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Structures Maintenance & Control using BIM oriented optimized method

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Abstract

The dissertation, entitled "Structures Maintenance & control using BIM oriented optimized method," investigates the transformative influence of BIM in construction engineering and maintenance management. It examines how BIM, serving as a digital mirror of physical and functional attributes, can augment the design, construction, and operation of infrastructures. The research further delves into how BIM can simplify maintenance control management, leading to cost reduction, efficiency improvement, and extension of structures' lifespan.

The research examines the development and application of BIM-based optimized methodology, focusing on their advantages such as cost reduction, operational efficiency, and enhanced collaboration among stakeholders. Considering this, the dissertation probes into alternative tactic through a comparative analysis, the study evaluates the effectiveness of BIM-oriented optimized methodologies against traditional standalone software solutions.

The conclusions drawn from this research could lay the groundwork for pioneering practices in the field, making a substantial contribution to sustainable and efficient infrastructure development. The study also aims to serve as an exhaustive guide for firms steering through the decision-making process concerning BIM implementation and its alternatives.

Keywords: Building Information Modeling, Building Maintenance & Control, Building Operations, Facility Management, Computer Aided Design, Lifecycle, Construction

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Preface

Welcome to this exploration of Building Information Modeling (BIM) and its impact on structures maintenance and control. This thesis investigates the potential of BIM-driven methodologies to enhance maintenance practices and compares them with traditional software solutions. Through real-world case studies and comparative analysis, the aim is to offer valuable insights for industry professionals and researchers alike.

Throughout this thesis, readers will delve into the intricacies of BIM technology, its application in structures maintenance, and its comparative analysis with standalone software solutions. By examining real-world case studies, methodologies, and comparative studies. The ambition of this master thesis is both to develop the understanding and implementation of BIM in existing buildings or new buildings with all integrated multi-discipline coordination and contributing to the Building Maintenance and control.

Torino, March 2024

Muhammad Talha

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Introduction

The advent of Building Information Modeling (BIM) has instigated a transformative wave in the construction sector, redefining the methodologies of infrastructure design, construction, and upkeep. This article, inspired by the dissertation “Structures Maintenance & Control Using BIM Oriented Optimized Method,” delves into the profound impact of BIM on construction engineering and maintenance management.

BIM, encapsulating the physical and functional characteristics digitally, acts as a potent instrument enhancing numerous aspects of infrastructure development and management. It provides a platform for stakeholders to visualize, scrutinize, and enhance the design, construction, and operation of infrastructures from inception to operation. Acting as a digital twin of real-world assets, BIM fosters informed decision-making, bolsters collaboration among project participants, and propels efficiencies across the project lifespan.

This article investigates the utilization of BIM in maintenance control management, emphasizing process simplification, cost reduction, and longevity of structures. By harnessing BIM-oriented optimized methodologies, organizations can reap substantial benefits, including cost savings, operational efficiency improvements, and improved stakeholder collaboration.

Acknowledging the variety of methodologies in the industry, this thesis presents a comparative analysis assessing the efficacy of BIM-oriented optimized methodologies via traditional standalone software solutions. Through rigorous research and case studies, this article aims to shed light on the comparative advantages and drawbacks of various methodologies, providing a roadmap for firms traversing the intricate terrain of BIM implementation and its alternatives.

The insights gleaned from this research hold the potential to mold innovative practices in construction engineering and maintenance management, fostering sustainable and efficient infrastructure development. As a comprehensive resource for decision-makers, this article seeks to equip organizations with the knowledge to make informed decisions about BIM implementation and fine-tune their approach to infrastructure development and maintenance.

In the ensuing sections, we will probe into the theoretical foundations of BIM, examine its practical applications in construction engineering and maintenance management, and assess the impact of different methodologies on project results. This article strives to contribute to the ongoing dialogue surrounding BIM and its pivotal role in shaping the future of infrastructure development and maintenance practices.

BIM

The term "BIM" was first introduced in 1962 by Douglas Engelbart in his paper "Augmenting Human Intellect: A Conceptual Framework," where he envisioned architects inputting specifications and data into a building design and witnessing the structure taking shape. This concept publication of Autodesk's "Building Information Modeling" white paper in 1992 and a subsequent book in 2003. However, it wasn't until recent years, particularly in more advanced countries, that BIM began to emerge from the misconception, prevalent in Italy and elsewhere, that it solely equates to 3D modeling. In reality, BIM represents a comprehensive process involving the generation and management of digital representations of physical characteristics and functionalities of assets. It aids professionals in the construction sector throughout all phases of an asset's lifecycle, from conception to disposal, making it far more than a mere evolution of CAD software focused solely on producing photorealistic renderings.[1]

Building Information Modelling is a digital representation of the physical and functional characteristics of a building. It has some key aspects that enable it to gather these data to achieve the goal of centralized information.

- **Collaboration:** BIM fosters collaboration among professionals throughout a building's lifecycle.

Design and Planning: Architects abears resemblance to modern parametric modeling and gained popularity with the

- nd engineers use BIM for design, clash detection, and feasibility analysis.
- **Construction:** Contractors benefit from accurate cost estimates and streamlined processes.
- **Operation and Maintenance**: BIM data aids building owners, governments, and property managers in decision-making.

BIM in building process

Building Information Modeling (BIM) is a transformative technology in the construction industry, aiming to create a design that is more cost-effective, efficient, and superior to the traditional 2D approach. This research paper explores the application and benefits of BIM in various fields within the building sector.

The adoption of BIM has been accelerated by the demands of the international market, prompting major Italian construction firms to invest in BIM training. The integrated design approach offered by BIM has proven advantageous in modernizing the management of construction projects, whether they are new, restorative, or maintenance works.[2]

BIM in Various Fields

1. **Architectural Design**: BIM enhances the effectiveness of designers compared to traditional methods. It facilitates cost estimation, realistic image processing, energy certification, and more. The 3D BIM model, rich with data, can be shared across different platforms without losing information quality.

2. **Structural Design**: BIM proves beneficial in reducing the interaction time between calculation programs and modeling software. It eliminates the need for new structural modeling, thereby reducing potential operator errors. BIM software allows easy import/export of information and bidirectional data exchange, enabling the evaluation of new or alternative solutions with professionals.

3. **Plant Design**: Plant design greatly benefits from BIM technology. The ability to quickly size and position plants ensures an excellent quality-price ratio, which is reflected in the management of the plants.

4. **Infrastructure Design**: BIM-oriented planning allows for project integration with other disciplines, drastically reducing errors and information gaps.

5. **Project Management**: Project managers can benefit from the implementation of BIM in the company. Through training, they can effectively interact with stakeholders and utilize BIM tools.

6. **Construction Site Management**: BIM enables the works director to stay updated on the work situation. New technologies facilitate the marking of elements and remote verification of their storage and positioning.

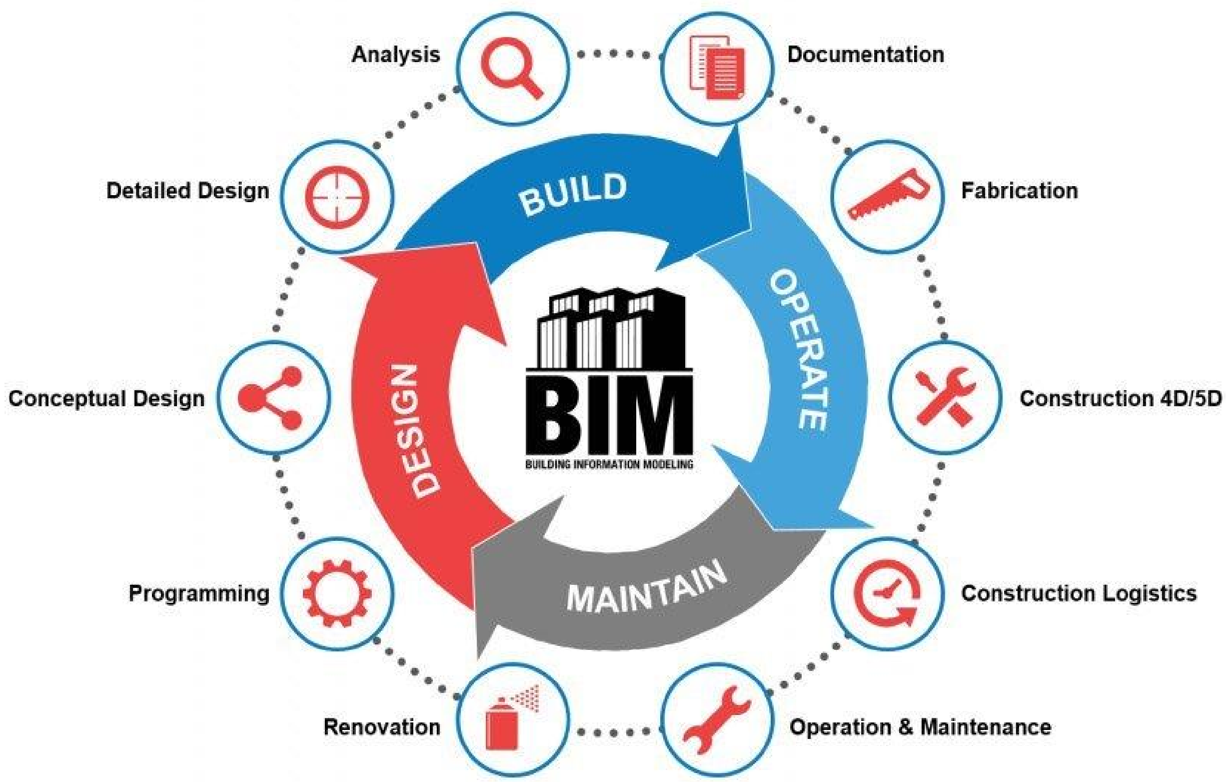


Figure 1:An overview of BIM process.[3]

BIM methodology optimizes the entire building process, improving the decision-making process among designers, the works director, the client, the construction company, suppliers, and the site director. Unlike traditional approaches, BIM workflows are managed collectively by all participants, with the BIM model at the center containing all information and real-time changes. This allows the entire team to stay updated about the project.[4]

Interoperability

The interoperability of these areas of knowledge helps the stakeholders i.e. the teams to have constant access to information amongst themselves that in the long run ensures smooth operations. Using the potential of BIM, it is in fact possible to deal with the same subject through the use of different software, using for example a neutral and open file format such as IFC format which can be opened by most professionals including architects, engineers and facility managers.

Building Information Modelling (BIM) interoperability refers to the ability of different software tools to read, write, and exchange data between BIM models. [5]

Figure 2:Interoperability of Building Information Modelling[6]

This is crucial for collaboration and information exchange in construction projects. Here are some key points:

1. BIM and Building Energy Model (BEM) Interoperability: Proper interoperability between BIM and BEM is paramount for integrating the digital world into the construction sector, thereby increasing competitiveness by saving costs. However, there exist challenges in creating energy models for large and complex buildings due to issues in transferring BIM data to sXML and IFC files.

2. Model-Based Interoperability: The construction industry is evolving from 2-dimensional CAD and paper towards semantically rich 3-dimensional digital models. The industry standard IFC data modeling format is commonly used for implementing tools that consume BIM models.

3. Challenges: Despite the benefits, there are challenges in exchanging building information models between various tools. These include the size and complexity of the models, and the need for more direct and central forms of rule over populations which had previously had greater autonomy.

Improving BIM interoperability can lead to better data exchange, collaborative project delivery, and rich information modeling. However, it requires efforts to enhance compatibility between BIM and model exchange formats.[7]

BIM Dimensions

The UK government has acknowledged that the transition of the construction industry towards comprehensive collaborative operations is a gradual process. This process is marked by clear and identifiable stages, referred to as 'levels', ranging from 0 to 3:

- **Level 0**: Using unmanaged computer-aided design (CAD) in two dimensions, data transmission takes place on paper or its electronic counterpart at this level.
- **Level 1**: CAD is maintained in 2D or 3D format at this level. A shared data environment, guaranteed by a consistent approach to data structure and format, is provided via a collaborative tool. Nevertheless, there is no integration involved and commercial data is handled independently by stand-alone finance and cost management programs.
- **Level 2**: This level presents a controlled 3D environment that is kept up to date using unique discipline-specific "BIM" tools and associated data. ERP software is used to handle commercial data, and proprietary interfaces or bespoke middleware are used to combine it. This BIM level could include 5D cost data and/or 4D construction

sequencing. In its BIM Strategy Paper, the UK government set a goal for the sector to achieve Level 2 BIM by 2016.

- **Level 3**: This is the highest level of BIM and demonstrates a completely coordinated, integrated process. "Web services" help to expedite this procedure, which conforms with the new Industry Foundation Class (IFC) requirements. This BIM level makes use of 5D cost information, 6D sustainability information, 7D project lifecycle management information, and 4D construction sequencing.

The progression through these levels signifies the construction industry's journey towards achieving full collaborative working, with each level marking a significant milestone in this journey. [8]

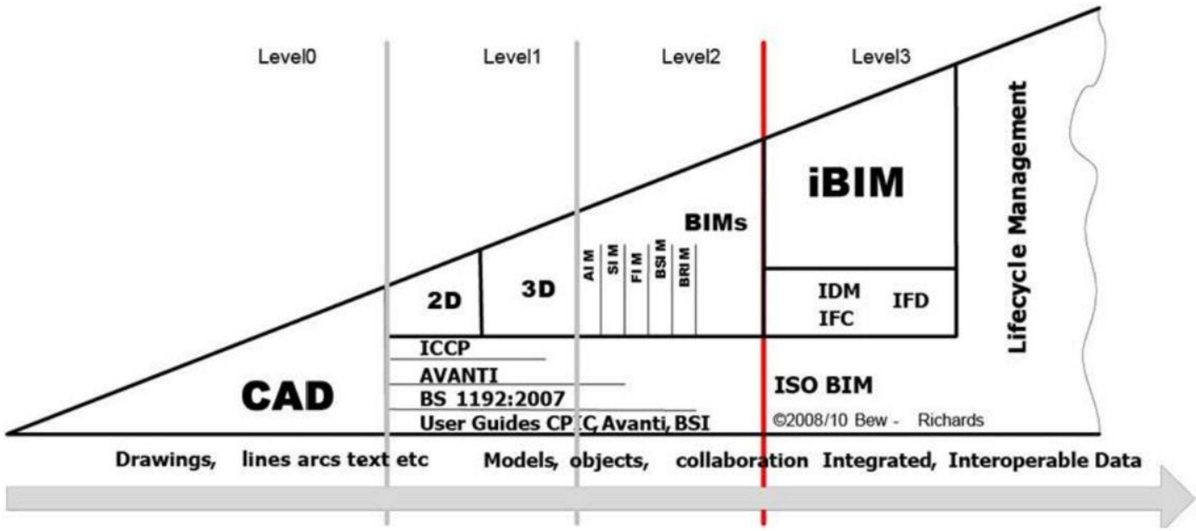


Figure 3: BIM maturity levels.[8]

Building Information Modeling (BIM) dimensions provide a comprehensive framework that encapsulates the potential of computerizing a project. They enable the extraction, amalgamation, and analysis of data that transcends the scope of conventional architectural modeling. As per the Italian BIM standards, UNI 11337, the following categorization is recognized:[9]

- **3D:** This pertains to three-dimensional modeling, which forms the basis of BIM by digitally representing the physical attributes of a building.

