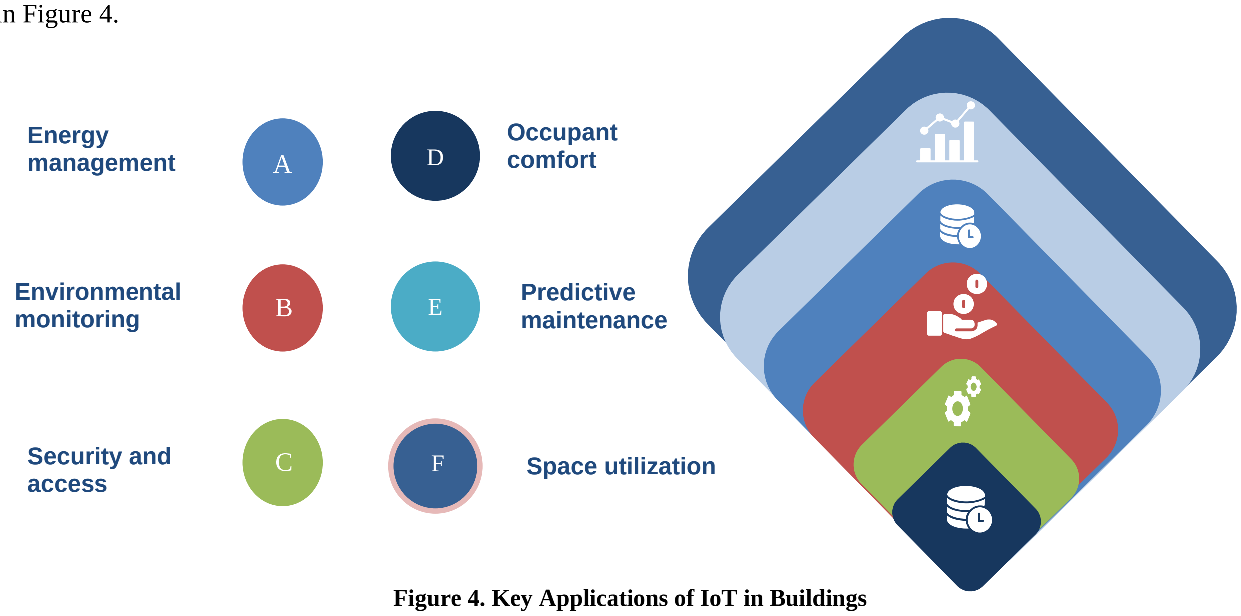


Figure 4. Key Applications of IoT in Buildings

a) Energy management [18]: IoT-enabled sensors and meters can monitor energy consumption in real-time, allowing building owners and facility managers to identify energy-saving opportunities, optimize energy usage, and implement demand response strategies.

b) Environmental monitoring [19]: IoT devices can measure and monitor environmental parameters such as temperature, humidity, air quality, and noise levels. This data helps maintain occupant comfort, assess indoor air quality, and identify potential issues requiring attention.

c) Security and access control [20]: IoT-based security systems enable remote monitoring and control of building access, surveillance cameras, and alarm systems. Real-time alerts and notifications can be sent to authorized personnel in case of security breaches or emergencies.

d) Occupant comfort and well-being [21]: IoT devices can monitor and adjust environmental conditions, such as lighting, temperature, and air quality, to optimize occupant comfort and productivity. Occupants can also have control over these settings through mobile applications or smart interfaces.

e) Predictive maintenance [22]: IoT sensors can monitor the health and performance of building systems and equipment, detecting anomalies and predicting maintenance needs. This proactive approach helps prevent equipment failures, reduce downtime, and optimize maintenance schedules.

f) Space utilization [23]: IoT sensors can track the occupancy and utilization of spaces within a building. This information enables facility managers to optimize space allocation, identify underutilized areas, and plan for efficient space utilization.

2.4. Key Features and Functionality

A BIM Maintenance System refers to the integration of Building Information Modeling (BIM) and maintenance management practices to streamline and optimize the maintenance of buildings and infrastructure. It leverages the capabilities of BIM, such as the digital representation of building assets and their associated data, to support efficient maintenance planning, scheduling, and execution. Figure 5 shows a summary of the main principles of a BIM Maintenance System and the key features of its functionality. So, this Paragraph is divided into two parts, the principles of a BIM Maintenance System will be discussed in the first part. Then, the main key features and functionality will be the second one. One of the important principles of BIM Maintenance is that BIM provides a digital representation of the building assets, including their geometric information, properties, and relationships [24]. This digital representation serves as a foundation for maintenance management activities. The second principle is “Data integration”, BIM integrates various data sources, such as equipment specifications, maintenance history, and performance data, into a centralized system [25]. This enables maintenance managers to access and analyze relevant information for effective decision-making.

Also, "Collaboration and communication" are the main ideas of BIM mainly between stakeholders involved in maintenance activities [26]. It enables seamless information sharing, issue tracking, and coordination among maintenance teams, facility managers, and other relevant parties [27]. Finally, the "Lifecycle perspective" for BIM maintenance is a very beneficial principle for the entire lifecycle of building assets, from design and construction to operation and maintenance [28]. This long-term perspective helps optimize maintenance strategies, improve asset performance, and extend the asset's lifespan [26]. The features of BIM Maintenance and its functionality are collected from the previous works and summarized in the following lines. "Asset management", the system provides a centralized repository for managing asset information, including equipment specifications, maintenance history, warranties, and service manuals [29]. This helps in tracking asset details, optimizing spare parts inventory, and ensuring compliance with maintenance requirements [30]. Also, maintenance managers can create and manage work orders within the system which is called "Work order management". Work orders can be assigned to maintenance teams, tracked in real-time, and updated with progress and completion status [31]. This streamlines maintenance workflows and improves transparency. On another hand, "Preventive Maintenance Planning" supports the planning and scheduling of preventive maintenance activities based on predefined maintenance strategies, manufacturer recommendations, or condition monitoring data [32].

Maintenance managers can create maintenance plans, define task frequencies, and generate maintenance schedules. Also, "Mobile Access and Field Data Capture" allows maintenance technicians to access work orders, record maintenance activities, and capture field data using mobile devices [33]. This enables real-time data capture and improves the accuracy and timeliness of maintenance records [34]. The system offers "Analytics and Reporting" capabilities to analyze maintenance data, track key performance indicators (KPIs), and generate reports on asset performance, maintenance costs, and compliance [35]. This helps in identifying trends, evaluating maintenance effectiveness, and making data-driven decisions [36]. Finally, "Integration with IoT Data and other Systems" which the system integrates IoT data from sensors and devices or with other software systems [37], such as enterprise asset management (EAM) systems, work order management systems, and building automation systems into the BIM model [38]. This allows maintenance managers to visualize real-time asset conditions, monitor performance metrics, and trigger maintenance actions. By incorporating these features and functionalities, a BIM Maintenance System enables maintenance managers to optimize maintenance strategies, improve asset performance, reduce costs, and enhance the overall operational efficiency of buildings and infrastructure assets.

