Proposed BIM-CMMS Framework for Facility Management in Digital Transformation Era

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Abstract

Digital transformation is crucial for construction projects due to its numerous benefits, including increased productivity and improved collaborative environments. This research discusses the stages, components, and strategies that lead construction projects to digital transformation. Furthermore, it aims to advance the technological process of 3D digitization in built environments and simplify management operations in the construction phase through digital methodologies. To achieve this, an integrated framework combining Building Information Modeling (BIM) and Computerized Maintenance Management Systems (CMMS) applications is proposed. By using these integrated models, facility management is simulated within a 3D environment via a CMMS. The results indicated that digital models and BIM could indeed be integrated through direct linkage mechanisms without compromising the efficiency of information synchronization and management. This 3D representation allowed for a better understanding of dynamics and spatial interactions, facilitating quicker identification of potential issues and more efficient maintenance operations. Therefore, integrating these advanced digital models not only improves operational efficiency, but also enhances collaborative environments. The proposed model represents what is known as a Digital Twin, a comprehensive system that manages all information flows associated with a building throughout its lifecycle.

Key words: Digital Transformation; Facility Management; Digital Twin; Maintenance; Building Information Management

1. Introduction

In recent times, as the times shift to the digital age, and as new technologies increasingly replace humans in many tasks, creative skills have become more important for engineering innovation. This is perhaps a reversal of the traditional focus on engineering development, which is necessary to keep up with the changes brought by digital transformation. [7]

Each project requires contracting with different parties, different visions, and goals in order to obtain the final product that has been completed within the previously specified constraints of time, cost and quality. This contract usually ends when the project is completed, and this often results in many disputes.[6]

Therefore, for moving forward, the final phase of the project must be addressed. Where, it is defined by BIM as the LOD 500. Furthermore, it is well known as “Operational Phase” and it is not that easy since at this stage, the focus is on the workflow of the facilities management during its operation and investment.[1]

The research aims to strengthen efficiency of the operational phase by linking a case study model of Building Information Modeling (BIM) systems with an information exchange platform, and extracting the desired benefit. Moreover, it investigates the catalysts of transformation in engineering innovation, and the manner in which it has progressively compelled engineers to reevaluate their approach to problem-solving [21]. In conjunction with this

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transformation, there is an intensified emphasis on the competencies and capabilities essential for achieving success as engineering innovators.

These indicators were established through a comprehensive scientific analysis of extant research and are concisely encapsulated in the following manner:

1. Improving information management:

- Providing accurate data: Allows all information related to the building to be stored in one place, making it easy to access when needed.
- Updating information: Data can be updated continuously, ensuring that all stakeholders are working on the latest information.

2. Increased operational efficiency:

- Performance analysis: Data can be used to analyze building performance and discover areas for improvement, such as energy consumption.
- Maintenance planning: BIM helps in proactively scheduling maintenance, reducing unexpected breakdowns and increasing the life of the building.

3. Enhance collaboration between teams:

- Better communication: BIM facilitates the exchange of information between different teams (such as engineering, maintenance, and management), which enhances collaboration and coordination.
- Reduced errors: Thanks to shared information, errors resulting from misunderstanding or lack of information are reduced.

The manuscript proceeds with an extensive examination of the existing literature pertinent to the topics of facility management and digital transformation. Subsequently, it delineates the research approach and methodological framework employed in the study. Thereafter, it elucidates the findings, accompanied by a thorough analysis of the proposed framework. Ultimately, it draws conclusions and posits recommendations for prospective research endeavours.

2. Literature Review

I. Facilities Management (FM) :

Traditionally Facilities Management (FM) is recognized as a “non-core” part of the construction sector, focused mainly on supportive services with no real business value. Due to existing inefficiencies, the FM importance is far from being appreciated [20].

FM constitutes for over 80% of the total project cost and hence its imperativeness ought to be acknowledged [4]. Conventionally the handover process takes up to several weeks for information to be collected and entered into FM systems [22]. The performance gap existing in FM practices unable to reap the benefits resulting from the efficient post-construction stage.

BIM 6D (sixth-dimensional Building Information Modeling) refers to the post-construction phase (O&M) of the building, however for many 6D stands for ‘sustainability’ mostly [15]. Indeed, both definitions are correct since BIM 6D is primarily oriented to improve FM practices efficiency, which apparently overlaps with the life-cycle performance of the building, hence its sustainability.

▪ BIM-based facility maintenance management :

Building Information Modeling (BIM) has the potential to significantly augment current computerized maintenance management systems (CMMSs) and facility management systems (FMSs) by facilitating improved information interoperability and enhanced visualization capabilities. In order to better utilize the rich information of BIM, its tools can be integrated with existing facility management systems [14]. A BIM-based framework was proposed by Chen et al. [5] to integrate BIM software with FM software to enable automatic scheduling of maintenance work order.