- **4D:** This dimension introduces time analysis or schedule management into the mix. It enables the visualization of the construction sequence, thereby facilitating efficient project management.
- **5D:** This dimension incorporates economic information management or cost analysis. It allows for the estimation of costs based on the design and materials used in the 3D model.
- **6D:** This dimension is dedicated to the assessment of sustainability from social, economic, and environmental perspectives. It aids in evaluating the project's impact on the environment and society.
- **7D:** This dimension focuses on management and facility management. It assists in the efficient operation, maintenance, and management of the facility after construction.

In addition to these, there are three more dimensions that are currently under discussion:

- **8D**: This dimension pertains to safety during the design and construction phase of the work. It aims to enhance safety measures and protocols during the construction process.
- **9D**: This dimension represents Lean construction, a method that focuses on minimizing waste and maximizing value in construction projects.
- **10D**: This dimension symbolizes construction industrialization, emphasizing the use of prefabricated components and modular construction techniques for efficiency and standardization.

These dimensions of BIM provide a comprehensive framework for managing various aspects of a construction project, from design to operation, contributing to more efficient and sustainable construction practices.

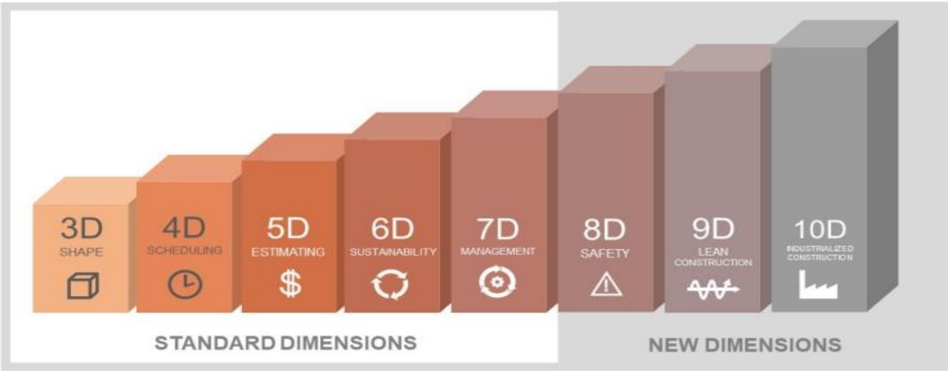


Figure 4: Dimensions of BIM[9]

BIM in Building Maintenance

The main topic of research is maintenance of a building. This spans from the design stage all the way to handing over to the final user. For this to be achieved I am going to utilize the BIM technology which brings together all the information about the building and keep updating with every change. These changes will greatly help in making the building more adaptable to and with the clear records of every aspect of it, the maintenance will eventually be easier.

In the context of building maintenance, BIM can be used to monitor the building's performance in real time and identify potential equipment maintenance and service issues3. It can enhance maintenance management by providing a 3D environment for tracking and managing related maintenance information.

Facility data may be easily updated and transferred in a 3D CAD environment thanks to the BIM technique, which also preserves facility data in a digital format. Project participants may manage facilities and get a summary of the present and past facility assets at a particular facility by utilizing the 3D facility asset. Additionally, throughout the maintenance phase, facility workers may monitor and get the most recent data regarding any fundamental facts, conditions, or maintenance.

BIM benefits

The adoption of Building Information Modeling (BIM) offers numerous benefits, which are likely to increase as practices evolve towards greater collaboration. BIM helps overcome the inefficiencies of traditional design methods, marking a historic moment in construction by achieving complete integration between planning and execution phases. All aspects of efficiency, process control, and cross-sharing of information are applicable and find their most effective expression in the transition to the construction phase.[10]

Various stages such as offer selection, procurement management, subcontracting, industrial accounting, construction, and work progress benefit from the comprehensive and shared information contained in a 3D model developed using the BIM approach. This leads to significant advantages in terms of process optimization, cost control, and management of variations.

BIM places design at the center of the process, in contrast to traditional CAD tools, which solely provide lines and geometric objects without any information or relationships. In BIM, every object is linked to all required parametric data and restrictions in addition to geometric and dimensional values. This information can interface with other data, such as structural, plant engineering, technical/management, calculations, estimates, work scheduling, cost/budget analysis, etc., thanks to the use of a standard protocol (IFC). This results in a comprehensive picture of the project throughout all of its conceptual, executive, and management phases.[11]

When it comes to maximizing operational flows and productivity, Building Information Modeling clearly outperforms traditional project management techniques. BIM has a substantial impact on cost optimization in addition to increasing the amount of data that can be found in the project's 3D models and the opportunities for sharing it. In addition to the obvious time savings, the real-time updating of all project tables in accordance with modifications made results in the complete removal of mistakes, duplications, and interferences, which in turn reduces errors and the need for corrections.[12]

Integrating Building Information Modeling (BIM) into the construction process can effectively resolve management issues that are common in the construction sector.

However, this integration requires a significant upfront investment, primarily in three areas: the purchase of software for building information modeling and management (BIMM), the acquisition of hardware systems capable of managing complex databases, and the development of specialized human capital to generate and manage these systems. These costs can be particularly burdensome for smaller companies.

Investments are often evaluated from the perspective of Return on Investment (ROI), which shows an exponential growth in the investment return curve. The graph typically displays a bell curve for the conventional design process, with the peak of resources and effort concentrated in the construction and documentation phase. In contrast, BIM shifts this peak to the end of the preliminary design stage, indicating that design modifications are simpler and cheaper in the early stages and become less effective and more costly as the process progresses.

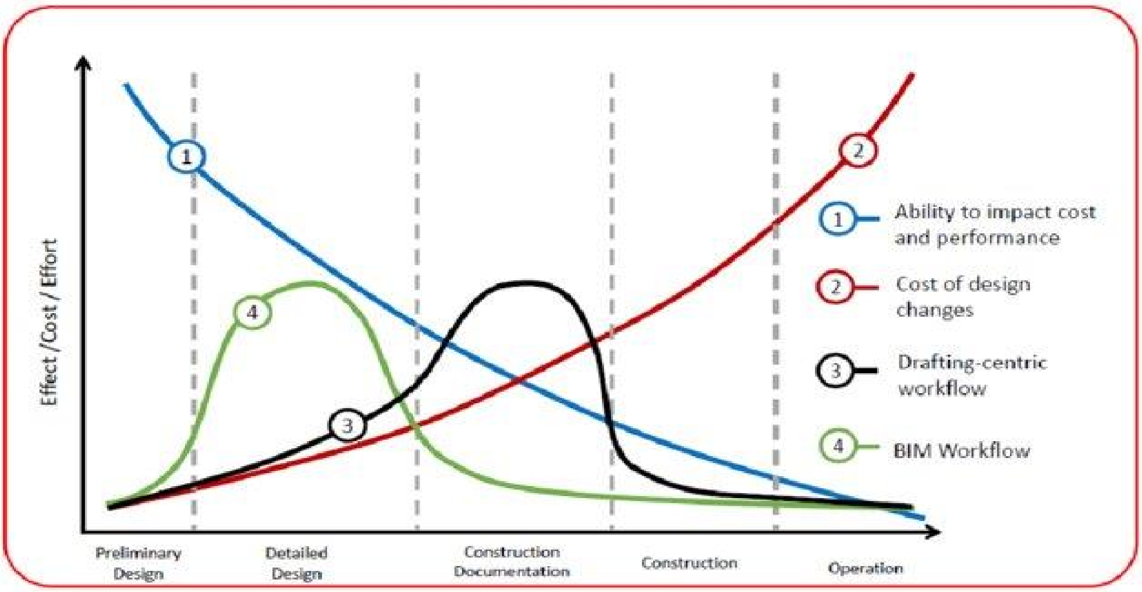


Figure 5: 'MacLeamy Curve' on BIM workflow.[13]

To summarize, strategically reducing design costs involves considering the following elements: developing an open-source Building Information Modeler (BIM), reducing costs through cloud-based sharing of building databases, and fostering specialized human resources through universities and educational institutions.

Maintenance

Maintenance in the construction industry encompasses the ongoing efforts to ensure the continued functionality, safety, and longevity of built structures and infrastructure. It involves a range of activities aimed at preserving, repairing, and enhancing buildings, roads, bridges, utilities, and other constructed assets throughout their lifecycle. Maintenance is a critical aspect of construction management, as it directly impacts the performance, durability, and overall value of constructed assets.[14], [15]

The OECD (Organisation for Economic Co-operation and Development) describes maintenance as a business role responsible for the ongoing surveillance of installations and all the repair and renovation activities required to guarantee the seamless functioning and excellent state of production facilities, services, and plant equipment.

In contrast, the UNI 13306:2018 standard characterizes maintenance as the integration of all technical, administrative, and managerial actions throughout the complete life cycle of an entity aimed at keeping or bringing back the asset to a condition where it can execute its necessary function.

As an additional example, consider how the ISO 55000:2014 standard defines asset management. It is described as the 'coordinated activity of an organization to realize value from assets.' In this context, an asset is an item, thing, or entity that holds potential or actual value for an organization. This could be seen as a broader concept that encompasses maintenance as one of its key activities.

Technical maintenance, also referred to as maintenance, is the term for a collection of procedures and methods used to guarantee the effective and continued operation of machinery, equipment, and other assets commonly employed in commercial settings. For equipment, assets, buildings, and entire companies to operate well and last a long time, care must be taken in developing an efficient maintenance program.

Importance of Maintenance in Construction

Significance of Upkeep in Construction

Maintenance is pivotal in construction projects for durability, safety, and operational effectiveness.

Here are some primary reasons why upkeep is essential:

Durability of Equipment:

- Consistent maintenance prolongs the life of construction machinery and equipment.
- Early detection and resolution of potential problems avert expensive malfunctions and keep equipment in working order.

Assurance of Safety:

- Construction environments are inherently risky. Adequate maintenance aids in identifying defective parts, damaged elements, or exhausted equipment that could endanger workers.
- Equipment in good condition contributes to a safer work environment.

Efficiency in Operations:

- Equipment in good working order enhances productivity and reduces downtime.
- Regular maintenance averts unforeseen malfunctions, thereby optimizing project schedules.

Detection of Issues at an Early Stage:

- Regular inspections uncover hidden issues that could interrupt construction processes if not addressed.
- Immediate action during maintenance stops minor issues from becoming major problems.

Hygiene and Lubrication:

- Routine cleaning and lubrication improve equipment performance.
- Accumulation of dirt and debris can hinder functionality, making it crucial to keep equipment clean.

Challenges in Maintenance

Balancing Priorities:

- Allocating resources effectively between preventive, corrective, and predictive maintenance.
- Ensuring minimal disruption to ongoing construction activities.

Access and Safety:

- Some equipment may be challenging to access for maintenance.
- Ensuring safety protocols during maintenance tasks.

Cost Management:

- Balancing maintenance costs with project budgets.
- Avoiding over-maintenance or neglecting critical tasks.

Skill Requirements:

- Skilled personnel (electrical, plumbing, HVAC) needed for specialized maintenance.
- Training and retaining qualified staff.

Maintenance strategy paradigms

After examining the notable classifications of maintenance strategies, a universal classification for these strategies is presented in this study in Figure 6. Each of these strategies is further explained in the subsequent sections. [16]

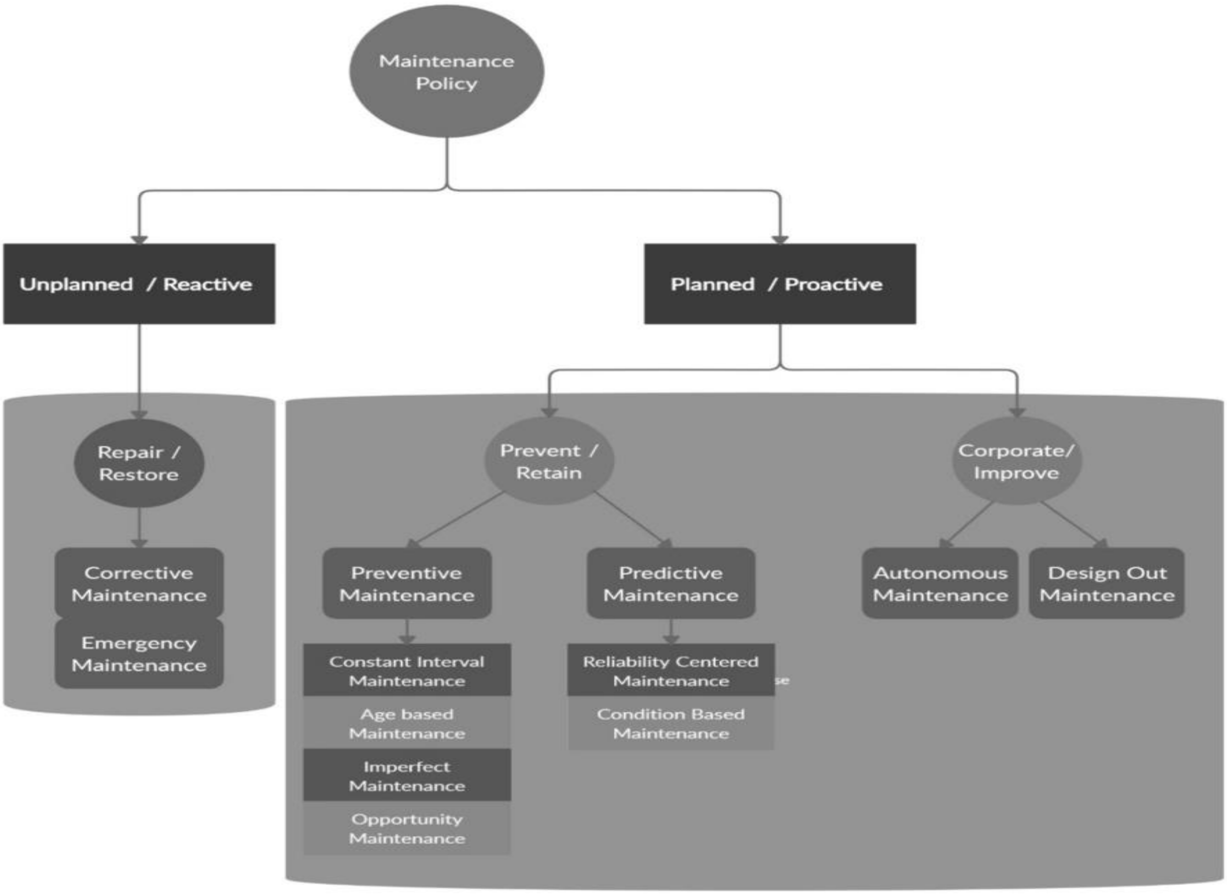


Figure 6: Classification of maintenance strategy models[17]

Corrective maintenance

Maintenance strategies such as corrective, breakdown, failure-based, or firefighting are among the earliest methods employed in the manufacturing industry. These strategies may be suitable for facilities with ample downtime, low asset value, or high profit margins. However, unexpected failure events can lead to substantial production losses and serious implications for personnel, the environment, and the system. These strategies are typically implemented when there is a lack of knowledge about system failure behaviour.[18], [19]

Emergency maintenance

This approach can be characterized as a series of maintenance tasks performed promptly to prevent harmful repercussions. The implementation of these tasks is determined by the immediacy of the action and the potential outcomes of not performing maintenance.[16], [17]

Preventive maintenance

This approach is designed to execute necessary maintenance tasks based on set standards to minimize the likelihood of malfunction or decline in operational efficiency of a device or system. [17]

It can be further divided into three distinct categories.