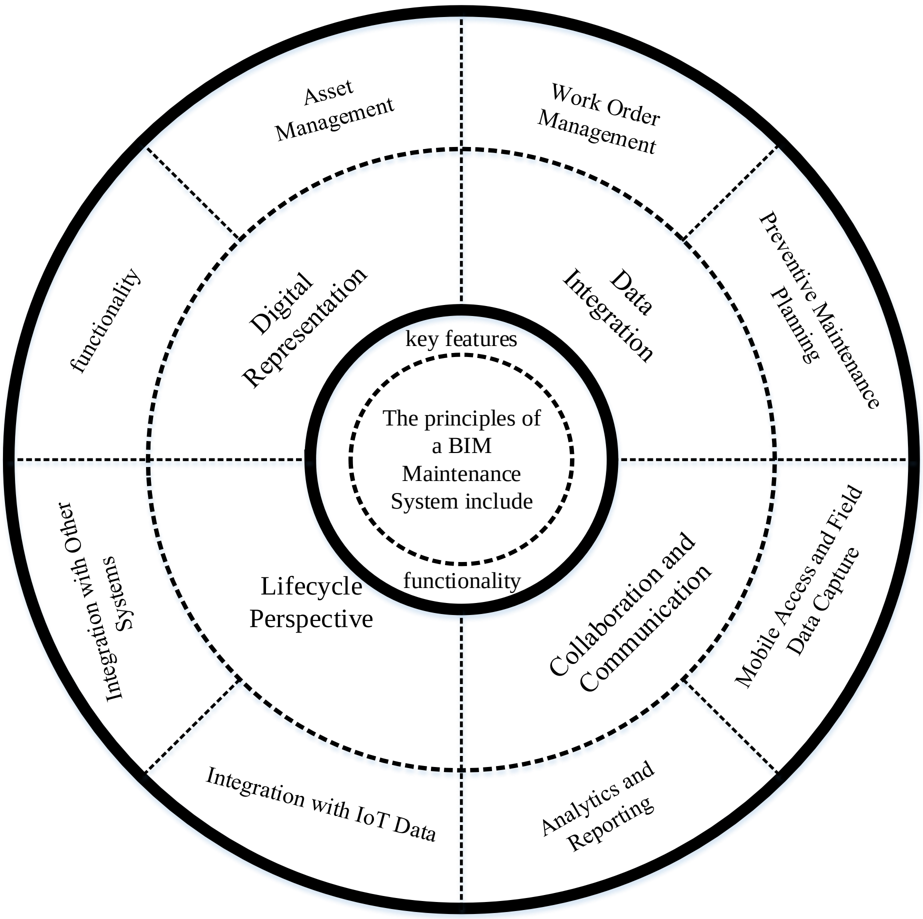


Figure 5. The main principles of a BIM Maintenance System and the key features of its functionality

2.5. Integration of BIM and IoT

The integration of BIM and Internet of Things (IoT) technologies enhances the capabilities of a BIM Maintenance System. IoT devices, such as sensors and actuators, can be connected to building assets to collect real-time data on their performance, condition, and usage. This data can then be integrated with the BIM model, providing valuable insights for maintenance activities. Figure 6 shows a summary of the enables of the integration BIM and IoT related to the previous works and literature reviews.

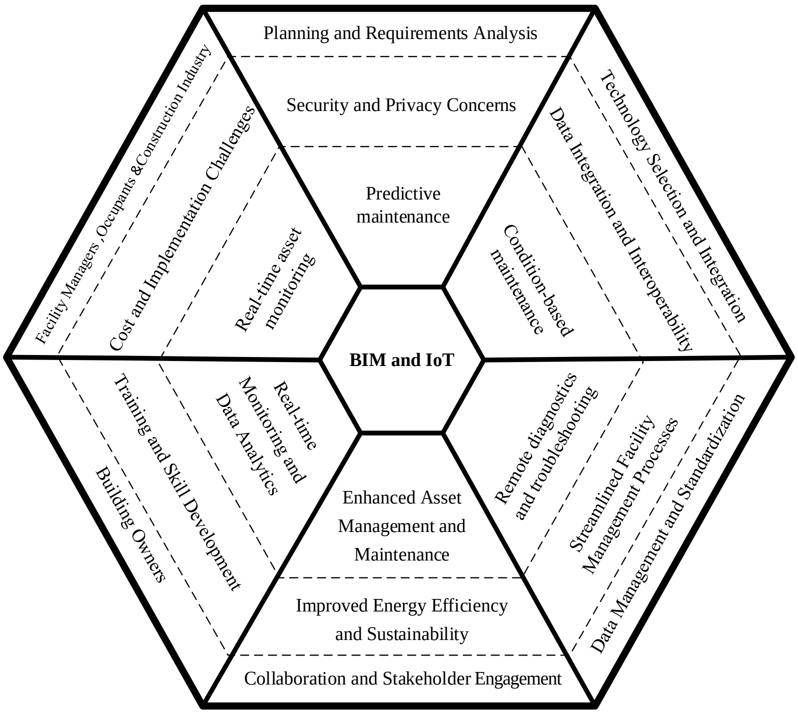


Figure 6. Summary of the enables of the integration of BIM and IoT related to the previous works and literature reviews

Related to Saini et al. [39], IoT sensors can capture real-time data on asset performance, energy consumption, and environmental conditions. This data can be integrated with the BIM model, allowing maintenance managers to monitor asset health, detect anomalies, and trigger maintenance actions based on actual asset conditions. On the other hand, by analyzing IoT data, combined with historical performance data and maintenance records, predictive maintenance algorithms can be applied [40]. These algorithms can identify patterns and trends, predict potential equipment failures, and recommend proactive maintenance activities. This helps prevent unexpected breakdowns, reduce downtime, and optimize maintenance schedules [41]. IoT sensors can provide continuous monitoring of asset conditions, such as vibration, temperature, and humidity [42]. Maintenance managers can set condition thresholds and receive alerts when assets deviate from normal operating conditions. This enables condition-based maintenance, where maintenance activities are triggered based on actual asset conditions rather than predefined schedules [43]. Also, IoT-enabled assets can be remotely accessed and monitored, allowing maintenance teams to perform diagnostics, and troubleshooting activities without being physically present at the asset location [44]. This reduces response times and improves maintenance efficiency. Integration of BIM and IoT in a maintenance system provides enhanced asset management capabilities. The digital representation of building assets in the BIM model, combined with real-time IoT data, enables maintenance managers to have a comprehensive view of asset information, including specifications, maintenance history, and condition data [45]. This centralized and up-to-date asset information improves asset tracking, maintenance planning, and decision-making. It facilitates proactive maintenance strategies, such as predictive and condition-based maintenance, leading to increased asset reliability, reduced downtime, and optimized maintenance activities.

The combination of BIM and IoT enables real-time monitoring of asset performance and condition, this combination supports sustainable design and allows occupants to participate actively in decision-making processes [46]. Data analytics techniques can be applied to analyze integrated data, identify patterns, and generate actionable insights. The integration of BIM and IoT in a maintenance system contributes to improved energy efficiency and sustainability of buildings and infrastructure [47]. IoT sensors can monitor energy consumption patterns, environmental conditions, and occupant behavior. By integrating this data with the BIM model, maintenance managers can identify energy-saving opportunities, optimize energy usage, and implement energy-efficient strategies [48]. Real-time monitoring of energy consumption helps detect abnormalities and wastage, enabling timely corrective actions [49]. Additionally, predictive analytics based on IoT data can anticipate future energy demands, optimize energy distribution, and support demand response initiatives. The result is reduced energy costs, enhanced sustainability, and a greener built environment. The integration of BIM and IoT streamlines facility management processes by improving communication, collaboration, and coordination among stakeholders [50]. The centralized BIM Maintenance System provides a common platform for sharing information, tracking maintenance activities, and managing work orders. IoT-enabled devices and sensors facilitate remote monitoring, diagnostics, and troubleshooting, reducing response times and minimizing the need for physical inspections. Mobile access to the maintenance system allows technicians to access work orders, record maintenance activities, and capture data in the field, improving efficiency and accuracy [51]. These streamlined facility management processes result in improved productivity, reduced administrative overheads, and enhanced overall operational efficiency. One of the challenges in implementing a BIM Maintenance System with IoT integration is the integration and interoperability of data from various sources. BIM models contain geometric, semantic, and behavioral data, while IoT devices generate real-time sensor data. Ensuring seamless integration and interoperability between these different data sources can be complex. It requires establishing standardized data formats, protocols, and interfaces to enable data exchange and synchronization between BIM and IoT systems [50].

Data mapping, transformation, and validation processes may also be necessary to align data structures and ensure data consistency throughout the system [52]. However, the integration of IoT devices into a BIM Maintenance System introduces security and privacy considerations [53]. IoT devices are vulnerable to cyber threats, and unauthorized access to these devices can compromise the integrity and confidentiality of data. It is essential to implement robust security measures, such as secure communication protocols, encryption, access controls, and authentication mechanisms, to protect the IoT infrastructure and the data it generates. Additionally, privacy concerns arise when collecting and sharing data from IoT devices. Compliance with data protection regulations and ensuring the anonymization or aggregation of sensitive information are important considerations in addressing these concerns [54]. Implementing a BIM Maintenance System with IoT integration involves costs and implementation challenges, it also lays the foundation for creating Digital Twins, which are virtual replicas of physical buildings that can predict performance, optimize operations, and facilitate maintenance [55]. The initial investment includes the purchase and installation of IoT devices, sensors, and infrastructure required for data collection. Integration with existing systems, such as BIM software and enterprise asset management systems, may require additional customization and development efforts [56]. Training and onboarding of personnel on the new system and technologies also add to the implementation challenges [57]. It is important to carefully plan and budget for these costs and allocate resources appropriately to ensure successful implementation. However, the successful adoption of a BIM Maintenance System with IoT integration requires adequate training and skill development for the personnel involved [58].