Information is critical for supporting efficient building maintenance management and daily operations [2]. A substantial amount of scholarly investigation has been undertaken to enhance the interoperability of information and the transfer of data within the context of Building Information Modeling (BIM). An IFC-based data model was proposed in 2001 to achieve integrated maintenance management for a roof system [8]. Two years later, the same research group presented a general object-based schema for asset maintenance management, which could support data transfer from the construction to the operations and maintenance (O&M) stage [9]. Furthermore, since

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the introduction of the Construction Operations Building information exchange (COBie) standard, people have been able to store maintenance information in BIM in a structured way [6]. COBie has been proven capable to improve the interoperability between BIM and CMMSs/FMSs [3].

- **Standardize the format of information exchange and transfer :**

The BIM concept conveys certain principles that shape an attitude towards building asset life cycle being strongly supported by technological advancements. The clue of BIM 6D is to integrate BIM model with existing FM software packages and hence assure a seamless flow of information with BIM model as a knowledge-based platform. However, due to the magnitude of this change the relevant software applications are still being implemented in isolation, deepening the interoperability issue [21]. COBie, as a simplified subset of IFC format, was created to tackle these inefficiencies, though the practitioners still find some space for further improvements.

The utilization of a cloud-oriented methodology for the augmentation of interoperability is frequently addressed within scholarly discourse, and is regarded as a promising trajectory for forthcoming advancements. As proposed by Redmond [17] the industry should focus on developing web-based BIM exchanges using the cloud platform incorporating both IFCs and SML (Simple Markup Language) files.

II. Digital Transformation :

The concept of "digitalization" pertains to the application of diverse digital technologies and web-based services that facilitate the storage, transmission, and interchange of substantial volumes of data, in addition to assisting, replacing, or cooperating with individuals in professional environments [7]. In this regard, digital transformation is viewed "…as a malleable form of organizing that enables continuous adaptation for influential digital ecosystem orchestration [10]. Digital transformation undergoes three different phases that are digitization, digitalization and digital transformation. Digital competition, digital technology and digital customer behavior are the external drivers of digital transformation [19].

- **Digital Transformation in the Construction Sector :**

Digital transformation enables construction firms to select the most appropriate technological solutions for their projects while also identifying the critical areas that necessitate increased attention to foster enhanced productivity and operational efficiency. Among the various technological advancements, building information modeling (BIM), three-dimensional printing, laser scanning, augmented reality/virtual reality (AR/VR), digital twins, and the internet of things (IoT) significantly contribute to the digital transformation of the construction industry [13]. The utilization of technology has the potential to assist enterprises within the construction sector in attaining their project objectives through the organization of processes, the integration of systems, the enhancement of cost-reduction methodologies, among other strategies. Nevertheless, it is imperative to take into account a multitude of factors when striving for a comprehensive transformation.

According to research done by the McKinsey Global Institute, digital transformation in the construction industry can result in 14 to 15 percent productivity gains and 4 to 6 percent cost reductions [12]. They suggest construction companies focus on fixing the current pain points instead of just installing some IT solutions. Another suggestion in the same report highlights the importance of reskilling and restructuring the engineering teams for better digital transformation. Due to the fragmentation along the project lifecycle, it requires coordinating among the organization to manage the change during digital solutions implementation of a construction project. However, that can be hard considering the short period given for the completion of a project [12].

- **Digital Twin :**

With the increased interest in Digital Twin, the construction industry began to follow suit in this area. While the definition of Digital Twin might seem similar to BIM, construction researchers highlighted the differences between these two concepts. Khajavi et al. [11] stated that although BIM and Digital Twin have similarities, they differ in multiple ways such as the purpose, technology, the end-users, and the facility life stage. The applications of BIM have been extensively investigated in the body of knowledge of construction.

While BIM is employed by architects and engineers throughout the design phase of the project to execute clash detection and material quantification, and by contractors to facilitate production oversight, constructability assessment, and site as well as safety management [18], it does not integrate with real-time data [11]. Digital Twin, however, is implemented to monitor the physical asset and improve its operational efficiency by analyzing real-time parameters [11]. The Digital Twin of a building for example can be used for operation and maintenance purposes by allowing facility managers to perform what-if analysis, ultimately enhance energy utilization, and improve residents' comfort [11]. The data collected using a Digital Twin during the operation and maintenance phase of the facility can be saved in a database to be used by architects on future projects [16]. Most applications

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of Digital Twin in construction are in the operation and maintenance phase of the facility whether the project is residential or industrial.

3. Research Methodology

Through the introduction of an integrative framework that amalgamates building information modeling with computerized maintenance management systems, which constitutes a methodology that is pertinent across diverse geographical settings and architectural designs, it is imperative to maintain transparency in its formulation; thus, it was implemented in the context of a particular case study.

This is done through three basic requirements that were worked on:

1- A BIM model of the building that provides complete information about the building and is constantly updated to form a digital twin identical to the facility, as digital twins enable the simulation of different scenarios that may arise in their physical counterparts, which facilitates the exploration and analysis of management tasks. This ability enhances decision-making processes.

2- A data source that can provide both engineering information and semantic information for facilities to help users understand the facilities and their condition.