Constant Interval Maintenance

Also referred to as time-based maintenance (TBM), this strategy involves conducting maintenance at set intervals, irrespective of the machine's current state. This approach is particularly useful when the machine needs to operate for extended periods. The intervals are optimized based on the risk of failure and the costs of preventive maintenance (PM).[20]

Age-Based Maintenance

This approach schedules maintenance tasks once the asset has reached a certain age. If a failure occurs before reaching this age, corrective actions are taken, and the next PM is planned. The age-based strategy is superior to the constant interval strategy because the latter can lead to failures shortly after minor repairs, resulting in wasted time and resources. Additionally, age-based maintenance typically has a lower frequency of maintenance compared to the constant interval strategy.[21]

Imperfect Maintenance

The strategies discussed above assume that the system is restored to its original state after maintenance, which is not always realistic. Imperfect maintenance addresses this limitation by considering the current system's uncertain state when planning future maintenance activities.[14], [17]

Opportunity Maintenance

This strategy takes into account the interdependencies among components and performs maintenance tasks based on the evaluation of the interrelated system condition. A common subcategory, the opportunistic age replacement strategy, replaces not only failed components but also those that have been in operation for a predefined time when a component fails.[17]

Predictive Maintenance

Modern measurement and signal processing techniques are used in predictive maintenance to precisely predict future problems and assess the current status of a system. Predictive maintenance (PdM) is more flexible than preventive maintenance (PM), which has a defined schedule. This is the main difference between the two types of maintenance.[22]

PdM strategies can be divided into two main categories:

- **Condition-Based Maintenance (CBM)**

Prognostic Health Management (PHM) is the result of the evolution of CBM over time. It includes all phases of the cycle from data collecting to decision-making, including feature engineering, defect detection, and prognosis procedures. System Health Management (SHM) is another name for CBM (PHM). The CBM approach makes maintenance choices based on data collection. This information helps determine the state of the system and helps plan the necessary maintenance tasks. By providing early diagnosis and prognostics, this method allows for preventative treatments that lower the chance of unanticipated failures. These days, this tactic is essential to process sectors like power plants, sugar and paper mills, oil refineries, and so on. It is not without restrictions, though, as not all apparatus or systems are practical or profitable for data collecting. [23]

- **Reliability-Centered Maintenance (RCM)**

Since every piece of equipment is different and functions in a different environment, reliability-centered maintenance, or RCM, acknowledges that not all equipment is equally vital or deteriorates at the same rate under the same circumstances. It seeks to reduce equipment life cycle costs by determining the best mix of CBM, PM, and Corrective Maintenance (CM). Rather than aiming to keep the equipment in perfect condition, its purpose is to maintain its degree of reliability. RCM is a two-phase system that evaluates the effect of the maintenance plan on reliability after first analyzing and classifying failure modes. Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA) are two other techniques used in this method. The paper by Prasetyo and Mercado Rosita, 2020, is an interesting case study using RCM to maximize the dependability of assets in a manufacturing company.

Autonomous Maintenance

Autonomous maintenance is a strategy that fosters collaboration between the maintenance and production departments. It involves training all levels of personnel to continuously monitor equipment and carry out minor maintenance tasks in the manufacturing facility. This approach eliminates the need for a dedicated maintenance technician and is a crucial component of total productive maintenance (TPM) [24]

Design-out Maintenance

Design-out maintenance is a strategy that aims to improve the system by redesigning it to minimize or eliminate the need for maintenance activities. This approach can be particularly effective when defects or failures occur because the operation exceeds design specifications. Another key feature of this strategy is the incorporation of ergonomic considerations into the system for the comfort of maintenance or operational personnel. A motor vehicle bearing manufacturing plant is deemed an appropriate application for this strategy.[25]

In summary, maintenance is integral to construction success. By implementing effective strategies and overcoming challenges, construction projects can operate efficiently, stay safe, and achieve long-term sustainability.[17]

BIM in Operation & Maintenance

The service life is defined by ISO 15686-1:2011 as the amount of time after installation that a building or any of its parts meet or exceed the performance standards. Because of deterioration brought on by both human and natural processes, all infrastructures and buildings have a limited lifespan. In order to maintain high standards, technicians and management must preserve the functional and physical characteristics of assets. A material has to be replaced after its anticipated service life is reached. The service life of materials in the Architecture, Engineering, Construction, and Operation (AECO) sector is primarily determined by economic variables.[26]

Because maintenance operations are becoming complex and financial resources are becoming more limited, asset management is a constant source of concern for technicians and managers. In this situation, maintenance is usually only done in case of true emergency. This method increases the danger of damage and fatalities in the worst-case scenario, increases maintenance costs, and inefficiencies in facility management planning. Preventive maintenance is therefore essential as a tactic to stop all infrastructures and buildings from deteriorating. Simple, continuous measures that are affordable and enable the appropriate use of resources across many assets are part of preventive maintenance.[27], [28]

In the legal context, the Italian public procurement code (Legislative Degree no.50 of 2016) mandates the development of a maintenance plan during the execution phase. Concurrently, the decree incorporates the European directive (2014/24/EU) on the gradual adoption of specific electronic methods and tools, such as BIM, using interoperable platforms.[28], [29]

Because of this, the ISO 19650-3 provides clarification on the use of information models for asset management across the full lifetime in the construction industry. The ISO recommends systems that appropriately disseminate information based on the phase of the building process, such as the Asset Information Management (AIM) and Project Implementation Model (PIM). As a result, during the course of the project, the BIM design model develops into the constructive PIM and then into the operational AIM model, enhancing itself with knowledge and data that helps the facility manager with his operational tasks and asset upkeep.

Facility Management and BIM

According to ISO 41011:2017, Facility Management (FM) is an organizational function that aims to improve people's quality of life and the efficiency of the core company by integrating people, place, and process within the built environment. Facilities (the structures and services required to support and facilitate a company's activity) are identified, specified, located, and supplied to provide and maintain service levels that meet business needs, resulting in a high-quality work environment at the lowest possible cost, according to the International Facility Management Association (IFMA).[30], [31]

Information understanding serves as the foundation for managerial actions in this intricate field. Known as the operations and maintenance (O&M) phase in literature, maintenance management is the life cycle activity that costs the most, accounting for around 60% of total expenses. BIM-FM integration, however, may be helpful to improve a building's performance and manage operations more effectively by lowering O&M expenses because managing maintenance tasks is rather difficult.

BIM, as defined by ISO 29481-1:2016, is a shared digital representation of an object's functional and physical properties that makes the design, construction, and management processes easier. BIM in facility management comprises a single information base made up of a Big Data database that offers helpful analytical support, emergency response support, safety management, and scenario preparation in addition to a building owner's handbook. The notion that BIM combined with FM is a sustainable operation is becoming more and more popular in this context, to the extent that the term Sustainable Facility Management was created.[32], [33]

Nonetheless, it frequently happens that the needs are not met by the technology. To handle maintenance information, additional software must be introduced to supplement BIM software authoring, which is not always equipped to store all the information describing O&M processes. Strong communication and information exchange are necessary for FM.

Computerized Maintenance Management System (CMMS) and Computer Aided Facility Management (CAFM) have been the instruments that have supported FM in recent years. Nevertheless, the facility manager's ability to pinpoint the precise site of maintenance and the history of changes is restricted by the conventional usage of paper or 2D digital plans, which restricts both of them in terms of visibility. In this sense, the BIM model might be a helpful tool to work with the FM as an interface to a repository, offering data gathering, monitoring, processing, and transformation, or as a source for data input, offering material/spatial data, reports, or technical analysis.[34], [35], [36]

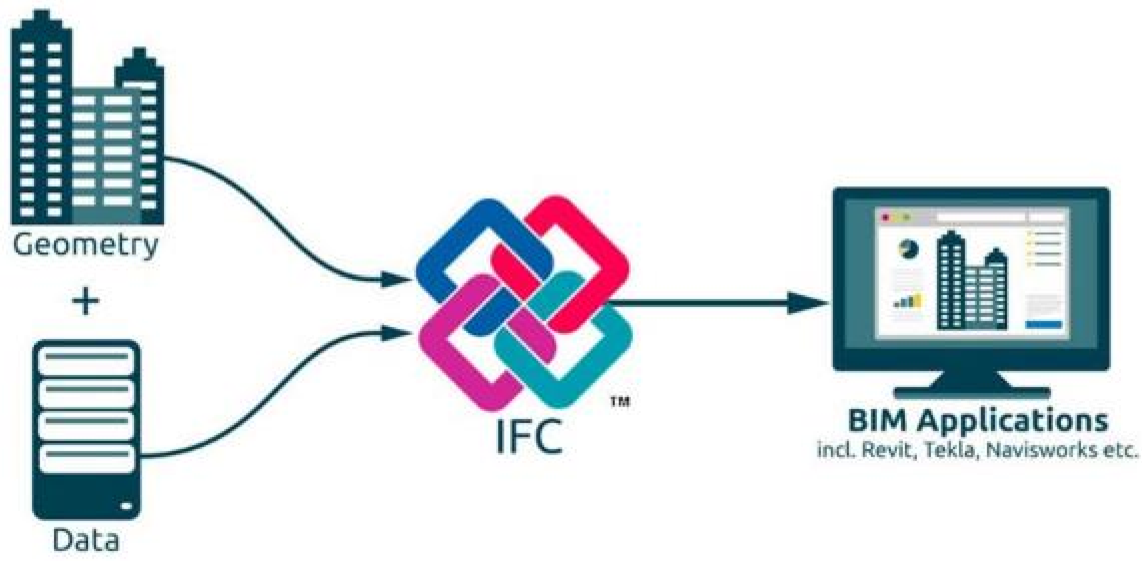


Figure 7: Representative figure of the information flow during the use of a BIM application (BUILDING SMART—Industry Foundation Classes (IFC)—buildingSMART International)[37]

Regulatory Framework – UNI EN ISO 19650 1 - 2 - 3

The building sector is going to undergo a digital revolution thanks to the hard work of the International Organization for Standardization (ISO). The ideas and methods for managing information throughout a building's life cycle are outlined in ISO 19650, "Organization of information about construction works – Information management using building information modeling." In collaboration with the European standards organization CEN (Comité Européen de Normalisation, or European Committee for Standardisation), this two-part standard was developed. As a result, the Italian Standards (UNI) must formally approve each ISO standard that CEN creates and implements. Real estate brokers and owners can enjoy several advantages by following these guidelines, such as reduced risk and maximized maintenance expenditures.[38]

This section outlines the key documents that facilitate the digitization processes of works, beneficial for both managers and economic operators:

OIR (Organizational Information Requirements): With the use of this strategy document, managers of construction property groups may specify the extensive information needs that must be met in order to centralize, standardize, and unify the management and upkeep of their assets. Managers, for example, have to create this document outlining the data they need to distribute and manage their assets inside their own business, especially if it is divided up across many local or regional divisions.[38], [39]

AIR (Asset Information Requirements): The information requirements for the asset under intervention are outlined in this document. In order to properly characterize the information models that are only connected to the characteristics of the property or various groupings of assets, it is imperative that all data in this document be defined.[38], [39]

PIR (Project Information Requirements): On the basis of the specific project, this paper outlines the data required to reply to the requests made in the OIR. Because of this, this paper starts with the information needs outlined in the OIR and then goes into detail about each project in particular. It is a contract that outlines the manager's and the company chosen to provide the asset management service.[38], [39]

EIR (Exchange Information Requirements): This document defines the information requirements of the single project and should be defined every time a contract is awarded.

specifications for each individual project and have to be specified each time a contract is granted.
The paper proposes a way to integrate Building Condition Assessment (BCA) procedures with Building Information Modeling (BIM) systems for Facility Management in order to support facility managers in making decisions about maintenance tasks. The major goal is to

create a maintenance management plan that gives professionals the assistance they need to prioritize maintenance interventions in a useful way:

- Asset Hierarchy System.
- Asset decay valuation method.
- BIM model with Revit software (Autodesk)

Two possible data gathering strategies are presented by the method: Dynamo: Through the use of Common Data Environmental and a visual programming language (VPL), mobile devices collect data into Excel spreadsheets that function as a database linked to the BIM model.

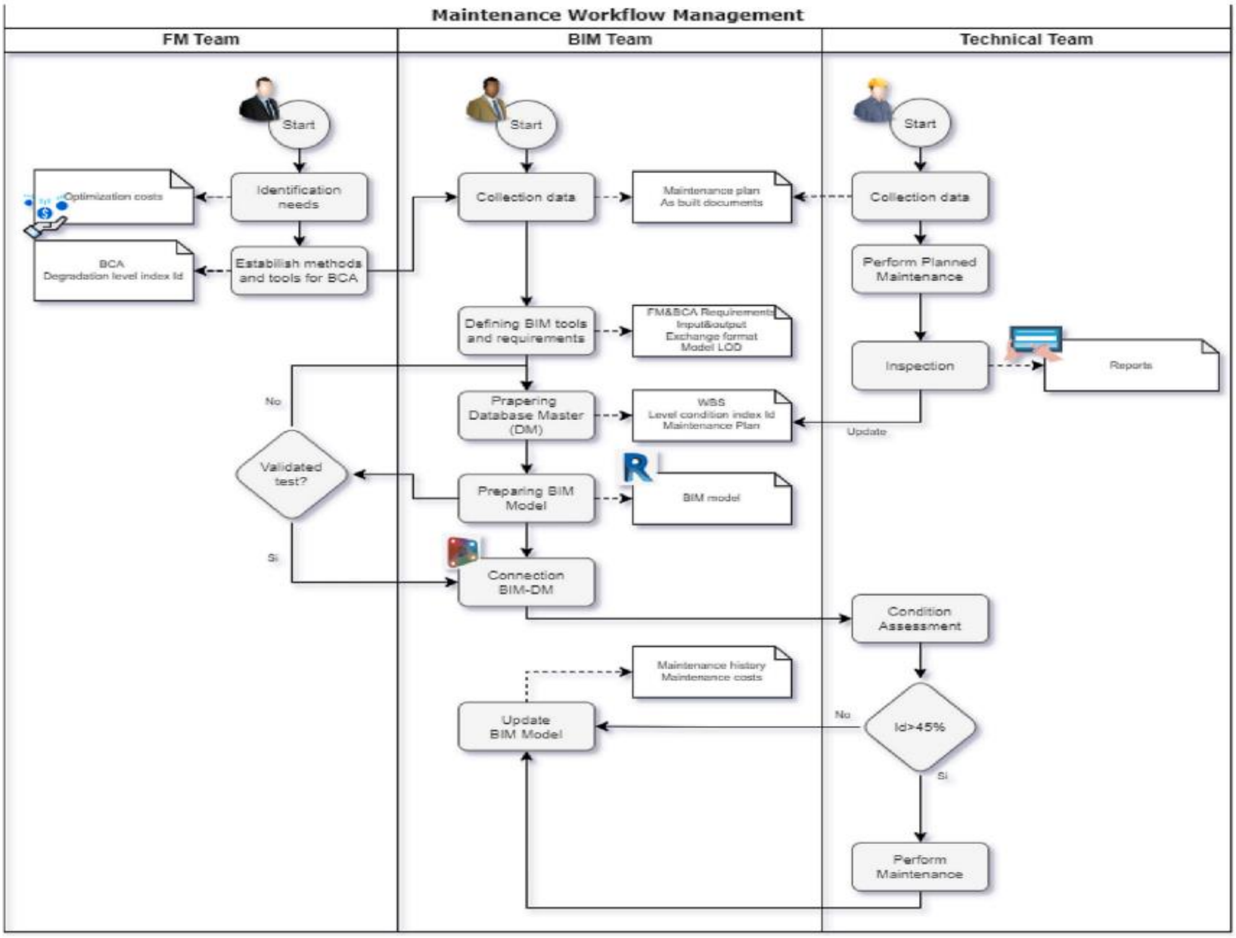


Figure 8: Maintenance Workflow Management[29]

Utilizing BIM for Evaluating Building Conditions

A comprehensive grasp of the building's condition is essential to overcome one of Facility Management's biggest challenges: the efficient maintenance of buildings and infrastructure. The limitations of traditional building condition assessment methodologies stem from their antiquated methods of data capture, collection, and reporting—many of which rely on paper records that are seldom linked to the as-built model. Information loss may result from this, which would raise expenses and performance standards. Thus, it's imperative to take into account the advantages of combining the Building Condition Assessment (BCA) and Building Information Modeling (BIM) processes. By seamlessly merging data on the project's present status into a unified digital model, BIM solves the problem of collecting and maintaining it. Because of this, the as-built model will be both 3D and contain semantic (non-geometric) data that may be updated over the course of the building's existence. Managers' maintenance chores will be made easier by the BIM model's updated database. The lack of sufficient and relevant information for management and maintenance operations is the major cause of the difficulties in implementing an asset management process in a BIM environment.[2], [40]

- Managing this information on platforms that are interoperable with those specific to FM.
- Minimizing the effort to update the model.