Maintenance managers, technicians, occupants, and other stakeholders need to acquire knowledge and skills in working with BIM and IoT technologies. This includes understanding BIM modeling principles, data management, IoT device installation and maintenance, data analytics, and cybersecurity best practices. Providing comprehensive training programs and resources to upskill the workforce is crucial to maximizing the benefits of the system and ensuring its effective utilization [59]. The first and most important step in implementing a BIM Maintenance System with IoT integration is thorough planning and requirements analysis. This involves defining the goals and objectives of the system, identifying the specific maintenance needs and challenges, and understanding the desired outcomes [60]. Conducting a comprehensive assessment of existing maintenance processes, data sources, and systems will help identify gaps and opportunities for improvement [60]. This planning phase sets the foundation for a successful implementation by ensuring a clear understanding of the project scope, requirements, and expected benefits. All phases of the project, including the planning phase, need Data management and standardization. Data management is a critical aspect of a BIM Maintenance System with IoT integration [61]. Developing a data management strategy is crucial to ensure data quality, consistency, and accessibility. It involves establishing data standards, protocols, and governance processes to manage data throughout its lifecycle. This includes defining data structures, naming conventions, metadata standards, and data validation rules [62].

Data integration and interoperability challenges can be addressed by adopting industry standards, such as the Industry Foundation Classes (IFC) for BIM data and protocols like MQTT or OPC UA for IoT data [63]. Implementing a centralized data repository or database that can handle both BIM and IoT data will facilitate efficient data management. Also, the successful implementation of a BIM Maintenance System with IoT integration requires collaboration and engagement with all stakeholders. This includes maintenance managers, facility managers, IT personnel, technicians, and end-users. Involving stakeholders from the early stages of the implementation process helps ensure that their requirements and concerns are addressed. Regular communication and feedback loops are essential to keep stakeholders informed about the progress, gather their input, and address any issues or challenges. Overall, BIM and IoT integration leads to more efficient project delivery, reduced errors, lower costs, and improved sustainability of buildings. The integration of Building Information Modeling (BIM) and the Internet of Things (IoT) holds significant potential for the construction and operation of buildings. By combining BIM's digital representation of the physical and functional aspects of a building with the connectivity and data exchange capabilities of IoT, a powerful synergy is created. IoT devices and sensors can be seamlessly integrated into the BIM model, allowing real-time data collection and exchange throughout the building's lifecycle. This integration enables enhanced monitoring, control, and optimization of various building systems, including energy management, HVAC, security, maintenance, and occupant comfort. The data collected from IoT devices can be linked to the BIM model, providing a holistic view of the building's performance and enabling informed decision-making. The integration of BIM and IoT enhances collaboration, improves efficiency, and enables data-driven insights and automation, ultimately leading to smarter buildings that are more sustainable, responsive, and user-friendly [64].

3. Problem Statement

The current maintenance systems at most construction companies are plagued by inefficiencies and ineffectiveness, resulting in significant downtime, inflated maintenance costs, and suboptimal resource utilization. There are many challenges in this way that can be summarized as follows:

1. Reactive Maintenance Approach: The absence of proactive measures leads to frequent maintenance, causing costly repairs and production delays.
2. Inventory Management: Unused spare inventory occupies valuable space, presenting a financial burden without providing tangible benefits.
3. Documentation and Reporting: Maintenance staff are overwhelmed by documentation and reporting requirements, compromising accuracy and timeliness.
4. Inefficiency and Ineffectiveness: The overall maintenance system lacks reliability and consistency, contributing to increased downtime and operational costs.

Proposed Solution: To address these challenges, there is a critical need to establish a robust maintenance program centered around preventive maintenance, streamlined inventory management, and technological advancements. Integration of IOT and proposed algorithm with Building Information Modeling (BIM) presents an opportunity to revolutionize maintenance processes. The algorithm and IOT leverage BIM data and sophisticated algorithms to:

1. Optimize Maintenance Planning: By considering asset criticality, maintenance importance, occupancy patterns, and operational constraints, the algorithm generates efficient maintenance schedules, minimizes downtime, and optimizes resource allocation.
2. Budget Allocation: Through analysis of asset condition, expected service life, and budget constraints, the algorithm recommends an optimal maintenance budget allocation. It prioritizes high-impact tasks while ensuring compliance with budgetary limitations.
3. Decision Support: The algorithm provides decision support to facility managers by simulating various scenarios within the allocated budget, enabling informed decision-making, and maximizing maintenance effectiveness.

Implementing this proposed solution promises to streamline maintenance activities, enhance operational efficiency, and optimize budget allocation for building operations with digital and automated data transfer.

4. Advancements in BIM and IoT Technologies

Advancements in BIM (Building Information Modeling) and IoT (Internet of Things) technologies have brought about significant breakthroughs in the construction and building management industries. BIM has evolved to support more complex and sophisticated modeling capabilities, allowing for the creation of highly detailed and accurate digital representations of buildings. Integration with IoT has further enhanced BIM's functionality by enabling real-time data capture from a vast array of sensors and devices. This seamless integration has opened up new possibilities for data-driven decision-making, predictive analytics, and optimized building performance. Advancements in IoT have resulted in more advanced and affordable sensors, improved connectivity, and enhanced data processing capabilities. These developments have made it easier to collect, analyze, and act upon valuable data from various systems within a building, such as HVAC, lighting, security, and occupancy. The combined advancements in BIM and IoT technologies have revolutionized the way buildings are designed, constructed, and managed, leading to increased efficiency, improved sustainability, and enhanced user experiences [65, 66].

The Internet of Things (IoT) can be highly beneficial for construction supervision, enabling real-time monitoring, data collection, and analysis. There are many methods to satisfy and implement IOT with real and sample devices. One of the most effective communication manners is the long-range (LoRa) communication protocols that leverage technology [63]. The main benefit of this method, which considers the basic and important criteria to choose this way for the research is the minimization of consuming energy which reflects the battery lifetime of the system devices [64, 67]. Plus, good securing and monitoring of IoT sensor data with an efficient transmission of IoT sensor data enables the system to operate in both outdoor and indoor scenarios [64]. Whatever, the transceiver interface unit (433 MHz band) for IoT sensor storing data in the cloud. Here are some tools commonly used with (LoRa) IoT devices for construction supervision:

- Sensors: Various sensors are deployed on construction sites to collect data about different parameters. For example, motion sensors can detect movement and activity levels, while temperature and humidity sensors can monitor environmental conditions. Other sensors include vibration sensors, pressure sensors, and proximity sensors. (The transmitter can securely exchange IoT sensor data to the receiver node at about 10 km).
- Wireless Communication: IoT devices in construction often rely on wireless communication technologies such as Wi-Fi, Bluetooth, or cellular networks to transmit data to a central hub or cloud-based platform. This allows for remote access and monitoring. (The receiver node accumulates the sensor data and stores it in the cloud for processing).

- Gateways: Gateways act as intermediaries between IoT devices and the cloud or central server. They collect data from multiple sensors and transmit it to the cloud for analysis. Gateways also provide security features such as encryption and authentication.
- Cloud Computing: Cloud platforms play a crucial role in IoT-based construction supervision. They store and process the data collected from various devices and provide a centralized location for analysis, visualization, and decision-making. Cloud platforms also enable remote access, collaboration, and scalability.
- Data Analytics and Visualization: IoT-generated data needs to be analyzed to extract meaningful insights. Data analytics tools help identify patterns, trends, and anomalies. Visualization tools, such as dashboards and reports, provide a user-friendly interface to monitor and interpret the data in real time.
- Building Information Modeling (BIM): BIM is a digital representation of a construction project that integrates various data sources. IoT devices can feed data into the BIM model, enabling real-time visualization and analysis of the project's progress, resource allocation, and potential issues.
- Remote Monitoring and Control: IoT devices allow construction supervisors to remotely monitor and control various aspects of the construction site. For example, they can remotely adjust lighting, HVAC systems, or security cameras. This enhances efficiency, reduces operational costs, and improves safety.
- Wearables and Personal Safety Devices: IoT wearables, such as smart helmets, vests, or wristbands, can be equipped with sensors to monitor workers' health, location, and movement. These devices can provide early warnings for potential accidents, track worker productivity, and enhance overall safety.
- Energy Management Systems: IoT-based energy management systems help optimize energy usage in construction sites. They monitor energy consumption, identify inefficiencies, and enable automated control of lighting, HVAC systems, and other energy-consuming equipment.
- Asset Tracking: IoT devices can be used to track and manage construction equipment and materials. GPS trackers, RFID tags, or beacons can be attached to assets, providing real-time location data, and enabling better inventory management, theft prevention, and maintenance scheduling.