3- An easy-to-use user interface that allows facility management employees to read and update facility information conveniently.

To enhance technological development in digitization, this paper proposes a comprehensive systematic process for integrating digital CMMS and BIM models. The goal of this integration is to achieve effective interoperability between the two platforms, using tools compatible with computerized maintenance management systems (CMMSs). This integration takes advantage of advanced 3D navigation within the built environment, allowing stakeholders to interact with and analyze data more intuitively. By enhancing this interoperability, the research aims to enhance management practices and improve operational outcomes in built environment applications.

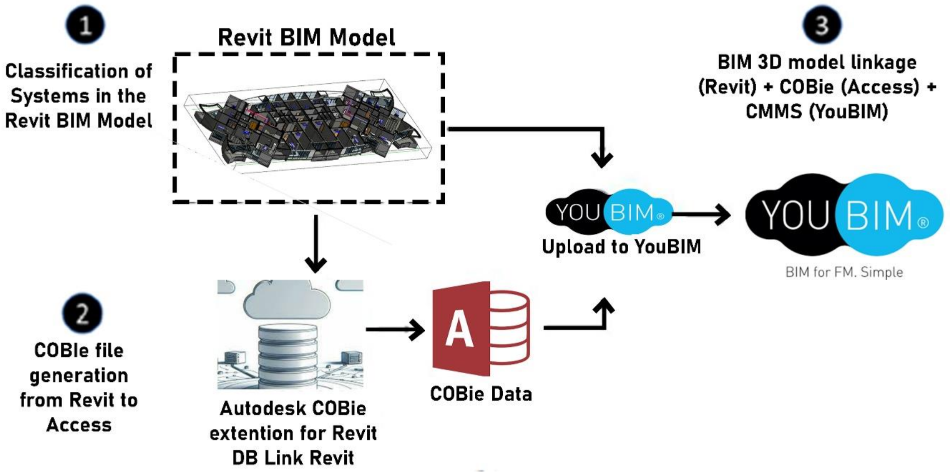

Figure 1. Schematic representation of the stages of work in the study

- In the first phase, authors will work on developing the Revit model for the floor on which the study will be applied by adding all the information to the Revit model.

- In the second phase, the model will be linked with a database: according to the (Construction Operation Building information exchange) COBie standard by inserting the DB link tool into the Revit program and exporting the information to an external database.

- In the third phase, a 3D simulation shall be employed to oversee the upkeep of the building's infrastructure by transferring all pertinent documents to the YouBIM platform, thereby acquiring a user-friendly interface that facilitates interaction and updates of the facility's information for all personnel and users.

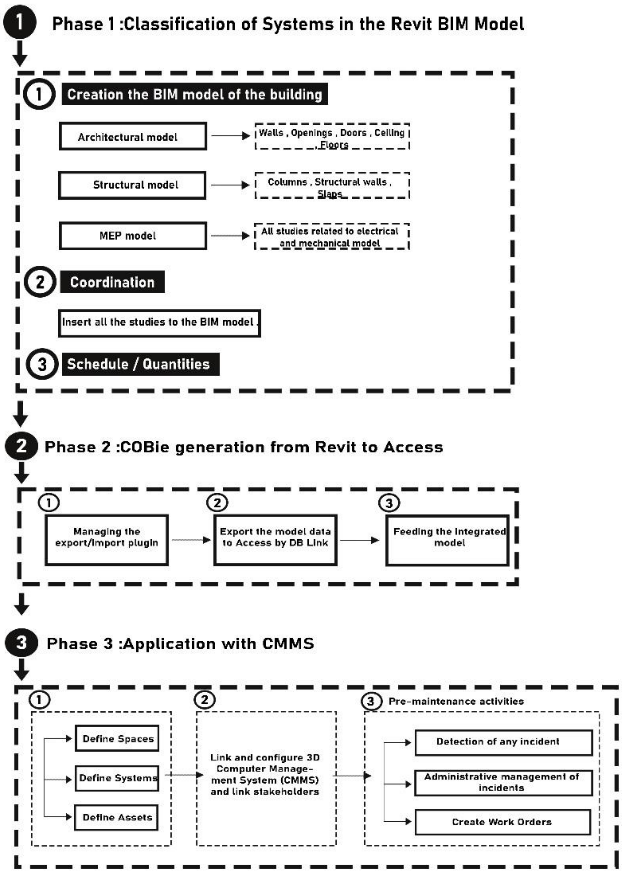

Figure 2. Schematic representation of the three proposed phases of the Building Maintenance Management Simulation – Phase (1)