Many studies on the integration of BCA in a BIM context have been conducted recently, most of them on university campuses. Some scholars have expanded their IT expertise by developing online platforms or.net language plug-ins to improve the features of BIM software authoring that is now available. Studies pertaining to the lifetime management of transportation facilities also show this tendency. According to published research, the BIM process's application to infrastructures has not yet reached the necessary levels of maturity for design management; as a result, it is still in its experimental stages throughout the maintenance phase.[40], [41]

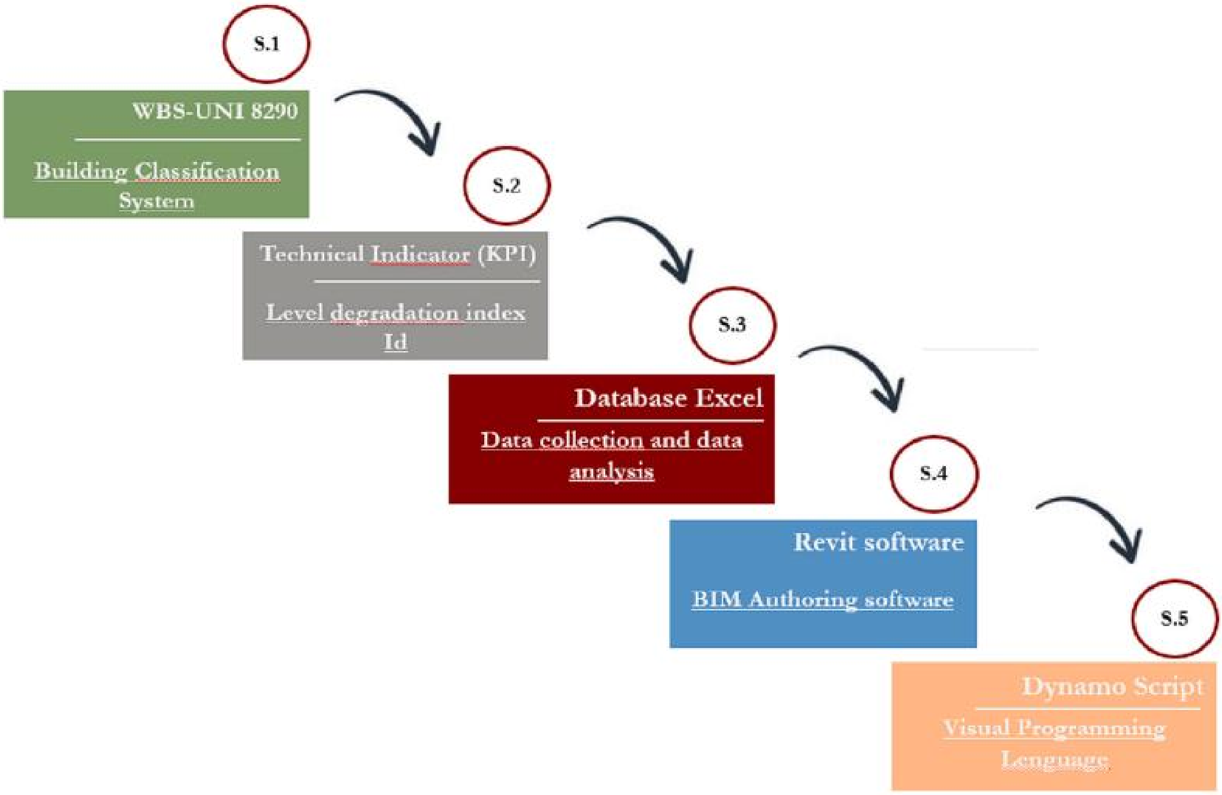


Figure 9: Tools for maintenance management through BIM model[41]

Methodology Using BIM in Construction of Buildings

Building Operation and Maintenance (O&M)

What is O & M?

Operation and maintenance (O&M) of buildings refer to the ongoing activities and processes involved in managing, preserving, and optimizing the performance of built assets throughout their lifecycle. This encompasses a wide range of tasks and responsibilities aimed at ensuring the safety, functionality, and sustainability of buildings over time.[42], [43]

The concept of O&M has been integral to the built environment for centuries, as civilizations sought to manage and preserve their architectural heritage. Early maintenance practices focused on basic repairs and upkeep to address wear and tear, while the modern understanding of O&M has evolved to encompass a broader range of activities driven by advancements in technology, sustainability practices, and regulatory requirements.[44], [45]

Three tiers of management and four key performance areas (KPAs) are distinguished in a comprehensive, industry-neutral framework for facility and real estate management that spans all aspects of building development and maintenance.

	KPA 1: Strategic Planning	**KPA 2: Portfolio Management**	**KPA 3: Project & Transaction Management**	**KPA 4: Operation & Maintenance Management**
	> > > > Production Life Cycle of Facilities > > > >			
Strategic Level	Strategic Planning	Optimized Investment Decisions	Optimal Capital Project Results	**Optimal Enterprise Performance**
Portfolio Level		Facilities Planning	Project Portfolio Management	**Facilities Portfolio Management**
Operational Level			Project Transaction Management	**Operations, Maintenance & Service Management**

Figure 10: Key Performance Areas in the Production Life Cycle of Facilities [46]

What is FM?

Facilities management (FM) is a comprehensive term that encompasses a variety of property and user-centric functions, all aimed at benefiting the organization and its employees. FM is all-encompassing, dealing with everything from property and financial management to maintenance and cleaning.[30]

The International Facility Management Association (IFMA) describes Facility Management as a process of designing, implementing, and controlling facilities (the buildings and services needed to support and facilitate the company's operations) to provide and maintain service levels that meet business requirements, create a quality work environment, and minimize costs. It's evident that this is a complex field where knowledge is the foundation for management, and it's therefore essential to have a wealth of diverse information. Facility Management is an integrated approach that, by designing, planning, and providing support services to the company's primary activity, aims to enhance the organization's effectiveness and enable it to adapt swiftly and easily to market changes.[47], [48]

Figure 11: FM as an integrated approach[49]

Facility Management in Italy and Europe

The Facility Management market in Europe began to expand, starting from the United Kingdom in the early 1980s, and then moving to Holland in the latter half of the same decade. In France, the development of Facility Management started from the late 1970s and the first half of the 1980s, focusing on the management of general services in organizations, unlike the United States where it was closely tied to property management. This evolved towards real estate Facility Management in the 1990s.[47], [50]

Germany witnessed the development of outsourcing processes from the early 1980s, driven by sectors such as cleaning, security, catering, and later, Information Technology. It was towards the end of the 1980s that a genuine Facility Management market began to establish itself, spreading to the Scandinavian countries in the 1990s.[47]

In Italy, the Facility Management market took its initial steps between the end of the 1980s and the first half of the 1990s, experiencing significant growth over the past two decades.

In addition, the rise of Building Information Modelling (BIM) has led to standardization efforts in the construction and maintenance sector. The CEN TC442 Building Information Modelling (BIM), a technical committee of the European Committee for Standardisation (CEN), develops and maintains standards in the BIM domain. These standards aim to enhance interoperability and information delivery specifications, which are crucial for effective facility management.[51]

For a comprehensive understanding of the Italian Facility Management market, it’s crucial to distinguish its two primary sectors. The market is essentially split into two broad categories, each with its own regulatory and procedural constraints, as well as distinct organisational and managerial characteristics:

- Large multinational and national corporations, including major public companies that have been privatised. These entities are marked by a high degree of organisation and a robust capacity to oversee suppliers and manage contracts effectively. Facility Management companies that compete in this market segment are dedicated to delivering high-quality services and are equipped to coordinate a comprehensive suite of integrated services (Total Facility Management).[50]

- Central and local public administrations (such as municipalities, provinces, regions, etc.) are required to procure services through public tenders, guided by the principles of the most technically and economically advantageous offer or the highest discount.[50], [51]

In Europe, the Facility Management market size is estimated at USD 360.17 billion in 2024, and is expected to reach USD 432.34 billion by 2029, growing at a CAGR of 3.72% during the forecast period (2024-2029). Europe is considered one of the biggest outsourced markets for facility management services in terms of maturity and sophistication.[47], [52]

In Italy, the Facility Management market was valued at USD 40.87 billion in the previous year. It is expected to grow at a CAGR of 2.14%, reaching USD 46.66 billion by the next five years2. However, the outsourced market in Italy is much smaller than other European countries with similar GDP and population size, such as the UK and France.[53], [54]

The use of standardized codes in construction and maintenance is a key aspect of Facility Management. The ISO 41001:2018 specifies the requirements for a facility management (FM) system when an organization needs to demonstrate effective and efficient delivery of FM that supports the objectives of the demand organization.[54]

Phases of FM

The phases of facility management in construction can be broadly categorized into the following stages:

Initiation Phase: This phase involves defining the project’s objectives and goals, conducting a feasibility study, and determining the size of the building or structure.

- Internal needs analysis, which is done through management choices, internal audit or benchmarking on companies operating in the same sector.
- Identification of the basket of services needed.
- Defining the expenditure budget.

- Definition of the outsourcing model to be applied.

Pre-Construction Phase: Also known as the planning phase, this stage involves creating schematic designs that include sketches of the space, materials, colors, and textures that will be used in construction.

- Definition of service levels (SLAs).
- Drawing up the technical specifications.
- Drawing up the specifications.

Procurement Phase: This phase involves the acquisition of all necessary materials, equipment, and services needed for the construction project.

Construction Phase: This is the execution phase where the actual construction work takes place. It involves the implementation of the project plan and the monitoring of the construction process.

Post-Construction Phase: Also known as the project closeout phase, this stage involves the evaluation of the project delivery, ensuring that all completion goals have been met, and the formal closure of the project. [55]

As you can see in the figure below, the concentric semi-circular arches that highlight the alternatives at the conclusion of each step are one advantage of the graphical representation provided by GEFMA. Following construction, one of the following actions, for instance, might be taken: acquisition, non-occupation, or commercialization.[56], [57]

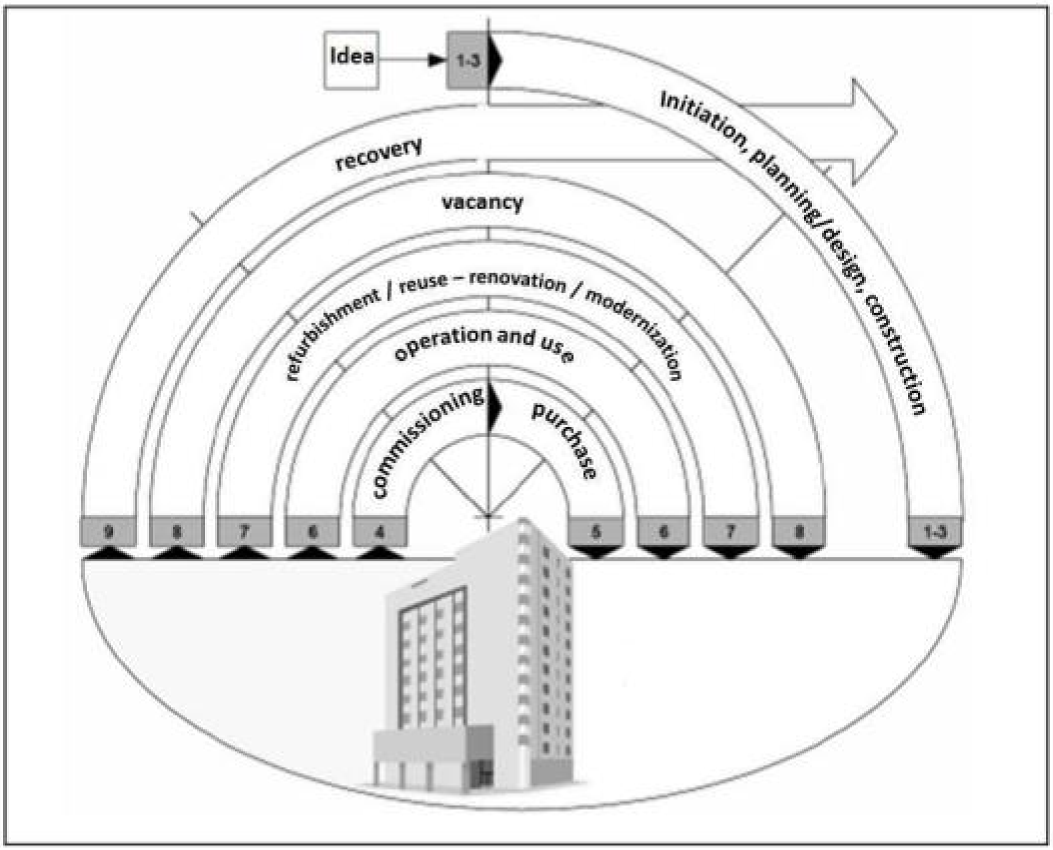


Figure 12: Phases of FM Source: GEFMA Directive 100-1: 2004.[57]

Integration of BIM and FM

In the current Architectural, Engineering, and Construction (AEC) sector, Building Information Models (BIMs) have become a common tool as professionals in these fields have grown more proficient in using technology-based processes. The increasing adoption of BIM in the AEC sector opens up the potential for these models to be used beyond construction, into post-construction workflows. However, this shift changes the traditional approaches to data transfer, documentation, and analysis. BIM may store both geometric and semantic data when the Owner/Operator's needs and expectations for Facility Management (FM) are clearly understood. This allows BIM to produce full FM outputs, such as interactive record models.[58], [59]