These are just a few examples of the tools and technologies used in IoT-based construction supervision. The specific tools employed may vary depending on the project's requirements, budget, and desired outcomes. Related to the previous tools, the proposed system includes all the previous components and the direction of the data flows as shown in Figure 7.

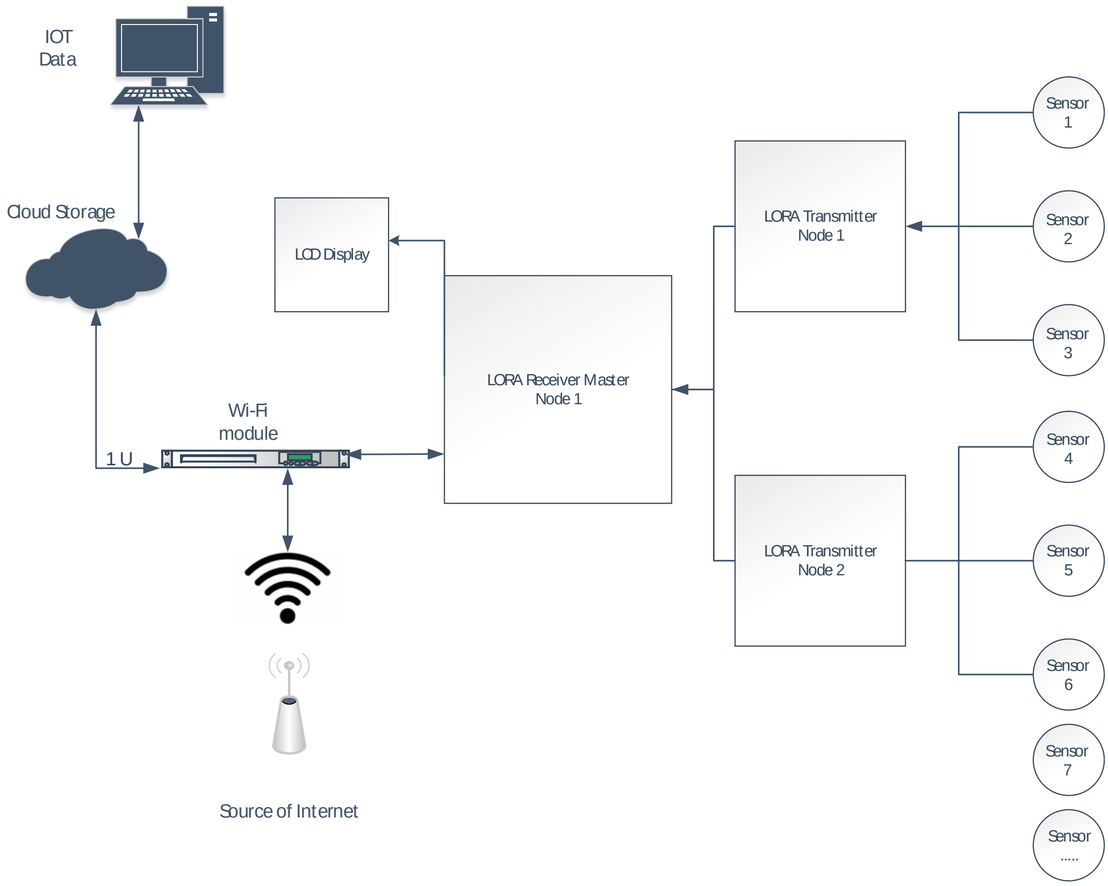


Figure 7. The components of the proposed IOT system

5. Flowchart of the Proposed Workflow

To enhance the current maintenance systems in the industry, a new workflow has been introduced using (IOT the Internet of Things sharing data system in this paper. The setting of this system depends on linking the facilities with sensors, each sensor sends the real data to the nearest transmitter node. Then, the master receivers receive all data from different transmitters to store it and then send it to the LCD and Wi-Fi module. Cloud systems are necessary also for the storage of these big data and recall it anytime. This improvement of this system will increase the accuracy of the data sharing, the real status of the facilities, and the actual situation for all items in the buildings. Figure 8 shows a flowchart for the improvement proposed workflow using Python to achieve the main goal of the research. There are three phases which are, firstly collecting actual data from each item, object, and facility by the mentioned IoT system. The second phase is importing these data to the 3D model with good compatibility and high accuracy. Then the last phase is optimizing and prioritizing the maintenance items related to some factors like dependency, importance, and the allowable maintenance budget at this period. Figure 9 shows the flowchart of each phase of these three phases briefly to create an automated maintenance system. Each one of these steps has its flow chart as shown in Each workflow is presented below to explain procedures for executing business processes to ensure consistency, reduce errors, and deliver high-quality results by creating the model of the building that needs a maintenance system, then exporting data to Excel, after inserting all the data that is needed to calculate then import this to the model and finally the optimum maintenance items list with a good priority, importance, and its items are is ready under condition that is the allowable budget in this maintenance period.