- **Phase 1 : Classification of systems within the Revit BIM environment:**

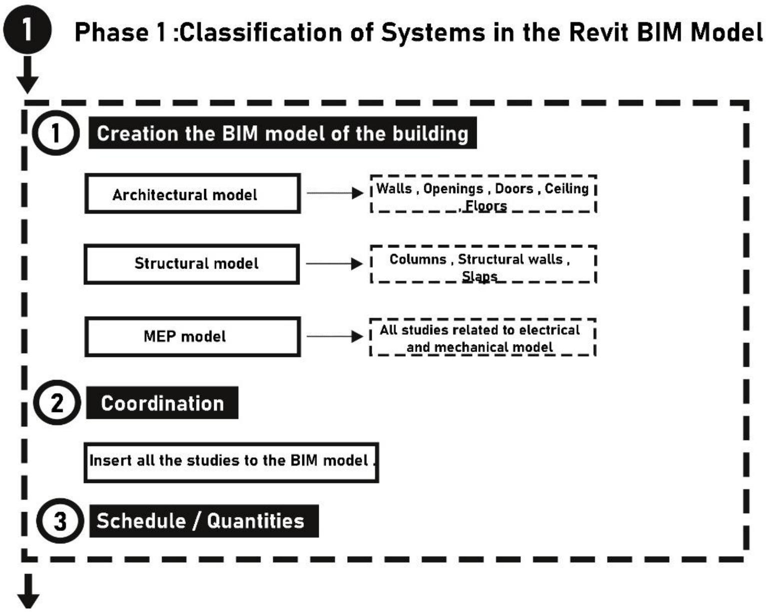

Figure 3. Schematic representation of the three proposed phases of the Building Maintenance Management Simulation – Phase (1)

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There is no doubt about the importance of having a model for each building that contains all its information and developments throughout its entire life cycle by entering the actual information for all elements and equipment and recording information about everything that has been updated under the items (installation\replacement\restart) and also (existing\under installation).

So in step (1), a residential floor was chosen from a tower currently being built in Marota City in Syria, then the focus in step (2) was on developing studies for this floor for most specializations in addition to ensuring that the elements and equipment used in these studies are available in the current market. This platform contains products for companies that provide their services in the Syrian Arab Republic, and these elements were approved after ensuring that they contain all the information required to complete the model in a way that serves its use in the facilities management phase.

Then in step (3), the authors meticulously organized the tables pertaining to the elements whose progress is to be monitored throughout the comprehensive life cycle of the project. It is noteworthy that the crucial components authors intend to incorporate into the tables include: Phase Created and Comment, which shall be amend in order to assess the viability of the integration process with the database.

Because of the first stage, authors have a 3D model of the floor containing all its information, in addition to tables containing information about the proposed model. In the case study, the categories that authors chose to schedule are wall quantities, air conditioning and lighting devices that were added from the previously mentioned platform, external air conditioning units, and internal air conditioning units.

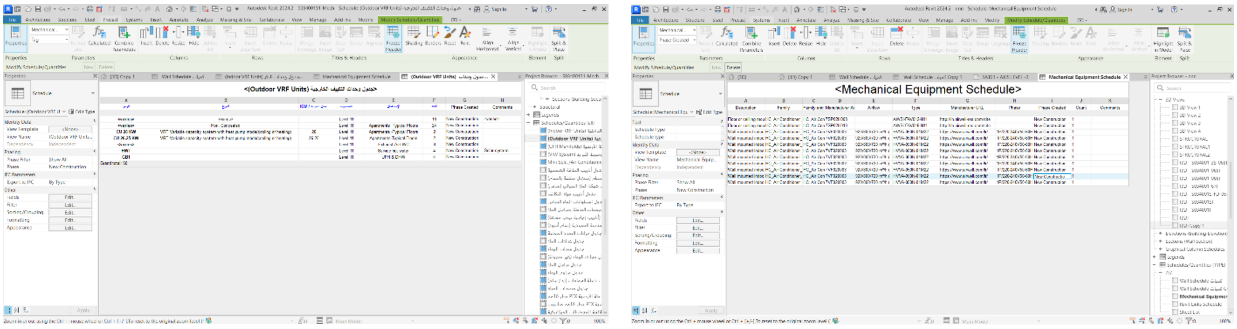


Figure 4. Mechanical equipment schedule

- **Phase 2 : COBie generation from Revit to Access :**

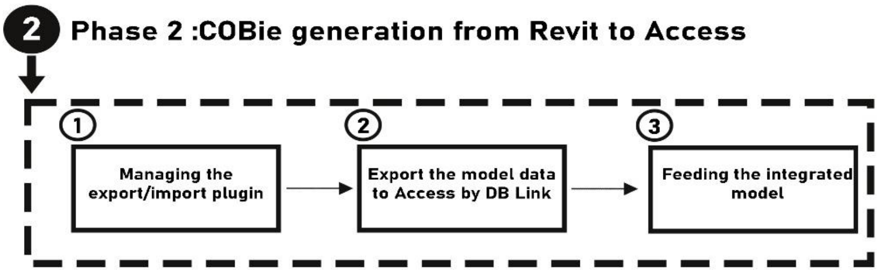
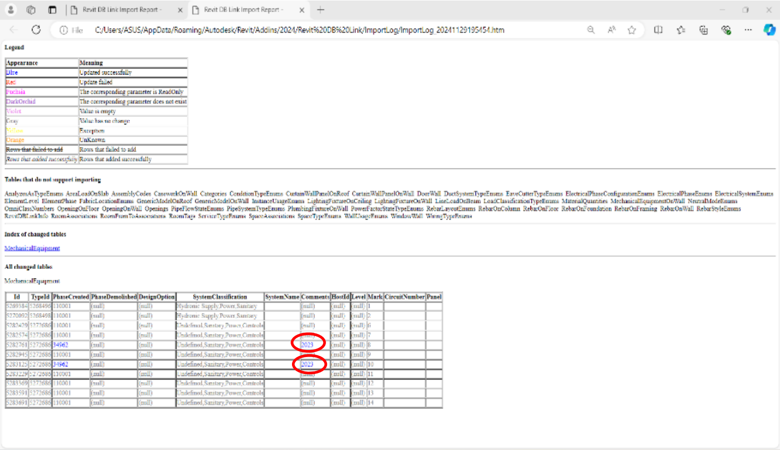