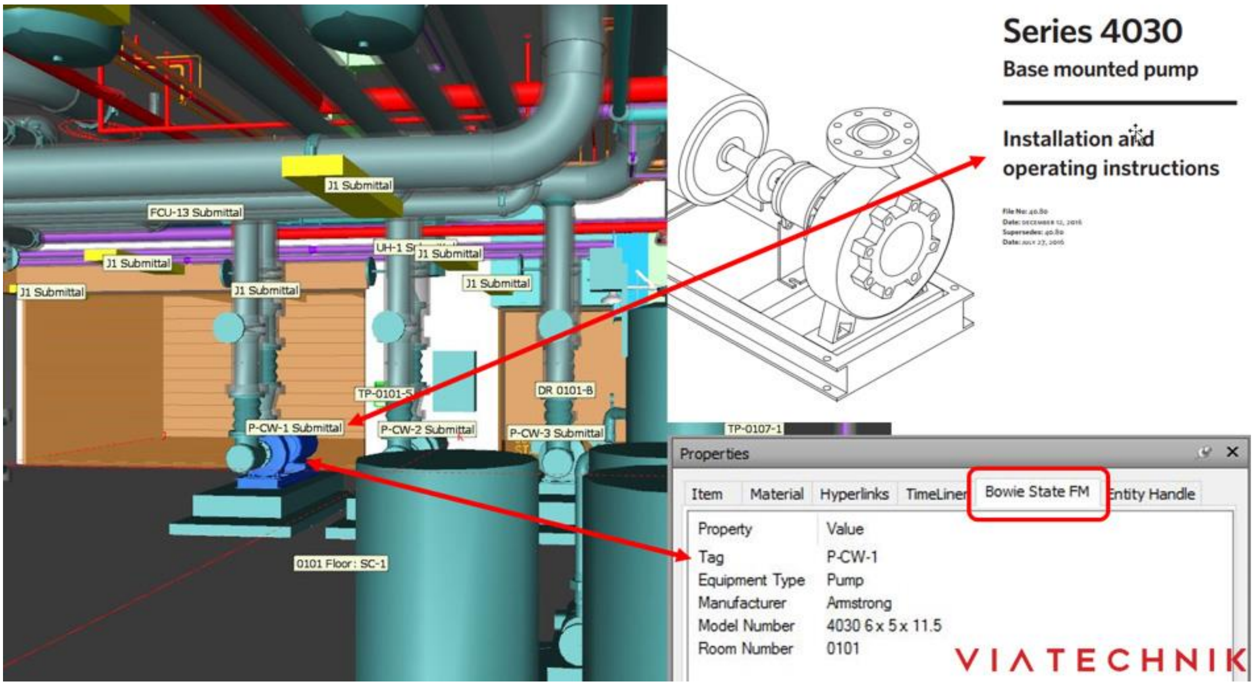


Figure 13: BIM as a consolidated repository of facility data on the Bowie State University Project. Photo: VIATechnik[59]

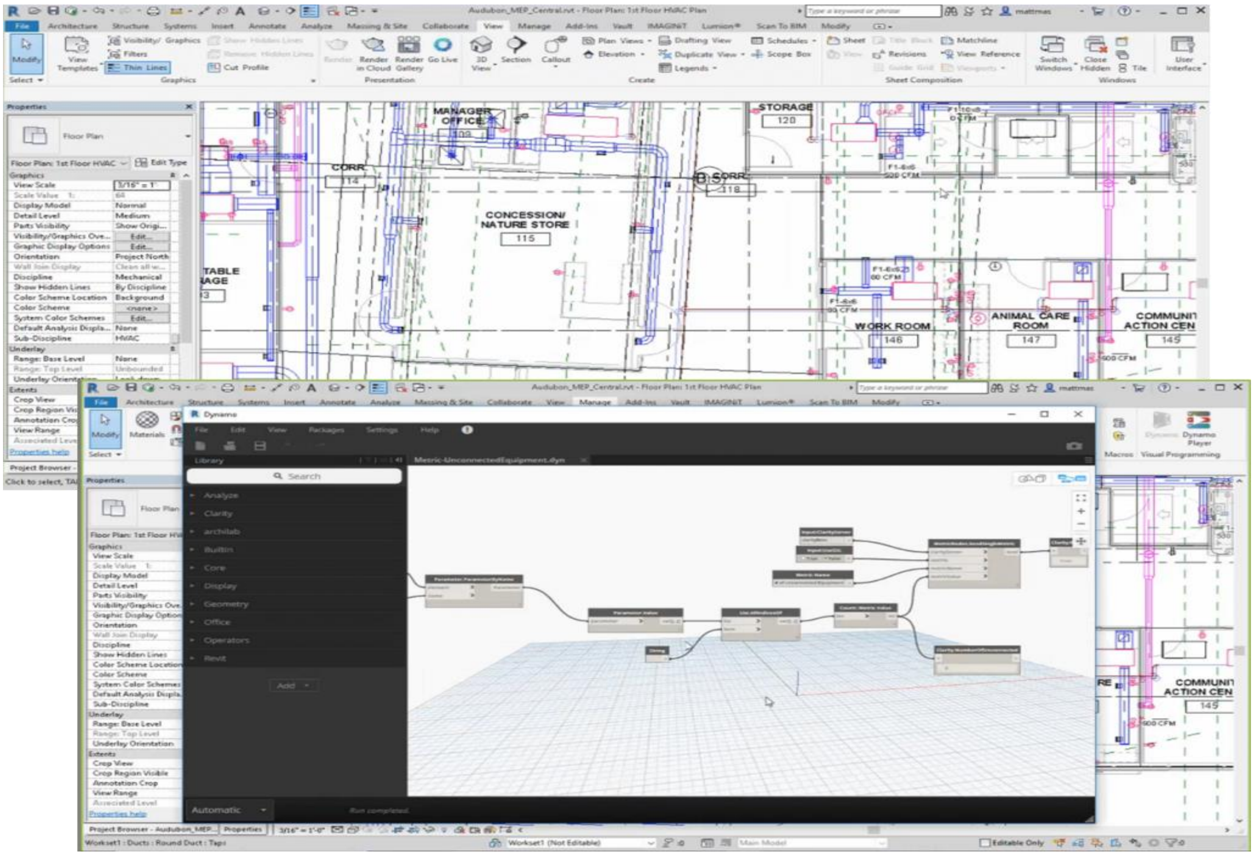


Figure 14: Automated data retrieval from BIM for FM (Dynamo and Revit).[59]

A virtual platform for handling real-time data may be created by combining Building Information Models (BIMs) with other Facility Management (FM) technologies, such as Internet of Things (IOT) sensors. Multiple data sources, such as room temperature for heat mapping, energy consumption, equipment performance metrics, and lighting in a three-dimensional environment, may be provided by BIM. This cloud-based integration of FM-BIM data and real-time data from IOT sensors:[59], [60]

- Makes sophisticated building data more accessible and organized.
- Enables more focused building operation to meet the needs of occupants.
- Generates a constantly updated “digital twin” that mirrors the physical building and assets.
- Contributes to the creation of a data repository for forecasting future operational requirements.

Owners are becoming more interested in the integration of Building Information Models (BIM) with Facility Management (FM). In order to provide sustainable, automated procedures during project closeout and operational stages, this calls for improved modeling and information documentation. Early identification of the owner's responsibilities and system requirements is critical to the success of BIM-FM integration. Developing strategies for the effective deployment of BIM for FM can be aided by early participation of FM stakeholders and assessment of FM demands.[61]

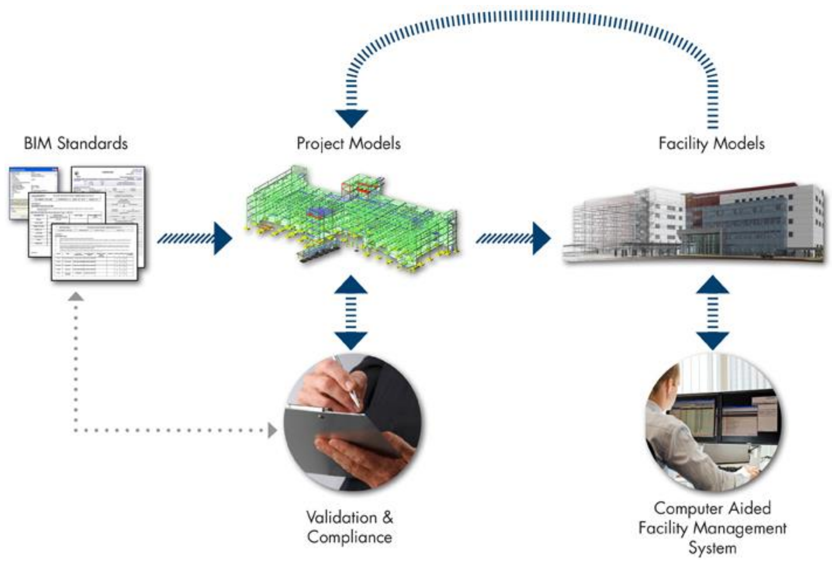


Figure 15: Strategies for the implementation of BIM for FM[59]

Despite this, the constraints imposed by the diverse modeling conventions of various AEC businesses and the intricate semantic interoperability problems they raise provide formidable obstacles. The duties and system requirements of the Owner/Operator should determine the model's content, format, and structure in order to optimize BIM for FM and simplify processes. In order to provide a shared basis for BIM-FM integration and a set of values that are important to all parties involved, these components should be recorded in a BIM Execution Plan and organizational BIM standards. By doing this, the facility's everyday operations will match the intended values, and the shift from a digital model to actual building performance will go more smoothly.[58], [59]

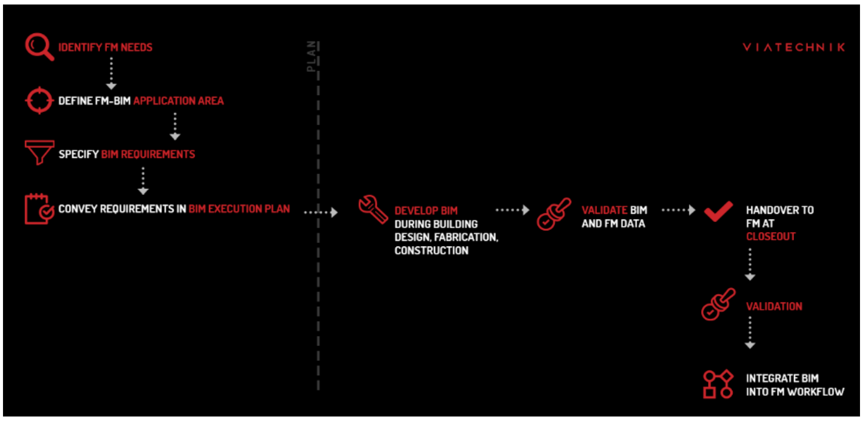


Figure 16: Setting the stage to mind the FM gap. Photo: VIATechnik[59]

BIM Applications for Facility Management in Operation & Maintenance Phase of Buildings

Applications of BIM may be seen at every stage of a facility's life cycle. These include design visualization, operations and maintenance, scheduling and sequencing, cost estimation, systems coordination, layout and fieldwork, and site planning and usage. Facilities management departments can use BIM for activities including space planning, renovations, and maintenance operations during the O&M phase.

More specifically, outlines the roles of BIM for FM as follows:

1. Providing information synchronously related to the building's service condition or performance, ownership and capacity, service duration, and financial status.

2. Offering data update records, and refining relocation plans and management.

3. Delivering physical information of the building and crucial financial data about available leasing area, rental income, and interdepartmental financial distribution.

Record modeling, maintenance planning, building system analysis, asset management, space management, and disaster planning and management are other applications of BIM in the operation phase. It is crucial to think about BIM's use in the context of the O&M phase in order to comprehend its relevance in building operation. These domains are included in operational management:[11], [62]

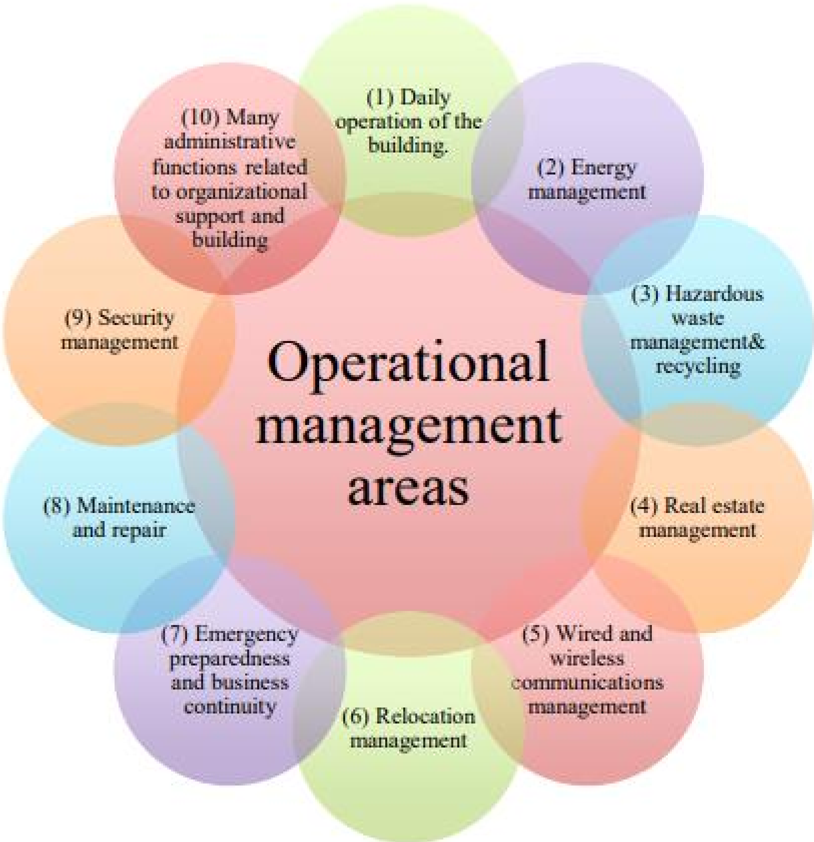


Figure 17: Operation management phases[63]

O&M Areas	BIM Use
Daily operation of the building	Equipment operating characteristics may be monitored in real time using BIM models. This aids in determining if the machinery is operating smoothly. This data may be gathered over time to produce an equipment maintenance database, which can raise management standards, increase building security, and lower the number of emergencies that occur while the facility is in use.
Energy management	Measuring waste and energy use can be aided by BIM. Facility managers may save operational costs and the impact on the environment by using it to make the study and comparison of different energy choices easier.
Real estate management	Organizations may regulate rental income, minimize vacancy, manage spaces like areas offered for lease, and eventually achieve significant reductions in real estate expenditures by integrating building data with BIM.
Wired and wireless communications management	The database is essential to BIM as it affects both the transmission capacity and the accuracy of the data input. This is a good option for task communication management and a requirement for using BIM.
Emergency preparedness and business continuity	Building management emergency response capabilities can be improved through the use of BIM techniques. It can quickly deliver vital information and pinpoint the exact location of the issue. It can manage the issue within a minimal range, even in emergency situations.

Table 1: Aspects of O&M and their BIM uses[4], [62], [64]

BIM data exchange and Interoperability

The concept of Building Information Modeling (BIM) emerged in the 1970s as the AEC industry sought ways to leverage computer technology for more efficient design and construction processes. Initially, BIM was primarily used for 3D modeling, but its scope expanded to encompass data-rich digital representations of building elements and their relationships.[65]

Over the decades, advancements in computing power, software development, and industry collaboration have propelled BIM from a novel concept to a mainstream practice. Today, BIM is integral to project delivery, facilitating collaboration, decision-making, and lifecycle management of built assets.

BIM data exchange and interoperability have evolved alongside the broader adoption of BIM in the AEC industry. From early efforts to standardize data formats to the development of collaborative platforms and workflows, the history of BIM interoperability reflects the ongoing quest for improved efficiency, collaboration, and innovation in construction projects.