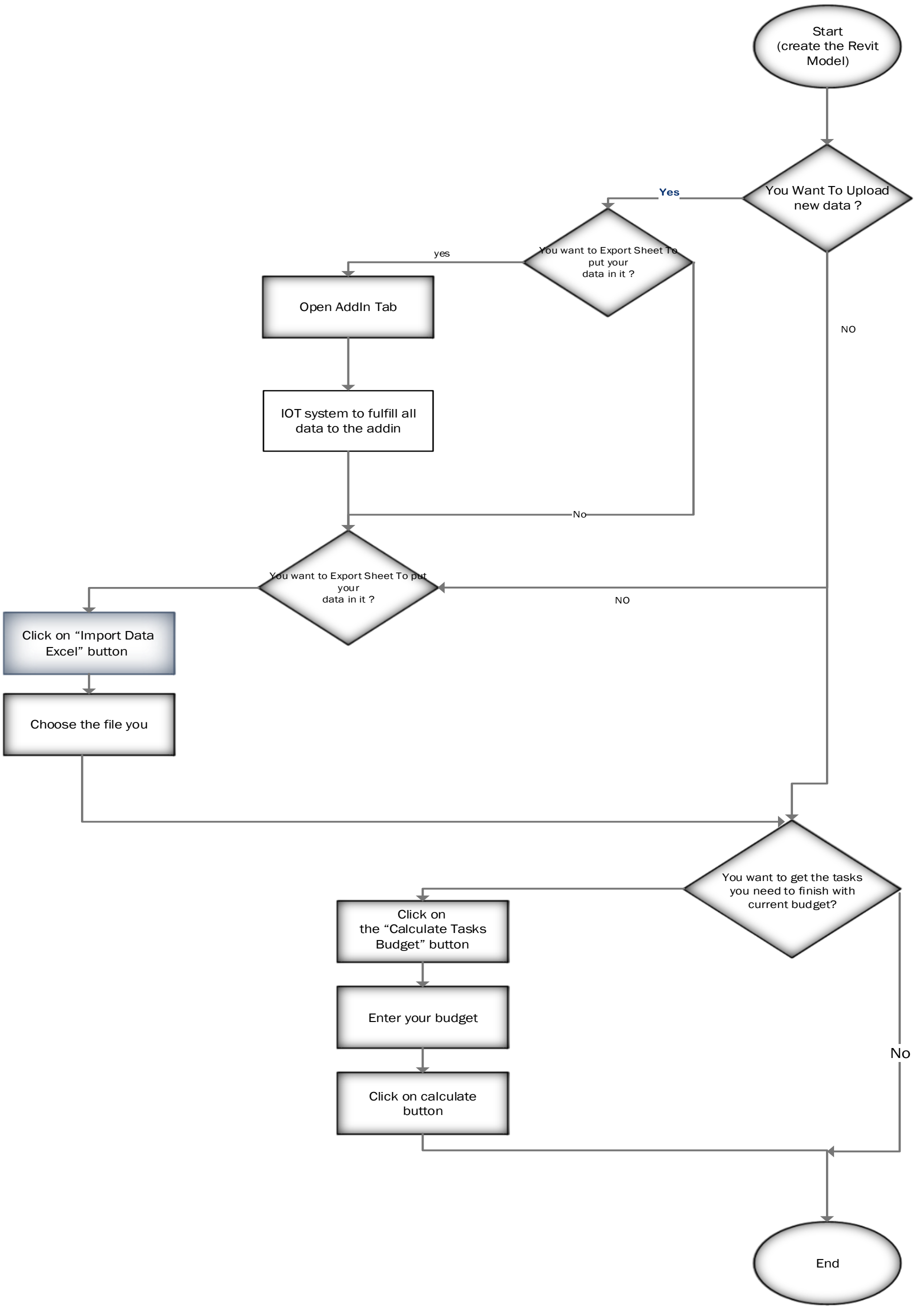


Figure 8. Flowchart for the proposed workflow

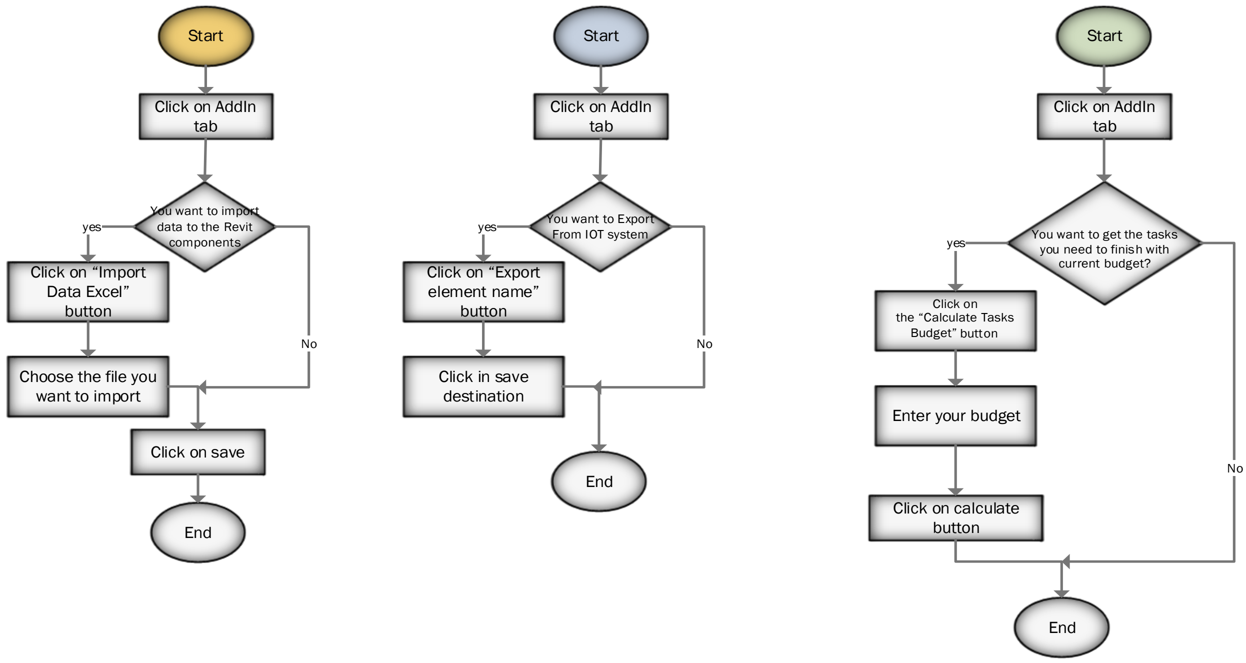


Figure 9. Flowcharts of Export Elements, Import Data, and Calculation of the Budget in the Proposed Framework

A Revit plugin is an additional software component that extends the functionality of Autodesk Revit. These plugins are typically developed by third-party developers or individuals and can be installed within Revit to enhance or introduce new features. Revit plugins are designed to automate repetitive tasks, provide advanced analysis and simulation tools, facilitate interoperability with other software, and offer specialized functionalities for specific industries or disciplines. They vary in complexity, from simple tools that streamline workflows to intricate add-ons that introduce entirely new capabilities. To use a Revit plugin, you generally download and install it from the developer's website or the Autodesk App Store. Once installed, the plugin integrates into the Revit user interface, providing users with additional options and tools. Plugins significantly enhance productivity and expand the capabilities of Revit, allowing users to customize their workflows and adapt the software to their specific requirements. It's essential to ensure that any plugins used are compatible with your version of Revit and come from reliable and trustworthy sources.

Revit elements are the fundamental building components used to create a digital model within Autodesk Revit software. These elements form the basis of the virtual representation of a building or structure. Common examples of Revit elements include walls, floors, roofs, doors, windows, stairs, columns, beams, and ceilings. All of these elements are parametric, meaning they can be easily modified and updated throughout the design process for improved efficiency and consistency. Each Revit element is associated with specific properties and parameters, such as dimensions, materials, and structural characteristics. These properties can be adjusted and customized to accurately represent the unique attributes of the building being modeled. In addition to these standard building components, Revit also offers specialized elements for various disciplines like electrical, plumbing, and mechanical engineering. These discipline-specific elements include pipes, ducts, conduits, fixtures, and equipment, enabling comprehensive design and coordination across multiple disciplines in a project. By utilizing these elements effectively, architects, engineers, and designers can create detailed and precise digital models that facilitate visualization, analysis, and coordination throughout the entire design and construction process.

Furthermore, some Revit plugins offer features for cost estimation or quantity takeoff that can assist with budgeting and maintenance planning. These plugins typically leverage the data within the Revit model to generate cost estimates or material quantities. To utilize such features, you would typically need to install a specific cost estimation or quantity takeoff plugin compatible with Revit. These plugins can vary in terms of cost and functionality, so it's essential to research and find the one that best suits your needs and budget. The ease of using these plugins can significantly simplify tasks, allowing users to link information to specific budgets and determine priorities quickly without engaging in complex processes. This makes it easier for non-specialists to identify optimal solutions.

6. Case study

The integration of BIM and IoT technologies holds great promise for enhancing building performance and facility management. By combining the strengths of the maintenance proposed algorithm with BIM and IoT, organizations can achieve proactive maintenance, energy optimization, occupant comfort, and remote monitoring capabilities. However, challenges related to data interoperability, security, and cost must be addressed for successful implementation. However, the implementation of using the proposed system to capture and store information on facilities through the BIM model helps to improve facilities, facilities maintenance information, and attaching documents in the proposed system. Revit was used to make the 3D BIM of the model and the case study. Also, the proposed system algorithm was written in Python language to prioritize maintenance of the facilities related to the importance factor and dependency within the allowable budget. The proposed algorithm has been added to Revit as the Addin button. The case study is focused on one type of facility which is the alarm of the fire system which is linked by some sensors to register all data related to this facility. So, some different sensors, transmitters, and one receiver, of them are used to create this system. All devices are connected and linked to the 3D Revit model for a 4×5 m^2 room, mainly with a fire alarm (smoke alarm) system to measure the efficiency of the proposed system, step by step for the process of the proposed system shown in Figure 10.