Figure 5. Schematic representation of the three proposed phases of the Building Maintenance Management Simulation – Phase (2)

COBie (Construction Operation Building Information Exchange) is a data exchange standard that allows information to be transferred from a BIM model to an operations and maintenance management model. It identifies lists and classifies graphical unit information in an Access data file to identify assets and systems within a CMMS application. It is important that a common code be assigned between both Revit and YouBIM software platforms.

To solve the problem of dealing with the huge database stored on the BIM model, as BIM applications such as Revit do not have the tools that help control the database, so in step (1) authors linked the model with the Access database program via DB Link. Where, DB Link is an interoperability tool between Revit and an ODBC or Microsoft Access database, which is what authors, will need interoperability to link the database

In step (2), all model information will be exported in the form of tables that users can view and modify via Microsoft Access. Then, when returning to the Revit program, the file will have to be re-imported to make the modifications. This information will be automatically modified on the tables and on the information of the elements within the parameter of each element. In addition to a report on the modifications that were made, which could be shared with any party. This report will show the modifications with a unified color code as follows:



Legend

Appearance	Meaning
Blue	Updated successfully
Red	Update failed
Fuchsia	The corresponding parameter is ReadOnly
DarkOrchid	The corresponding parameter does not exist
Violet	Value is empty
Gray	Value has no change
Yellow	Exception
Orange	UnKnown
~~Rows that failed to add~~	Rows that failed to add
Rows that added successfully	Rows that added successfully

Tables that do not support importing

AnalyzesAsTypeEnums AreaLoadOnSlab AssemblyCodes CaseworkOnWall Categories ConditionTypeEnums CurtainWallPanelOnRoof CurtainWallPanelOnWall DoorWall DuctSystemTypeEnums EaveCutterTypeEnums ElectricalPhaseConfigurationEnums ElectricalPhaseEnums ElectricalSystemEnums ElementLevel ElementPhase FabricLocationEnums GenericModelOnRoof GenericModelOnWall InstanceUsageEnums LightingFixtureOnCeiling LightingFixtureOnWall LineLoadOnBeam LoadClassificationTypeEnums MaterialQuantities MechanicalEquipmentOnWall NeutralModeEnums OmniClassNumbers OpeningOnFloor OpeningOnWall Openings PipeFlowStateEnums PipeSystemTypeEnums PlumbingFixtureOnWall PowerFactorStateTypeEnums RebarLayoutEnums RebarOnColumn RebarOnFloor RebarOnFoundation RebarOnFraming RebarOnWall RebarStyleEnums RevitDBLinkInfo RoomAssociations RoomFromToAssociations RoomTags ServiceTypeEnums SpaceAssociations SpaceTypeEnums WallUsageEnums WindowWall WiringTypeEnums

Index of changed tables

MechanicalEquipment

All changed tables

MechanicalEquipment

Id	TypeId	PhaseCreated	PhaseDemolished	DesignOption	SystemClassification	SystemName	Comments	HostId	Level	Mark	CircuitNumber	Panel
5269384	5268496	110001	(null)	(null)	Hydronic Supply,Power,Sanitary		(null)	(null)	(null)	1		
5270092	5268498	110001	(null)	(null)	Hydronic Supply,Power,Sanitary		(null)	(null)	(null)	2		
5282429	5272686	110001	(null)	(null)	Undefined,Sanitary,Power,Controls		(null)	(null)	(null)	6		
5282574	5272686	110001	(null)	(null)	Undefined,Sanitary,Power,Controls		(null)	(null)	(null)	7		
5282761	5272686	34962	(null)	(null)	Undefined,Sanitary,Power,Controls		2023	(null)	(null)	8		
5282945	5272686	110001	(null)	(null)	Undefined,Sanitary,Power,Controls		(null)	(null)	(null)	9		
5283125	5272688	34962	(null)	(null)	Undefined,Sanitary,Power,Controls		2023	(null)	(null)	10		
5283229	5272688	110001	(null)	(null)	Undefined,Sanitary,Power,Controls		(null)	(null)	(null)	11		
5283369	5272686	110001	(null)	(null)	Undefined,Sanitary,Power,Controls		(null)	(null)	(null)	12		
5283591	5272686	110001	(null)	(null)	Undefined,Sanitary,Power,Controls		(null)	(null)	(null)	13		
5283691	5272686	110001	(null)	(null)	Undefined,Sanitary,Power,Controls		(null)	(null)	(null)	14		