The importance of BIM data exchange and interoperability cannot be overstated in today's construction landscape. As projects become more complex and stakeholders more diverse, seamless communication and collaboration enabled by interoperable BIM data are essential for delivering successful outcomes and driving sustainable growth in the industry.[65], [66]

Looking ahead, continued advancements in technology, standards development, and industry collaboration are expected to further enhance BIM data exchange and interoperability. By embracing open standards, investing in interoperable tools and platforms, and fostering a culture of collaboration and innovation, the AEC industry can unlock the full potential of BIM to address current challenges and shape the future of construction.[7], [66]

Data exchanges between two applications are typically carried out in one of the four main ways listed below:

- Direct, proprietary links between specific BIM tools.
- Proprietary fi le exchange formats, primarily dealing with geometry.
- Public product data model exchange formats.
- XML - based exchange formats.

The development of standardized formats such as Industry Foundation Classes (IFC), COBie, and STEP has been crucial for enabling interoperability among disparate software platforms.

These formats facilitate the exchange of BIM data while preserving its integrity and meaning across different systems.

Industry Foundation Classes

The Industry Foundation Classes (IFC) is an open file format, neutral to any platform, and created by buildingSMART. It establishes a structure and guidelines for data related to construction and building. IFC, being an open format, allows the file’s structure, build-up, and terminology to be viewed and utilized. It is tailored specifically for the construction industry, employing terms like building, storey, and space. The IFC schema is defined using the EXPRESS data definition language, and IFC data files are text files that adhere to the STEP physical file format. EXPRESS data definition language is a standard that outlines how data is structured and referenced. The STEP physical file format is a widely used text language for data exchange. Model View Definitions (MVD) are a part of the IFC framework, which is used for exchanging data related to construction. This data can encompass material quantities, FM, programming, and H&S. IFC Model files are designed to contain only a portion of the complete IFC framework.[67], [68]

Since IFC is a framework, models—also known as Model View Definitions—are exported as a subset of IFC. For example, COBie corresponds to FM Basic Handover, an MVD. When utilizing IFC2x3, the common MVD for transferring design models is the Coordination View. IFC2x3 is the most widely used and implemented version of the IFC, despite IFC4 being the most recent version (which is now on its second addendum).[67]

IFC4 Addendum 2 was issued in 2016, while IFC2x3 was released in 2006. The format is seldom updated and is comparatively stable. Newer versions mostly introduce new features and solve issues, however maintaining backward compatibility is still a goal. The IFC format is positioned as a long-term accessible way to save model information because the schema structure is also maintained inside the export itself.[67], [69]

IFC Exports and structures

Specific file formats are associated with design software, such as Autodesk Revit and ArchiCAD. Since apps can read native files, sharing model data between firms using the same software is simple. It's not ideal to force a certain piece of software on a team, though, as not every project member may have access to the original design software. The open IFC file format becomes important at this point. The file formats required for data sharing should be specified by project regulations, which are established through a BIM Execution Plan (BEP) and an Employer's Information Requirements (EIR). Designers will export their design model as an IFC file as necessary. Since data must be mapped from the source model to the IFC format, this procedure might be complicated. Although much of this work has been automated—either by the program or by add-ins—some manual mapping may still be required for some data parameters.

Despite their initial complexity, the data in IFC files is legible since they are text files. The File Header, File Data, Project Spatial Data, and Element or Object Data are the four separate portions that make up an IFC file. The file name, IFC version, and IFC MVD are among the details included in the file header. Unit definitions and author details are provided in the File Data section. Although they are in the same part overall, Project Spatial Data and Object Data provide distinct information. While object data offers parametric information such as color, material qualities, and thermal properties, spatial data describes a graphical item's shape, position, and physical attributes.[70], [71]

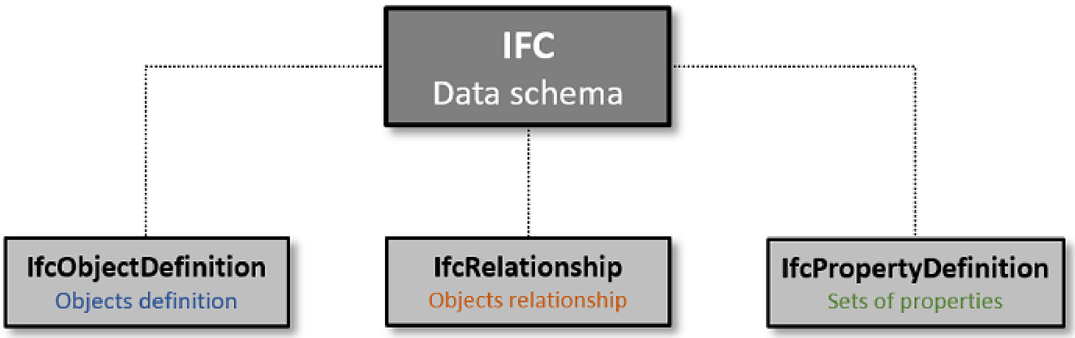


Figure 18: Exporting an IFC file and Model Checking through IFC model viewer.[72]

There are many different types of model viewers available, some with extensive capabilities like construction workflow simulation and interference testing, such as Naviswork. But all you really need if you're trying to confirm that model exports are accurate is a basic IFC viewer. The interfaces and command set of these viewers are easy to use.

Here are a few IFC model viewers you might find useful for checking models:

- Autodesk Viewer
- Solibri Model Viewer
- BIMer Viewer
- BIM Viewer Online
- UsBIM Viewer+

These viewers are fantastic since you may upload files straight to their free web versions. This implies that you may view your IFC files from anywhere, including on mobile devices like tablets and smartphones, and that you can verify your exports without downloading any additional software.

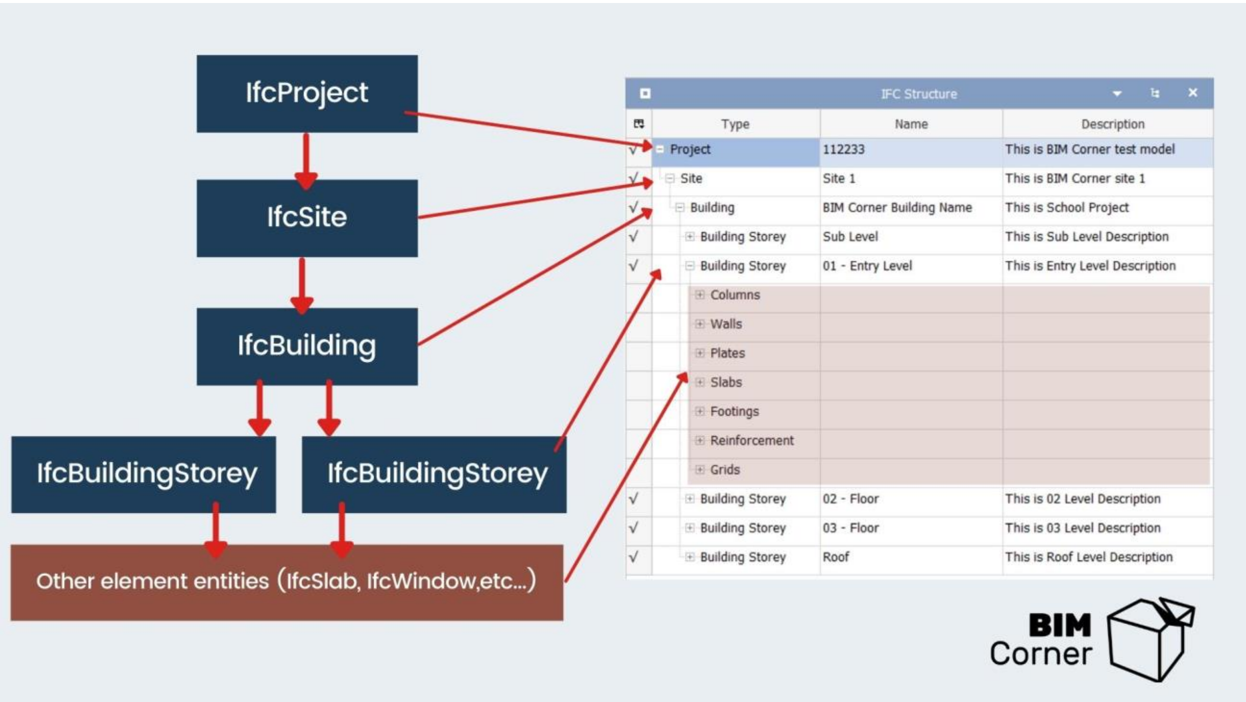


Figure 19: Interoperability between IFC and BIM[73]

Since most widely used software operates in silos, interoperability has become a hurdle. The intricacy inside the sector is also heightened by individual suppliers who are keen to launch their merchandise into the marketplace. This issue emphasizes how urgent it is for the Building Information Modeling (BIM) community to step up efforts to provide open-source techniques. Furthermore, there is a continuing discussion in the industry on the kind of facility data that need to be provided, as well as the best time and manner for doing so.

Software applications with IFC and BIM features

	Deployment
BEXEL MANAGER	BEXEL Manager aims to improve the efficiency of construction projects by integrating BIM, BOQ generation, and project management capabilities into a single software platform. It offers a comprehensive solution for managing construction projects, from design coordination to quantity takeoff and cost estimation.
costx	a comprehensive construction estimating and takeoff software that supports integration with BIM models. It allows you to import IFC files and link the BOQ items with the BIM components for accurate quantity extraction and cost estimation
BLUEBEAM	primarily known as a PDF markup and collaboration tool, Bluebeam Revu also offers quantity takeoff functionalities. It supports integration with BIM models and allows for linking BOQ items to the corresponding elements in the model using IFC data.
innovaya	a software solution that combines BIM, estimating, and project management capabilities. It supports the creation of BOQs, quantity takeoff, cost estimation, and project tracking, all integrated with BIM models .
PriMus Computo e Contabilità	Procore's platform is offered as an online, cloud -based app for desktop computers. Procore is also available via iOS, Android, and Windows mobile apps. it offers one of the largest selections of third -party product integrations through the Procore Marketplace.

Figure 20: Software used for the interoperability between IFC and BIM Author

Construction Operation Building Information Exchange COBie

A subset of IFC called COBie (Construction Operations Building Information Exchange) was created to solve these issues. The goal of the recently introduced BS 1192-4, which replaces COBie-UK-2012, is to address the problems with the earlier standards and enable more effective building asset acquisition and management. Improving interoperability using a cloud-based strategy is a hot issue that is frequently seen as the best course for future development. The industry should focus on creating cloud-based, web-based BIM exchanges that incorporate SML (Simple Markup Language) files with IFCs. A specific information model that meets the demands of FM experts and provides advantages in the field of cloud-based BIM has been made possible by the introduction of COBie.[6], [74]

A standardized protocol called the COBie schema was created to collect and provide vital BIM information for asset management during a facility's operational phase of life cycle. Delivering COBie data for different building components, such rooms and technical equipment, is often done using spreadsheets.

The original purpose of COBie was to make as-built data importation into FM systems easier. Nonetheless, the labor-intensive, disjointed, and complicated nature of its execution has drawn criticism. Even while COBie can offer the format needed for information sharing, it frequently finds it difficult to help the owner find and request certain semantic data in accordance with FM information needs.[5], [75]

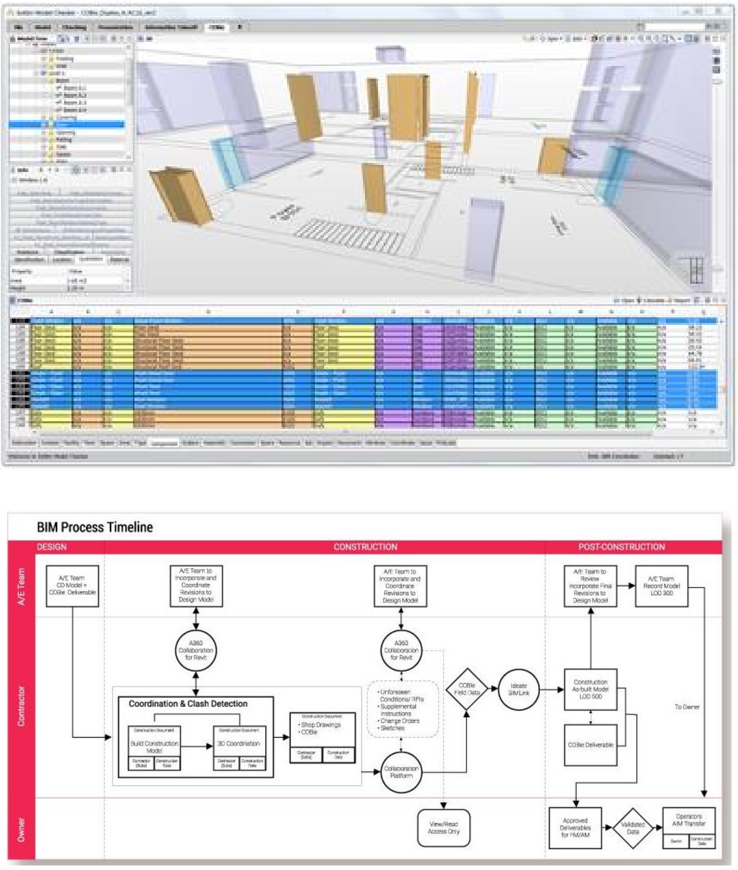


Figure 21: Spreadsheet using the COBie standard.[76]

Level of Development LOD

When it comes to Building Information Modeling (BIM), it is imperative to begin with well-defined goals that have been mutually agreed upon both the designer and the customer. These goals serve as a roadmap for establishing an information model development approach. The degree of detail, which is established depending on the requirements determines the model's quality.

The degree of growth and the amount of detail are the two main ideas at play here. The quantity of information that directly advances the project's development is referred to as its degree of development. On the other hand, the degree of detail pertains to all the data that is present in a BIM piece.[1]

It's crucial to remember that when all of the model's data is relevant to the project's design, these two levels may overlap. This overlap makes sure that every bit of data is necessary to complete the building process.

LOD is a standard that enables practitioners in the AEC industry to precisely define and communicate the dependability and content of BIMs at different phases of the design and building process, according to the BIMForum Committee of the Associated General Contractors. LOD200, for instance, denotes that the Model Element is a generic system, item, or assembly with approximate quantities, size, form, placement, and orientation that is visually represented inside the model. [77], [78]

Moving from LOD100 toward LOD500, additional details are often provided by increasing the precision and amount of both visual and non-graphic information for model pieces according to their respective LOD level. According to the LOD categories, the specification is more akin to a language that users may use to specify these needs for their own businesses or initiatives. The Level of Detail (LOD) in Building Information Modeling (BIM) is guided by many international standards. These consist of American, British, and Italian standards.[79]

The idea of LOD as a mix of two elements—the visual representation of a project (Level of Geometry, or LOG) and the data associated with the objects in the BIM model (Level of

Information, or LOI)—is a common thread throughout these standards, especially the British and Italian ones.[79], [80]

This implies that a project's geometric component and its informational content are inextricably linked. They add to a thorough grasp of the project and are not distinct entities but rather two sides of the same coin.