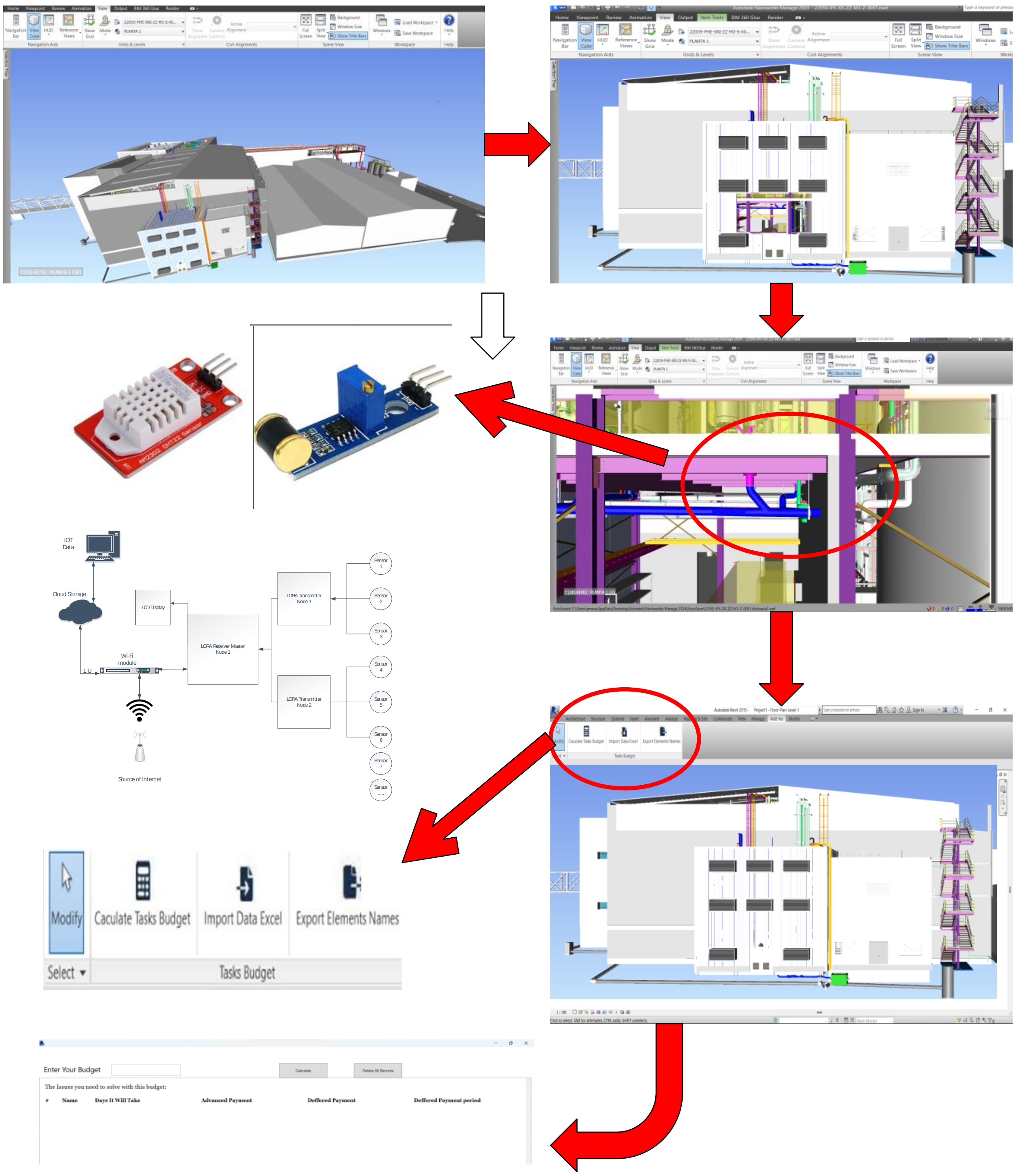


Figure 10. Step by Step for the proposed system applied to a case study

6.1. Step by Step for Implementation of the Proposed System

To implement this add-in, the following are the steps that explain briefly how this plugin works. The procedure of this plugin consists of five main steps, as the following:

Step one, create a BIM (3D, 4D, or 5D) model for the building. The model in this research is done by Revit which is a powerful tool for architects, engineers, and construction professionals as it allows them to design, visualize, and analyze buildings in a 3D, 4D, 5D, and nD environment. This model introduces many services such as visualization, database, sharing data, simulating lighting, ventilation, sustainability, energy analysis, etc.

Secondly, at the same time sensors, transmissions, receivers, and cloud storage for the IOT system are ready to set up and linked together and then feed the BIM model with an update report for each item that is tied by a sensor. Then the previously collected data by the IOT system will integrate with the data collected from the created models including material properties, dimensions, and structural information. This integration of geometry and data enables better coordination and collaboration among project facilities team members.

Thirdly, the date of each item is automated filling all the cells in the Excel sheet under the supervision of a maintenance engineer. The supervisor should also check and fill all the following columns:

An important column**:** each item has its important rank; the rank is divided into ten weights. (one means very low importance and ten means a very important item).

Immediate and related to the time of payment: there are only two weights of this cell which are zero or one. One means the payment will be immediate time without any delay, zero means that the payment will be later.

Postponed by days: this column is linked directly with the previous one, because it asks about the advance payment would be ready to pay and whether the choice was immediate or late.

The deferred column: is the responsible column for the remaining amount of money that will be paid later. The deferred payment period asks about the duration needed to pay the remaining money by days.

Dependency column: the responsible column for linking each item with its components. All these columns appear in Table 1, shown below.

Table 1. Main Columns of the Algorithm

Task	Importance (1 to 10)	Immediate	Postponed (days)	Advanced	Deferred	Deferred payment period (days)	Depends (comma separated)
Fire alarm	8	-----	10	0	10,000	30	Fire system

The fourth step is determining the allowable budget for the facility maintenance during this period. After that, the algorithm is ready now to prioritize the very importance of facilities and their components related to the allowable budget.

The fifth and Final step, a final report is ready related to the previous optimum solution.

6.2. Discussion and Analysis

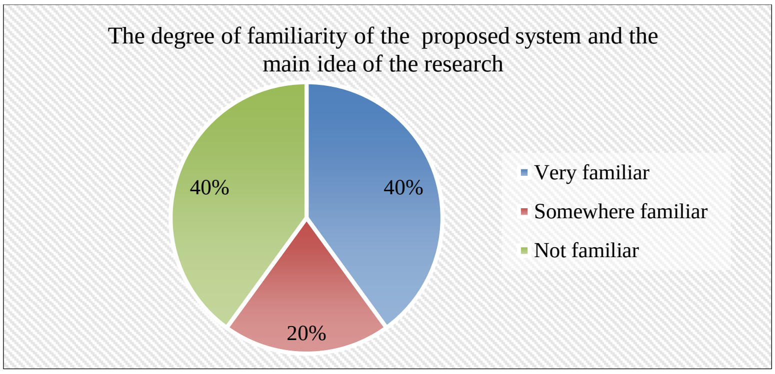
The methodology used to evaluate the proposed system depends on a survey (https://docs.google.com/forms/d/1hACgZLysnqGs3hRgemmNZnZ5i9eNLBWhV9Lsa_eVeug/edit?pli=1) for building information modeling specialists in the Egyptian construction industry. The questionnaire was created to get a clear vision of the most influential populations on integration between BIM and IOT with the proposed maintenance algorithm in Egypt. The next equation was used to determine the sample size.

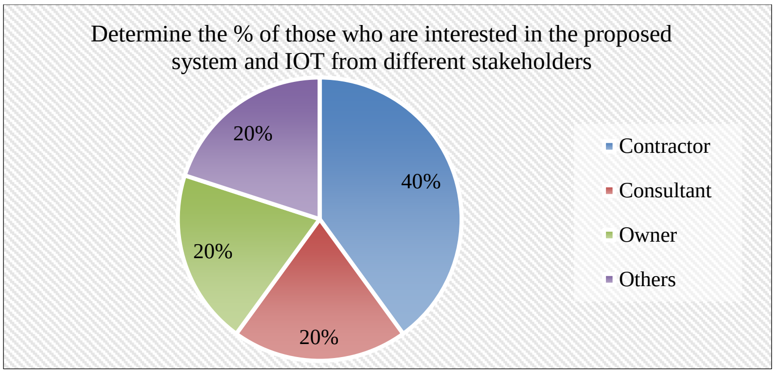
$$Smple\ Size\ = \frac{\frac{z^2 * p(1-p)}{e^2}}{1+(\frac{z^2 * p(1-p)}{e^2 N})} \quad (1)$$

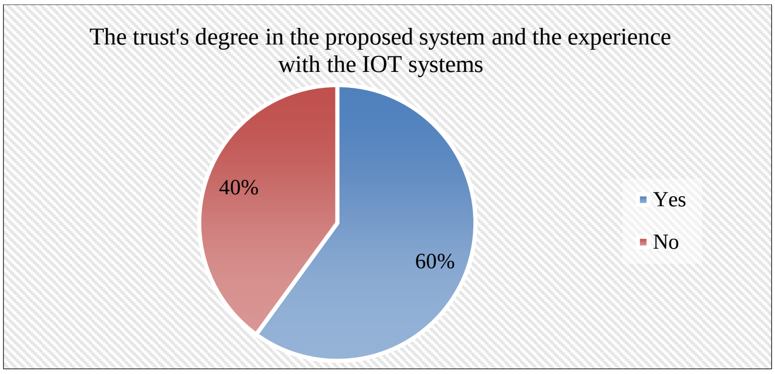
where **N** is population size, **e** is Margin of error (percentage in decimal form), **z** is z-score, **p** is Percentage Value (as a decimal).