Figure 6. Database modification report

- **Phase 3 : Application with CMMS :**

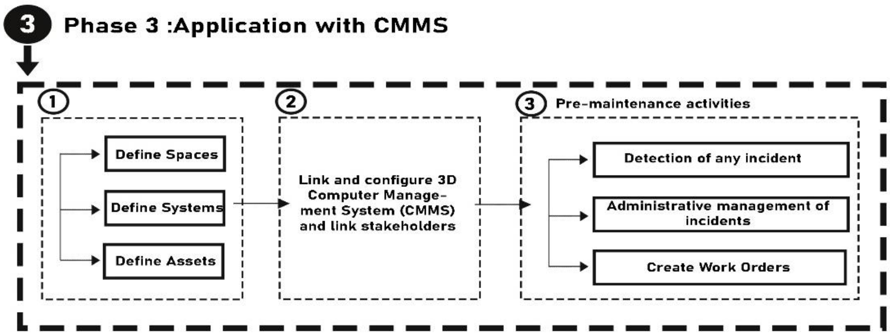


Figure 7. Schematic representation of the three proposed phases of the Building Maintenance Management Simulation – Phase (3)

Step (1) is applied directly to the equipment group while modeling it in Revit, several assets are identified and grouped, which are assigned a “name and classification”, thus forming the system.

-Mechanical installation diagram of the entire floor, showing the arrangement and integration of the various components.

-Perspective of the heating and cooling system and its subsystems within the same floor, providing a detailed perspective of the components and configurations to enhance the understanding of the system’s functions and design.

Figure 8. Mechanical study modeling and design

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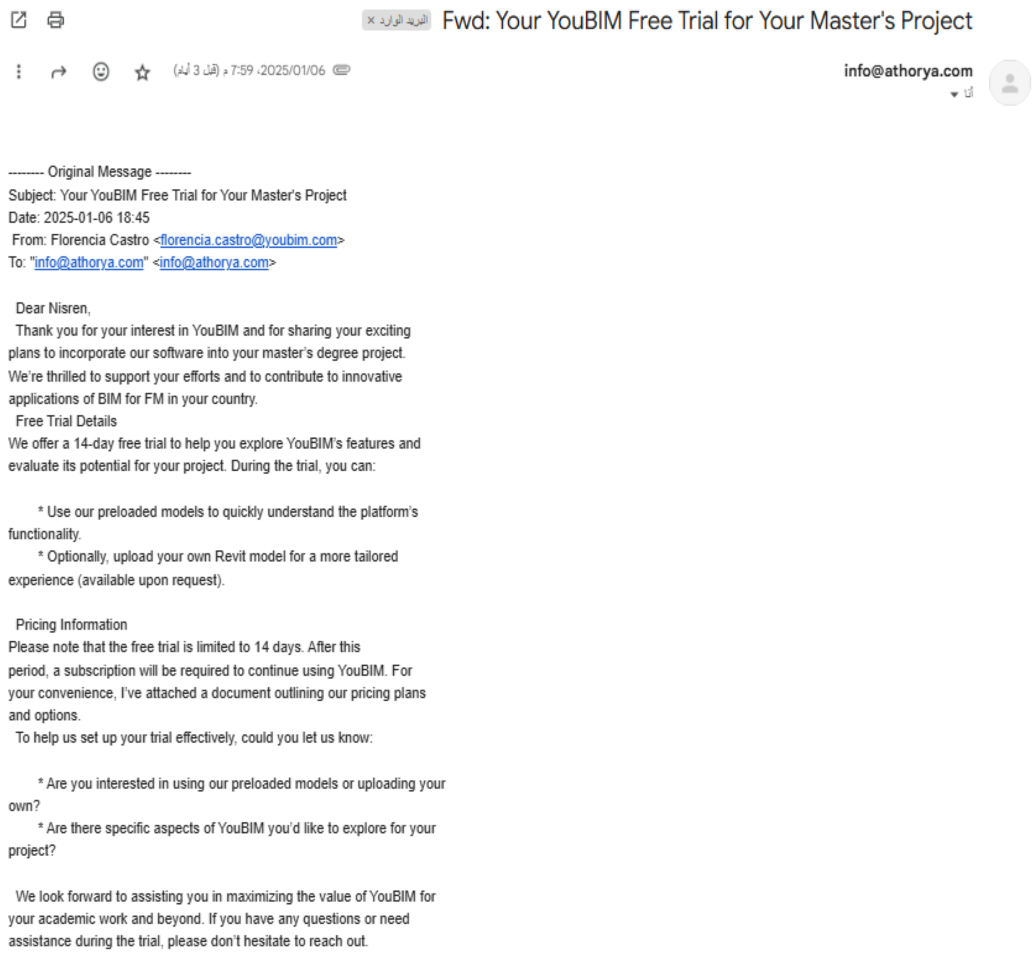
In stage (2), the Revit model alongside the COBie (Access) file that was developed for our specific model ought to be uploaded to the YouBIM platform, which is categorized as a Computing Application Facilitating the Facilities Management Process (CMMS); however, owing to the sanctions enforced upon Syria, the authors were unable to engage in this experience with respect to their own model. Consequently, the authors have initiated correspondence with the company through e-mail and have obtained an affirmative reply endorsing collaboration on the research pertaining to the utilization of the site for the scholarly objectives that they aim to delineate in this study; this collaboration will be facilitated via a pilot model accessible on their website. Thus, authors have deduced the outcomes that can be derived from employing this site through research and pilot instances.