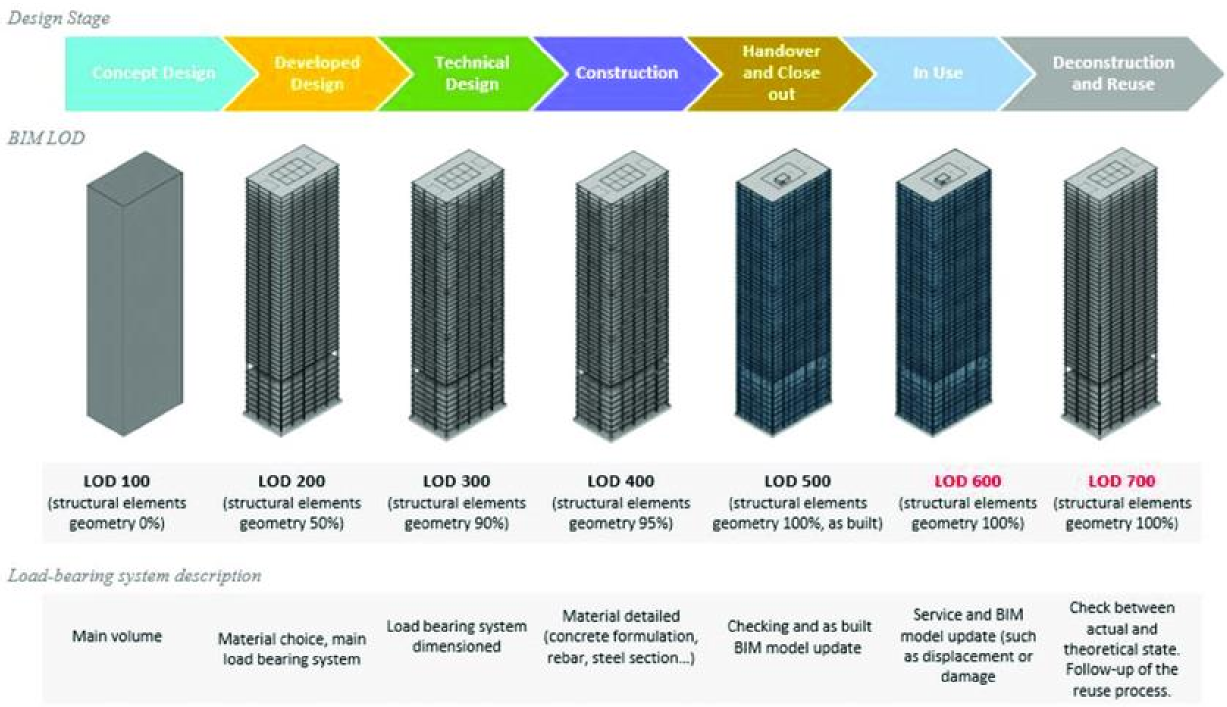


Figure 22: Graphical representation of LOD.[81]

Object-oriented modeling

Building Information Models (BIMs) provide a three-dimensional representation of buildings, complete with detailed data on all components. This allows for automated access, sorting, and examination of the model, making it useful throughout the lifespan of a building.

The key to BIMs is their logical structure and the clear definition of objects, which are crucial for more advanced applications beyond simple visualization. BIMs are designed around objects and are inherently adjustable, blending physical elements with smart behaviors that can be tailored using a mix of geometric and non-geometric parameters and rules.

The elements within the model are governed by a network of relationships, rules, conditions, and constraints, all of which are established within a component family. The values assigned to these parameters can differ between model elements based on their individual settings.[82]

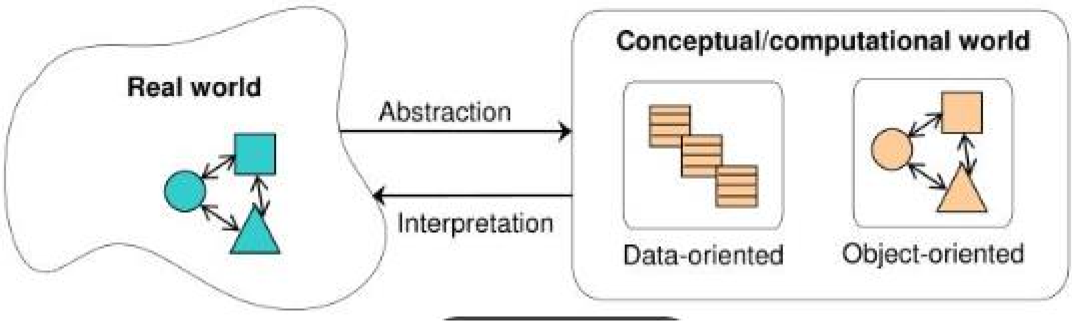


Figure 23: Relative parameter for object oriented modeling. [6]

This method has numerous advantages. It allows for automatic adjustment and alteration of element properties, enables automatic updates in the model following minor changes, and facilitates the extraction of model data for analysis during various stages of the project lifecycle.[58], [83], [84]

New Proposed Method

Grasping the Significance of Revit and BIM in Building Implementation

In the domain of building design and implementation, it's vital to comprehend the significance of various tools and methodologies. Consider Revit as an example. Like many other software, Revit has a constraint - it's unable to access files generated in versions superior to its own. This requires that the entire process be executed using a pre-set version from the beginning. This crucial aspect must be integrated into the Building Execution Plan (BEP).[85]

Nonetheless, it's important to note that applications like Revit are merely tools. They aid the process but are not capable of independently generating a Building Information Modeling (BIM) product. BIM is not a software, but a methodology. It's an all-encompassing strategy that manages a range of workflows, not just the creation of a model.

Therefore, as we explore further into the sphere of building implementation, let's bear these subtleties in mind. After all, the first step towards successful implementation is understanding the tools and methodologies available to us.

Indeed, managing information in Revit is crucial for efficient project execution. At a graphical level, the model data can be managed by:

1. **Project Browser Organization**: The Project Browser is a key tool for navigating and managing views in Revit. It allows users to organize, sort, and filter views to streamline the design process.
2. **Creation of New Views**: Creating new views can help manage the model data by allowing users to focus on specific aspects of the model. These views can be standard, plan, section, 3D, or drafting views.
3. **Display Filters**: Display filters in Revit allow users to control the visibility of specific elements in a view based on certain criteria. This can greatly aid in managing the complexity of the model.

4. **Planning Tables**: A tabular portrayal of the model elements, together with their attributes and parameters, is provided by planning tables. With its ability to provide a thorough overview of the model data, this is a very effective information management tool. When modifications are made to the model, the tables are immediately updated, guaranteeing that the data is always current.

These methods, when used effectively, can greatly enhance the management of information in Revit, leading to more efficient and accurate project execution.[86]

The Evolution of Infrastructure Maintenance:

A BIM based optimized Approach.

In the realm of infrastructure maintenance, the application of Building Information Modeling (BIM) has emerged as a transformative approach. This research study delves into the key steps involved in the application of BIM, with a focus on differentiating between the design, construction, and operation phases.

The cornerstone of this method proposal is the creation of a comprehensive database right from the design phase. This database serves as a valuable resource during the subsequent construction and operation phases. It's noteworthy that certain phases were already defined prior to the introduction of the BIM method. While these phases continue to exist, their execution has been redefined due to the contrasting philosophies of the traditional and BIM methods.

The culmination of this BIM application is a singular 3D model of the infrastructure. This model encapsulates all the requisite information for the effective conservation management of the infrastructure. It's a testament to the power of BIM in revolutionizing infrastructure maintenance, offering a more streamlined and efficient approach to managing and preserving our built environment.

In the realm of digital construction, the Building Information Modeling (BIM) methodology serves as the foundational framework. The initial BIM authoring software employed in this study is Autodesk Revit. This software is renowned for its comprehensive capabilities spanning various domains such as architectural design, MEP engineering, structural engineering, and construction.

The methodological workflow proposed in this research incorporates a variety of digital tools. A key inclusion is the Industry Foundation Classes (IFC) format, an open and neutral data model that ensures interoperability among different software used in the construction and facility management sectors.

The workflow also integrates free software capable of interacting with the BIM model. Notable examples include solutions from manufacturers such as ACCA, known for software like Edificius, and Trimble Navigation, recognized for products like SketchUp and Tekla Structures. Another tool incorporated in the workflow is sheet link an add-in developed by Diroots which is a freeware software solution designed specifically for the AEC industry in maintenance sector.

The workflow further leverages office packages, which could range from the Microsoft Office Suite, providing Word for document processing, Excel for data analysis, and PowerPoint for presentations, to Google Workspace, offering similar functionalities with the added advantage of cloud storage.

As the research progresses, additional tools enhancing the BIM workflow will be introduced. These could include visualization tools like Lumion, collaboration platforms like BIM 360, and many more. Each tool will be elaborated upon in detail as they are encountered in the research process.

This research aims to unravel the intricacies of BIM methodology and the digital tools that facilitate its implementation, providing valuable insights for the field of digital construction.

This necessitates the exploration of an efficient methodology that enables engineers to leverage the advantages of information models without the prerequisite of owning licenses for BIM authoring software or the need to download and master the use of costly Facility Management software.

To facilitate this, a comprehensive understanding of information sharing methods, particularly the utilization of the Industry Foundation Classes (IFC) format, is crucial. The IFC format is an open, data model standard that enhances interoperability in the building industry, making it a vital component in this context.

To evaluate the efficacy of the proposed workflows, a rudimentary model has been assumed as a prototype case study using Autodesk Revit. This model will serve as a practical example, guiding the implementation of the processes under study. This hands-on approach not only tests the workflows but also provides tangible insights into their real-world application.

A unique methodology was formulated as a prototype case study. The process unfolded as follows:

As-built BIM Model

The goal is to develop a tool that makes it simple to access updated documentation and quickly extract the necessary data. Because of this, it's essential to employ the BIM technique, which enables improved control over the whole planning process without requiring the updating of every single CAD file. The goal is to develop a BIM system that links all relevant management data from the technical registry to maintenance and cost savings, beginning with the setup of parametric building models.

This paper explores the potential benefits of Building Information Modeling (BIM) for facility and maintenance management using an analytical methodology that draws on several case studies. This method makes it possible to fully analyse and understand the crucial function that BIM technology plays in both the operation and maintenance phase as well as the delivery phase, which includes design and construction.

1. **Data Analysis and Development**:

The initial step involved a thorough examination of the information and blueprints related to the project. For instance, consider a building which includes various facilities such as research offices, classrooms, and laboratories. It spans multiple floors and has a specific orientation features a unique roof design that accommodates mechanical equipment. It also has a specific rainwater drainage system. The interior finishing varies across different floors and rooms, with a range of materials used for floor and ceiling finishes. The exterior doors and windows of also have specific design features.

The 2D architectural designs, technical documents, service manuals, and information on the materials used for the façade, floors, and walls were all given by the building management.

We constructed the model using Autodesk Revit, as per our expectations. The fire safety system, HVAC system, plumbing system, and architectural design are all included in this model. The goal of the model is to contain just the most necessary components. This straightforward strategy was used to make scheduling regular inspections and creating maintenance logs easier. This methodology offers a simplified and effective approach to building management by allowing us to concentrate on the essential systems and their upkeep requirements.

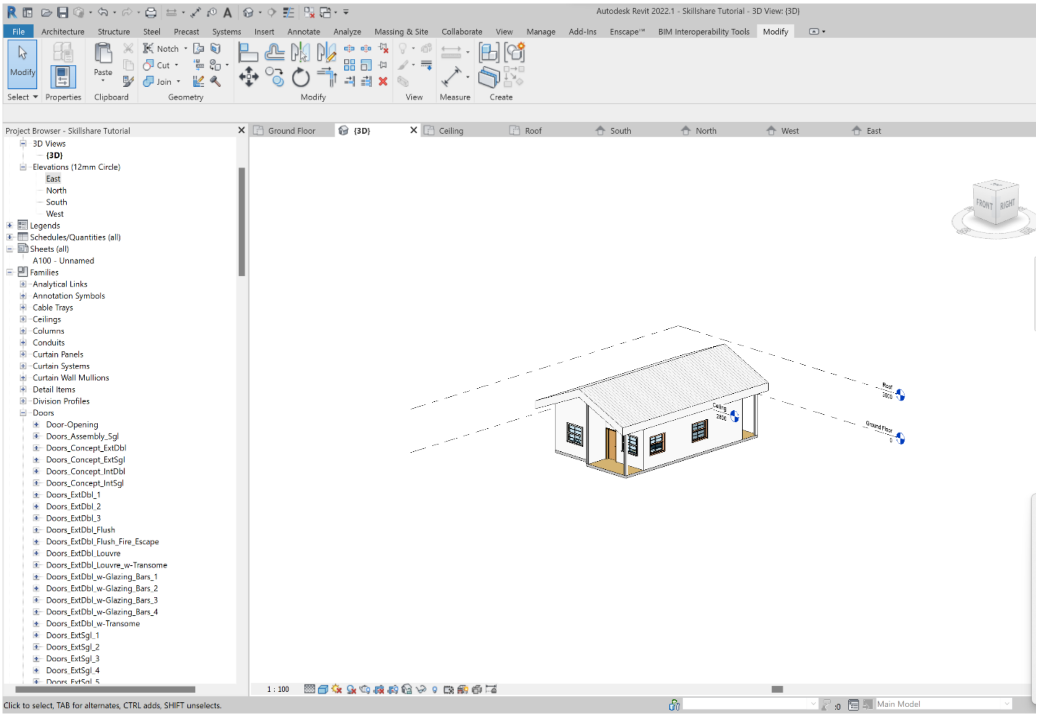


Figure 24: Model creation using Revit.[87]

Figure 25 presents the integration of the various systems in the as-built BIM model.

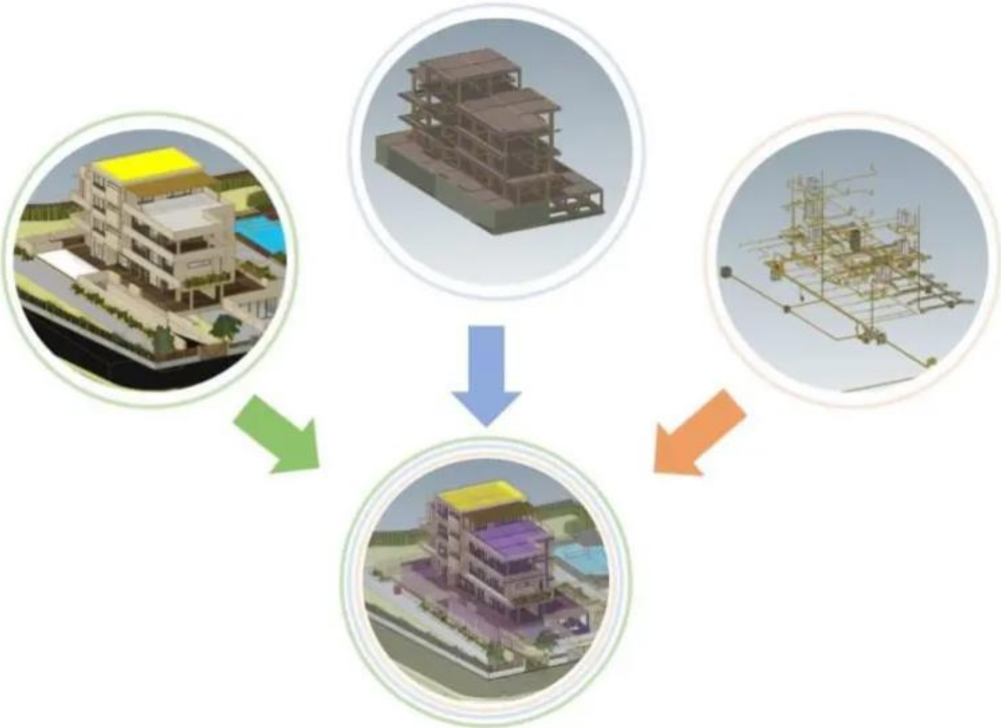


Figure 25: Assembled the As-built BIM model from different disciplines.[88]

2. **Parametric Information Integration**:

In the subsequent stage of our research, the intend is to incorporate parametric data into the corresponding architectural components, thereby enriching the model's intricacy and utility. Revit allows for the creation of three distinct types of parameters:

- Project Parameters
- Shared Parameters
- Global Parameters

The specifics of these parameters can be found on the official Autodesk website. We introduced parametric data into the architectural elements using shared parameters. In Revit, shared parameters are assigned to various object families and carry a range of information, specifically data pertaining to the construction elements and their associated maintenance activities. This approach enhances the depth and functionality of our architectural models.