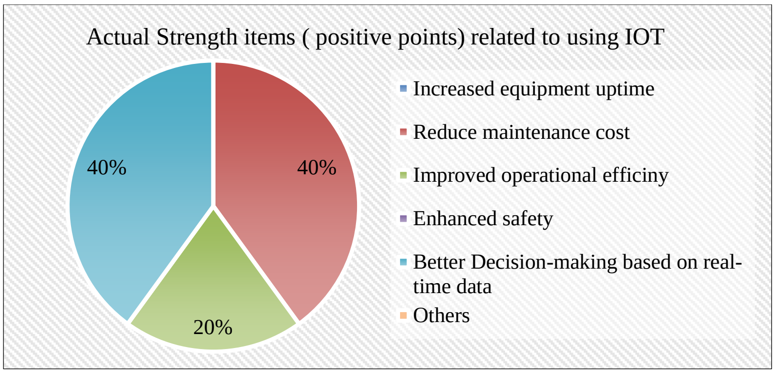
Since the Number of Engineers=850,000, the Confidence level = is 99%, Margin of Error = is 100; Therefore, the sample size = 143 influenced using BIM.

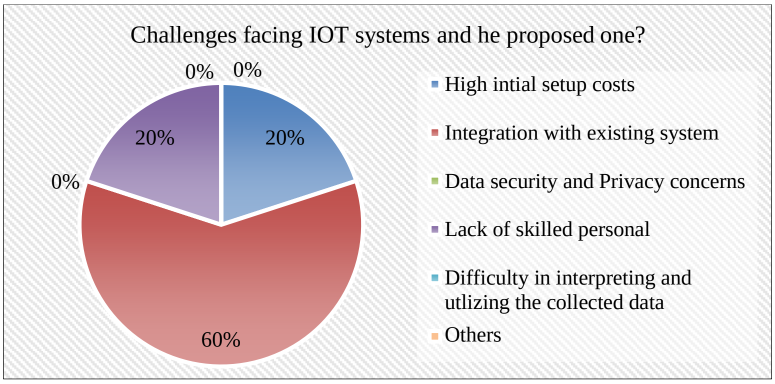
The questionnaire is designed to evaluate the proposed work because it’s very hard to validate it by any previous works or benchmarks. The difficulty of validation comes from the availability of the data needed from previous works or benchmarks to simulate it by the proposed system. Each question in the mentioned questionnaire has a goal or a measurable target to evaluate the proposed system accurately. The below discussion explains briefly each question, its goal or measurable target, and its results. Figure 11 shows the result for each question that was used to evaluate the proposed integrated system.

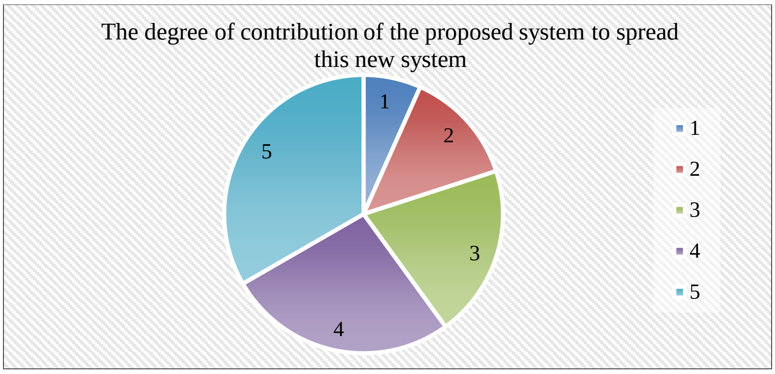

The degree of familiarity of the proposed system and the main idea of the research
40%
40%
20%
Very familiar
Somewhere familiar
Not familiar

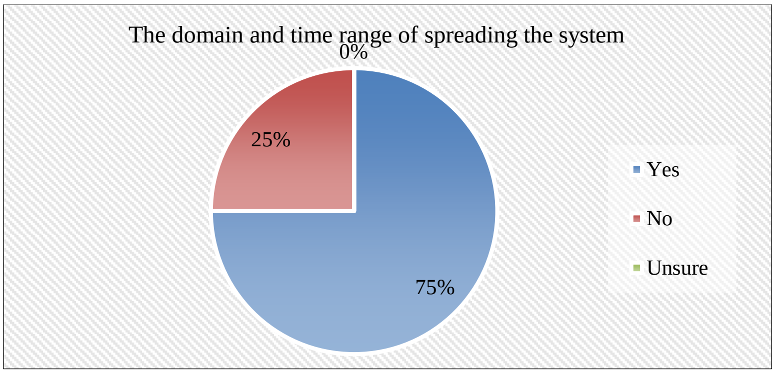

Determine the % of those who are interested in the proposed system and IOT from different stakeholders
20%
40%
20%
20%
Contractor
Consultant
Owner
Others

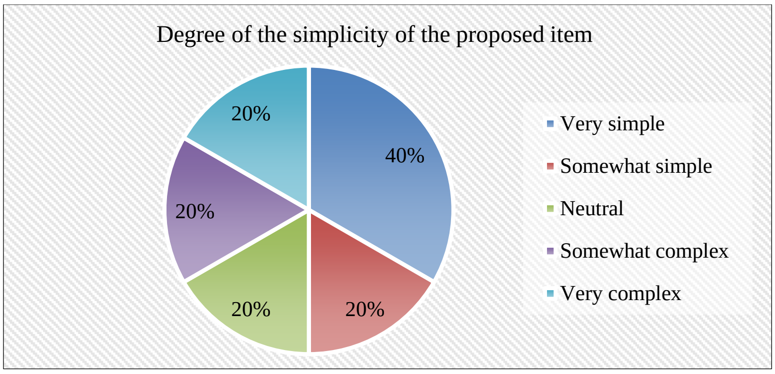

The trust's degree in the proposed system and the experience with the IOT systems
40%
60%
Yes
No

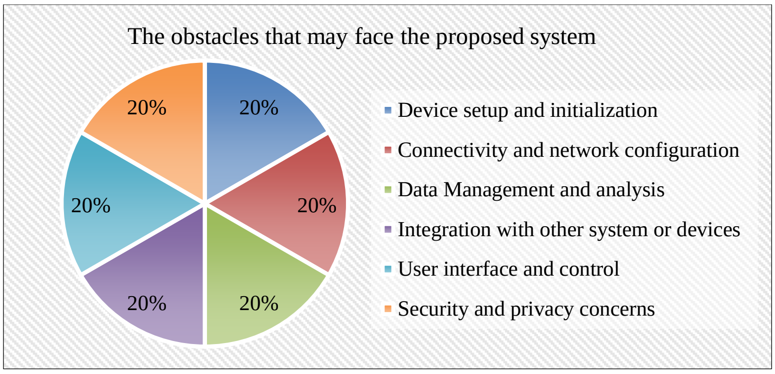

Actual Strength items (positive points) related to using IOT
40%
40%
20%
Increased equipment uptime
Reduce maintenance cost
Improved operational efficiny
Enhanced safety
Better Decision-making based on real-time data
Others

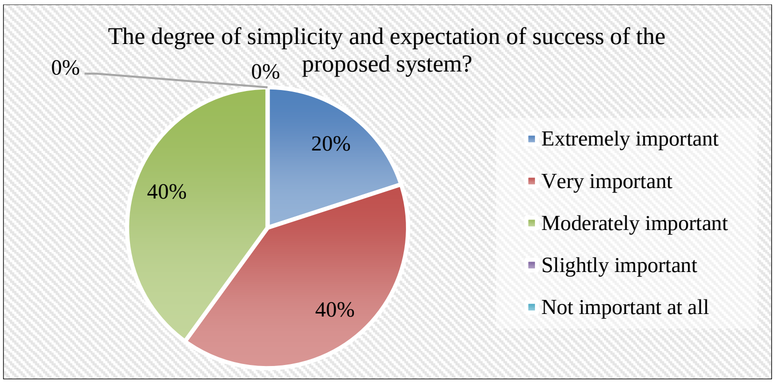

Challenges facing IOT systems and he proposed one?
0%
0%
20%
20%
0%
60%
High intial setup costs
Integration with existing system
Data security and Privacy concerns
Lack of skilled personal
Difficulty in interpreting and utlizing the collected data
Others


The degree of contribution of the proposed system to spread this new system
1
2
3
4
5
1
2
3
4
5


The domain and time range of spreading the system
0%
25%
75%
Yes
No
Unsure


Degree of the simplicity of the proposed item
20%
40%
20%
20%
20%
Very simple
Somewhat simple
Neutral
Somewhat complex
Very complex


The obstacles that may face the proposed system
20%
20%
20%
20%
20%
20%
Device setup and initialization
Connectivity and network configuration
Data Management and analysis
Integration with other system or devices
User interface and control
Security and privacy concerns