Fwd: Your YouBIM Free Trial for Your Master's Project

2025/01/06، 7:59 م (قبل 3 أيام)

info@athorya.com
أنا

-------- Original Message --------
Subject: Your YouBIM Free Trial for Your Master's Project
Date: 2025-01-06 18:45
From: Florencia Castro <florencia.castro@youbim.com>
To: "info@athorya.com" <info@athorya.com>

Dear Nisren,
Thank you for your interest in YouBIM and for sharing your exciting plans to incorporate our software into your master's degree project. We're thrilled to support your efforts and to contribute to innovative applications of BIM for FM in your country.
Free Trial Details
We offer a 14-day free trial to help you explore YouBIM's features and evaluate its potential for your project. During the trial, you can:

* Use our preloaded models to quickly understand the platform's functionality.
* Optionally, upload your own Revit model for a more tailored experience (available upon request).

Pricing Information
Please note that the free trial is limited to 14 days. After this period, a subscription will be required to continue using YouBIM. For your convenience, I've attached a document outlining our pricing plans and options.
To help us set up your trial effectively, could you let us know:

* Are you interested in using our preloaded models or uploading your own?
* Are there specific aspects of YouBIM you'd like to explore for your project?

We look forward to assisting you in maximizing the value of YouBIM for your academic work and beyond. If you have any questions or need assistance during the trial, please don't hesitate to reach out.

Figure 9. Email from YOUBIM

Subsequently, in the third phase, which is regarded as the final stage, authors execute a series of activities prior to the commencement of the maintenance monitoring procedure. Among the activities that must be implemented are:

1. Asset management is all the elements that make up the structure in which maintenance will be performed, from a screw that requires a predictive process to an industrial electrical panel, as the process of filtering the equipment configured in the model using the assets option within the computerized maintenance management system (CMMS) allows users to organize and manage different assets efficiently, facilitating quick and effective access to data relevant to maintenance and operational needs.

2. Asset details management through the "View Details" option, which displays a pop-up window containing all the information associated with the asset. In addition, it allows linking or filling in information that has not yet been updated or included, such as "Asset Data", "Type" data that provides more information about the asset, data about the system to which it belongs, work orders created, linked documents or inclusion of new documents, etc.

3. Work orders are created according to the status, in the preventive, corrective and predictive maintenance group. In this way, the manager will be able to classify them quickly, as classifying work orders according to the type of maintenance within the 3D computerized maintenance management system allows users to manage and prioritize maintenance tasks efficiently, ensuring the allocation of appropriate resources and procedures for each type of work order.

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4. Implementing and monitoring maintenance work digitally, which depends on documenting the work orders associated with them and updating them continuously.

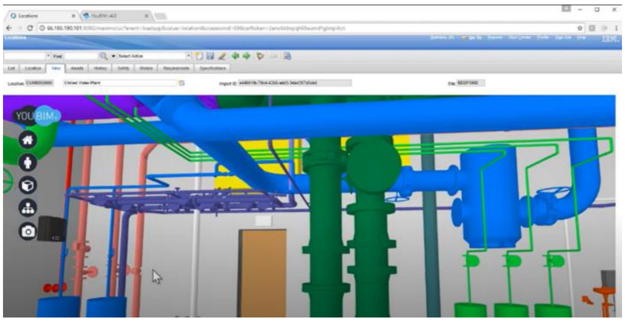


Figure 10. 3D visualization of assets using the 3D navigation tool within CMMS

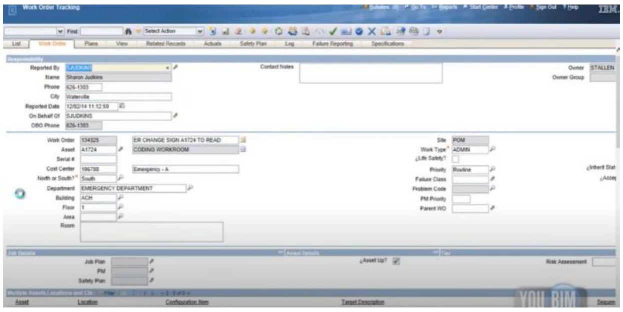
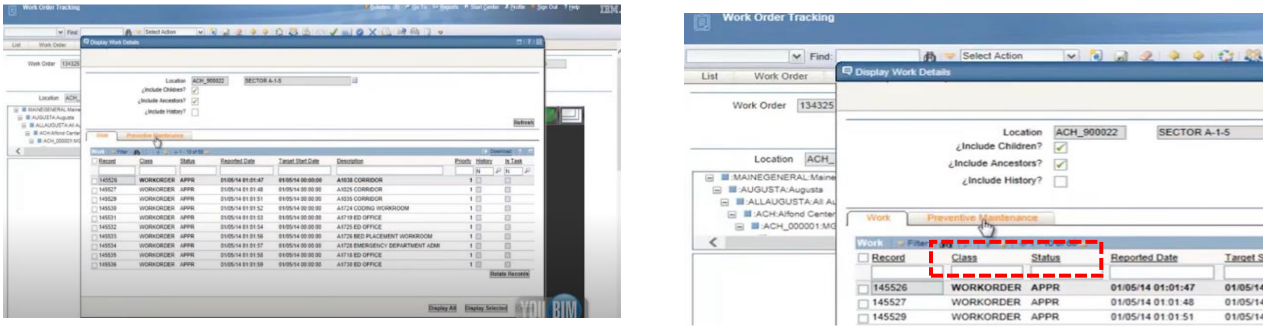


Figure 11. Dashboard for monitoring maintenance



Work Order 134325

Location ACH_900022 SECTOR A-1-5

¿Include Children? ☑

¿Include Ancestors? ☑

¿Include History? ☐

:MAINEGENERAL:Maine
:AUGUSTA:Augusta
:ALLAUGUSTA:All Au
:ACH:Alfond Center
:ACH_000001:MG

Record	Class	Status	Reported Date	Target S
145526	WORKORDER	APPR	01/05/14 01:01:47	01/05/14
145527	WORKORDER	APPR	01/05/14 01:01:48	01/05/14
145529	WORKORDER	APPR	01/05/14 01:01:51	01/05/14

Figure 12. Dashboard for supervising maintenance work (2)

4. Result and Discussion

The application of integrated models for the simulation of building facility maintenance management has proven to be an exceptionally effective tool. These models act as true virtual libraries, where all the information contained and their attributes – both external and internal – are easily accessible through advanced 3D visualization capabilities. Experimental results from this application indicate that asset management using integrated 3D models, in contrast to traditional 2D tools, yields significant improvements in several critical areas:

1) Improved identification and allocation of facility needs:

The 3D environment facilitates faster identification and allocation of operational needs and tasks related to facilities. This improved capability allows for more efficient allocation of resources and faster response to maintenance requirements.

2) Objective and immediate location of equipment:

Integrated models enable the accurate and immediate location of equipment affected by incidents or work orders. Furthermore, these models facilitate the immediate identification of relevant stakeholders, which simplifies communication and coordination efforts.

3) Centralized and easily accessible information on equipment:

The transition to a 3D framework allows for the centralization, digitization and accessibility of equipment information from virtually anywhere, whether in the field or within the office environment. This level of accessibility enhances decision-making processes and operational efficiency.

4) Maintenance prediction through simulation:

The ability to simulate different maintenance scenarios allows for proactive prediction of maintenance needs, thus reducing potential downtime and improving the overall life of facilities.

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5) Organized 3D information management:

The 3D environment allows for the organization of information generated throughout the design and construction processes. This organization is crucial for maintaining comprehensive project documentation and facilitating future reference.

6) Effective management of public spaces and infrastructure:

The application of these integrated models extends to the management of public spaces and infrastructure, providing a comprehensive approach to urban planning and facility management.

7) Access to comprehensive information on equipment:

Users can access all information associated with the model, allowing for a deeper understanding of its operational information.

8) Possibility of integrating sensors:

The models provide opportunities to develop and integrate applicable sensor technologies, enhancing real-time monitoring and management of building facilities.

5. Conclusion

Integrated building maintenance simulation models have demonstrated considerable efficacy, offering 3D virtual libraries that contain readily accessible information and sophisticated 3D navigational capabilities. These models markedly improve asset management and resource optimization, achieving resource savings ranging from 80 to 90% in select instances (excluding resources related to the GIS and BIM modeling processes) in comparison to conventional two-dimensional tools. Nevertheless, a significant limitation identified in the findings pertains to compatibility issues concerning various formats and the integration of digital information across diverse types of three-dimensional Computerized Maintenance Management System (CMMS) software. It is particularly noteworthy that certain software fails to accommodate widely utilized document formats, such as Portable Document Format (PDF). This compatibility dilemma underscores the necessity for ongoing advancements in software interoperability. Ultimately, the findings elucidate the practicality of documenting and refining digital three-dimensional maintenance planning, alongside the comprehensive implementation process. The simulation application signifies a successful evolution from the utilization of two-dimensional CMMS technologies to a computer-aided maintenance tool within a three-dimensional context, which is inherently visual and intuitively accessible.

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Conflicts of Interest: “The authors declare no conflict of interest.”

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