The degree of simplicity and expectation of success of the proposed system?
0%
0%
20%
40%
40%
Extremely important
Very important
Moderately important
Slightly important
Not important at all

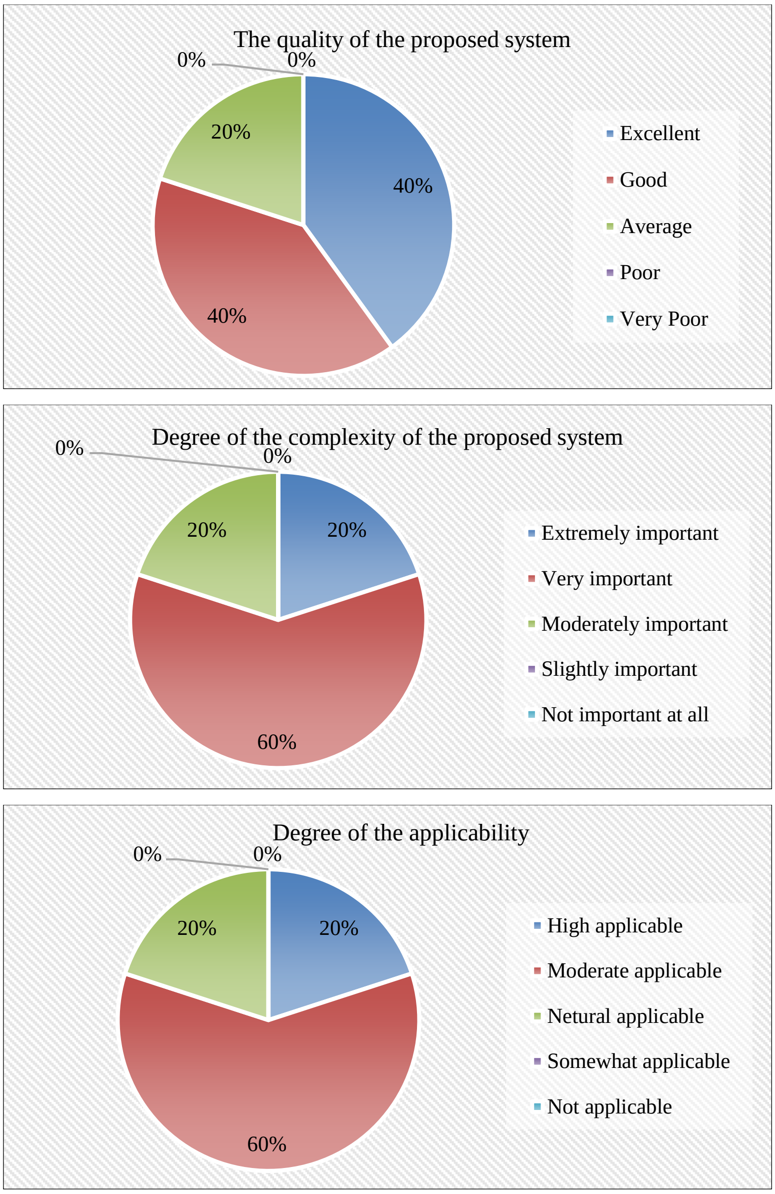


Figure 11. Results of the Questionnaire by Expertise on the Proposed Integration System

The goal of the first question is "determining the degree of familiarity of the IOT system and the main idea of the research". The results mention about 40% for the familiar and the same percentage for the non-familiar, with 20% somewhat familiar. The second question covers "the percentage of those who asked about the proposed system and IOT to cover all key players in different projects". 40% of participants were contractors, and then 20% for each remaining category were consultants, owners, and others, respectively. The third question covers the experience with using IoT systems, which reflects the trust's degree on the proposed system from the questionnaire. About 60% of surveyors had experience with IOT, and the remaining were first-time with IoT. The target of the fourth question was to measure the suitability of the proposed system with different types of maintenance. The results show 20%, 40%, and 40% for preventive maintenance, predictive maintenance, and asset tracking, respectively. The next question focuses on "positive points related to using IOT in automation construction". Better decision-making based on real-time data acts about 40% of the surveyor's suggestions. Also, 40% to reduce maintenance costs, and the remaining 20% for improved operation efficiency. 60% for integration with the existing system, 20% for lack of skilled persons, and 20% for others were the results of "Challenges facing the systems" in the sixth question. The seventh one asks about "the degree of satisfaction with the IOT-based maintenance solutions". The 8th question covers the readiness of construction firms to implement new systems, as proposed in this research. The results were surprising because about 70% said yes and 30% said no. That was mentioned to qualify the proposed system. The 9th question deals with the "Degree of simplicity of the proposed item". 40% said it's a very simple one, and 20% said that the system is a complex one. Also, 20% said that is a somewhat simple system, and 20% said it's a neutral system. The 10th one deals with "the obstacles that may face the proposed system". The results illustrate that there are five main obstacle categories, of which 20% are device setup and initialization. Also, 20% are for security and privacy concerns. 20% for connectivity and network configuration, 20% for integration with other devices, and finally 20% for data analysis and management. "How important is simplicity in

IOT solutions to you?" was the 11th question, with 20% for extremely important, 40% for moderate, and finally 40% for the very important category. The 12th question asks about "The quality of the proposed system". The question gets 40% for excellent and good, respectively. Then 20% for the average category. The 13th one measures the "degree of complexity of the proposed system". About 60% said that it was very important, 20% said it was moderately important, and the same percentage

7. Conclusions

Maintenance of buildings is one of the big problems facing owners, facility managers, engineers, and many stakeholders. The revolution with touchable growth of technology such as Artificial intelligence (AI), Digital Twins, Building Information Modeling (BIM), and the Internet of Things (IoT) guides us to use these technologies in different fields, mainly improving the maintenance performance of buildings. The integration of BIM and IoT technologies holds great promise for enhancing building performance and facility management. By combining the strengths of BIM and IoT, organizations can achieve proactive maintenance, energy optimization, occupant comfort, and remote monitoring capabilities. However, challenges related to data interoperability, security, and cost must be addressed for successful implementation.

This paper proposed a workflow by integrating BIM and an algorithm for Maintenance System with IoT and highlighted its potential to enhance building performance and facility management. Also discussed were the implications of BIM and the proposed algorithm of Maintenance System with IoT integration for various stakeholders, including building owners, facility managers, and occupants, using a case study. The findings collected by a questionnaire for some experts emphasize the importance of adopting this integrated approach to optimize building operations, improve maintenance practices, and create sustainable and intelligent built environments. The results of the questionnaire analysis showed the qualifications and performance of the proposed system. Finally, the following can be summarized as the main conclusions of the research:

- The proposed system (IoT, maintenance algorithm, and BIM) is qualified, with good quality, applicable, and suitable for improving building performance.
- The proposed system can be used for different types of maintenance, such as predictive maintenance. Asset tracking, and preventive maintenance.
- The proposed system reduces maintenance costs, enhances Decision-making based on real-time data, and improves operational efficiency.
- Integration with the existing system, high initial setup costs, and a lack of skilled personnel are the highest challenges facing the spread of the proposed system.
- Device setup and initialization, connectivity with network configuration, Data Management, Data Analysis, Integration with other systems or devices, user interface and control, and security and privacy concerns are the main obstacles to the proposed system.
- Integrating a Building Information Modeling (BIM) Maintenance System with the Internet of Things (IoT) can have several implications for owners, they improve asset value and performance, reduce operational costs, and enhance decision-making capabilities due to real-time data and analytics.
- Streamlined maintenance processes, predictive maintenance capabilities, and better management of building systems leading to increased efficiency and reduced downtime are the biggest implications for facility managers related to this proposed integrated system.
- Finally, occupants with this integration and the proposed system might experience improved comfort and safety, as well as a more responsive and adaptive building environment.

8. Declarations

8.1. Author Contributions

Conceptualization, A.E. and M.A.M.; methodology, A.E.; formal analysis, M.A.M.; investigation, M.A.M.; resources, A.E. and M.A.M.; data curation, A.E.; writing—original draft preparation, A.E., M.A.M., and A.E.H.; writing—review, A.E., M.A.M., and A.E.H.; supervision, A.E.H.; funding acquisition, A.E., M.A.M., and A.E.H. All authors have read and agreed to the published version of the manuscript.

8.2. Data Availability Statement

The data presented in this study are available in the article.

8.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

8.4. Conflicts of Interest

The authors declare no conflict of interest.

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