Focusing on shared parameters, it is easy to understand their usefulness. Their operation allows, as mentioned, the sharing of data between different projects and files, which is a fundamental aspect of Facility Management.

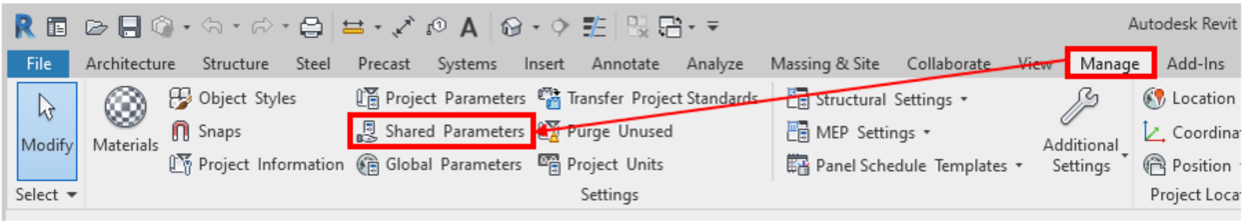


Figure 26: Creation of shared parameter in revit.[89]

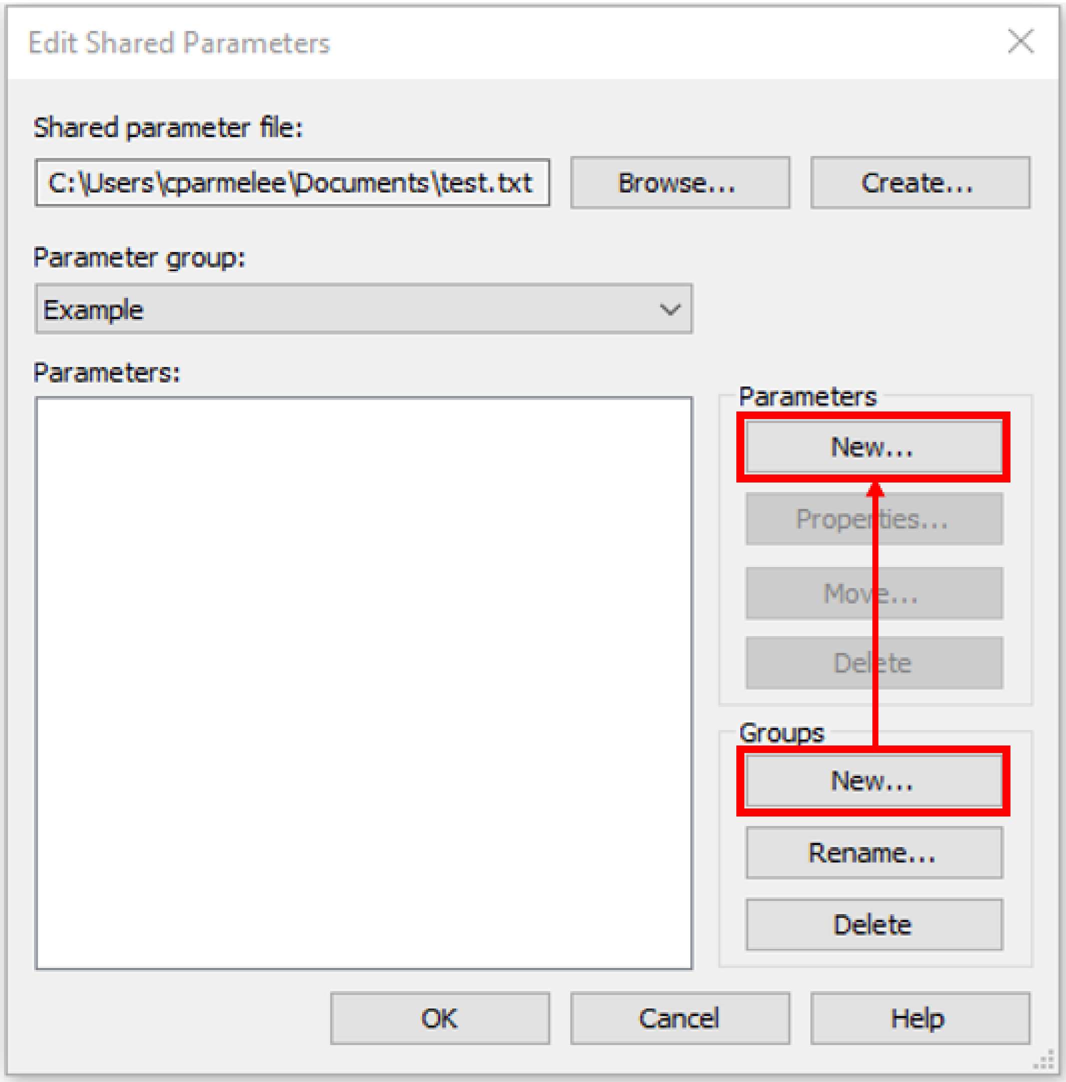


Figure 27: Shared parameter panel.[89]

we utilized shared parameters due to their versatility and adaptability. These parameters are independent files that can be imported into various families or projects as required. This feature allows for a high degree of customization, though limited to two specific data points:

- the name of the parameter
- the discipline or type of parameter

This approach provides us with a flexible and efficient way to manage and manipulate our data across multiple projects or families.

3. **Omniclass Standard Application**:

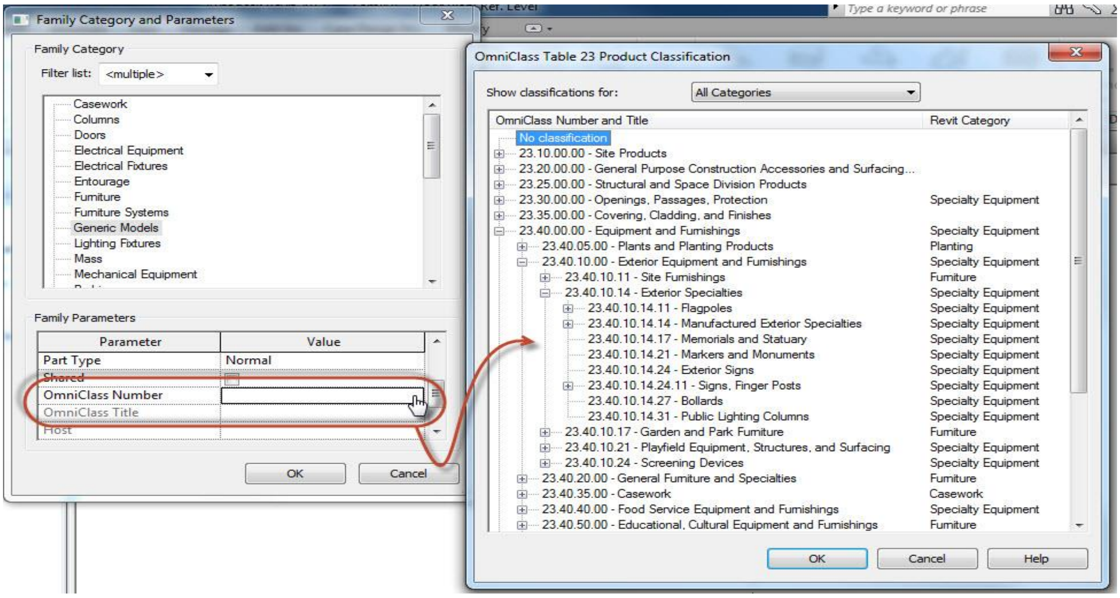
In the realm of Architecture, Engineering, and Construction (AEC), the OmniClass Construction Classification System (OCCS) plays a pivotal role. It's a key component of Building Information Modeling (BIM), a process that allows for the efficient organization and categorization of project information.

The OCCS is a widely recognized classification system that offers a standardized method for arranging, sorting, and accessing information throughout the entire lifecycle of a facility, from its inception to demolition or repurposing.

The International Organization for Standardization (ISO) Technical Report 14177 - Classification of information in the construction sector, released in July 1994, provided a global foundation that the OCCS is in accordance with. Later on, this study was transformed into ISO 12006-2: Organization of Information on Construction Works - Part 2: Framework for classification, which is now a standard.

There are fifteen tables in the OCCS, each of which represents a different facet of construction data. These tables can be used to categorize more complex subjects, or they can be used separately to classify certain kinds of information.

The segmentation of information kinds into a collection of distinct, coordinated tables is the basis of the OCCS tables' structure. A particular facet or viewpoint of the overall information accessible in the built environment is the basis for the organization and content of each table.



To guarantee consistency and interoperability, the Revit software was integrated with the Omniclass standard, a categorization system designed for the construction sector. Omniclass is a technology that, when applied to a Revit model, classifies areas according to a predetermined purpose. This method is quite helpful since it lets us determine the upkeep needs of individual components according to the precise area they are located in. When considered a component of this technique, this procedure makes it easier to manage spaces and the related maintenance requirements in a way that is more human-centric and efficient. It also provides a more approachable manner for handling and comprehending complicated construction data.[90]

4. **Maintenance Plan Development**:

A thorough examination was necessary in order to manage and maintain the construction items in an efficient manner. The purpose of this examination was to list the elements that are present in each area, together with the materials that make them up and their current state. A computerized data gathering tool that uses an Excel spreadsheet and has many drop-down options to make it simple to input all relevant information about the building's areas and goods may be built to speed up this procedure. Because of this, we were able to produce a database that, taking into account the state of the building and its elements, offers a precise and trustworthy graphical depiction of the current structure. This data is especially important for the development and continuous updating of the maintenance schedule. This database creation can be done with the help of the above OCCS defined.

In the field of established structures, the execution of building condition evaluations is crucial for the development of fitting maintenance strategies tailored to each specific case. A preventive maintenance blueprint was formulated to select building components, with the objective of enhancing their longevity and augmenting their functionality.

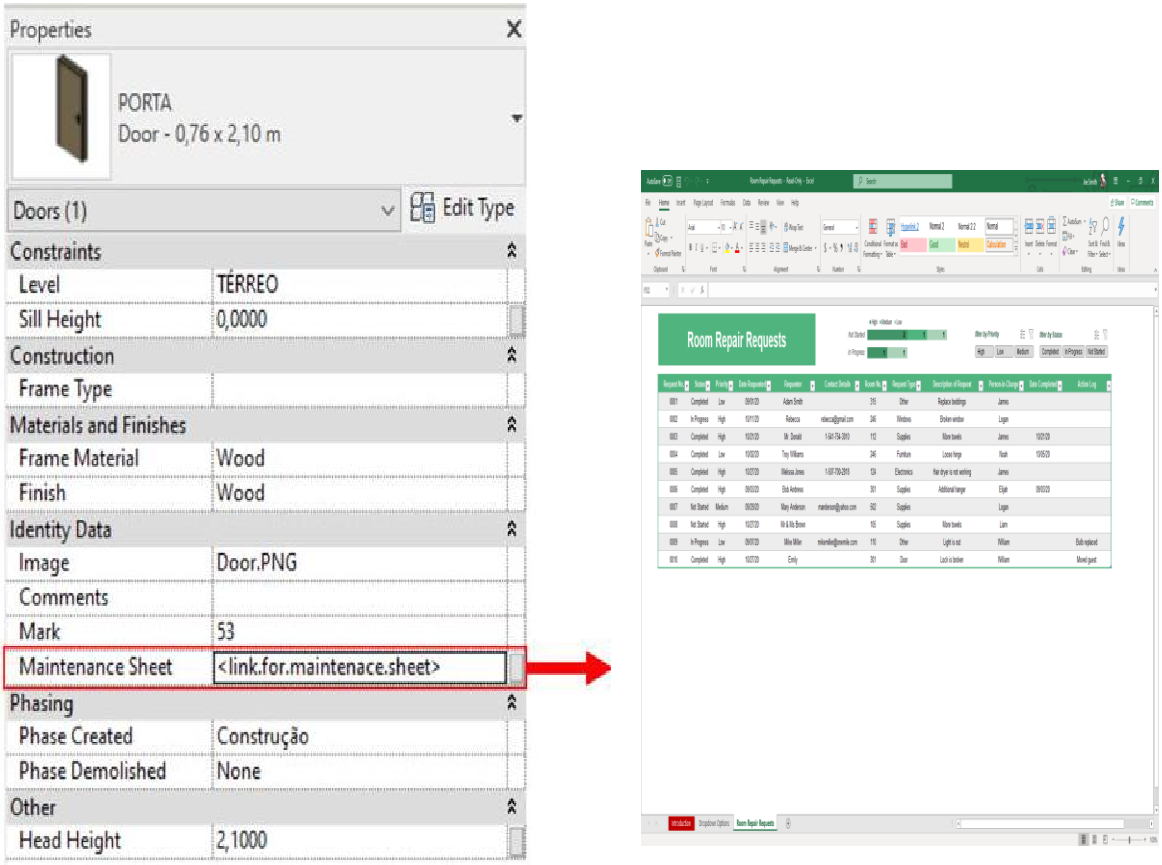


Figure 28: Development of maintenace plan and connecting it to revit

In due course, the data derived from the preventive maintenance were integrated into a 3D model via the utilization of shared parameters as discussed previously. Upon the establishment of these shared parameters, the maintenance-related data was correspondingly linked to each individual object. This methodology underscores the significance of a systematic approach in building maintenance, paving the way for more streamlined and effective management practices.[91]

5. **Dynamo Routine Development**:

Considering the inefficiencies associated with the manual method of compiling parameters, characterized by the cumbersome process of selecting numerous model elements, a more streamlined and functional approach was necessitated. Particularly in projects of standard size, where the volume of modeled objects is substantially larger, the integration of simplified or automated methods for assembling design parameters becomes pivotal for efficient data management. Therefore, a Dynamo routine was developed to establish a bidirectional interaction between Revit and Excel, facilitating efficient data exchange.

Building Information Modeling (BIM) is a cooperative approach where interoperability between various software is a key characteristic. Specifically, the interoperability between Excel and Revit software can be achieved through two methods of automated data synchronization.

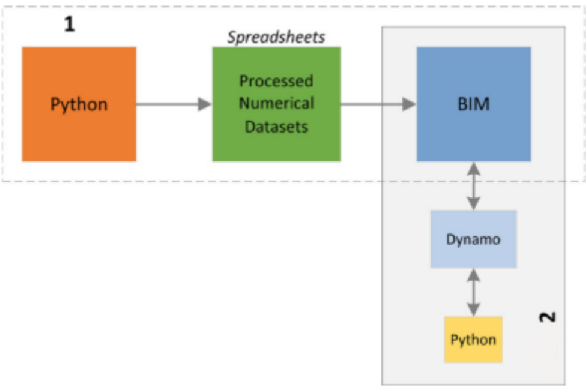


Figure 29: Two methods of data exchange. author[92]

In Revit, this synchronization is accomplished using Visual Programming. An add-in called Dynamo extends Revit's parametric functionality. It enables Python programming, which is translated from Revit using Nodes. These Nodes facilitate the creation of 'scripts', which are custom algorithms for data processing and new geometry creation.

Dynamo proves to be highly beneficial for various tasks related to data management, information retrieval, and the generation of operation and maintenance deliverables in the format requested by the end-user.

An example of graphical representation taken from a case study [92]

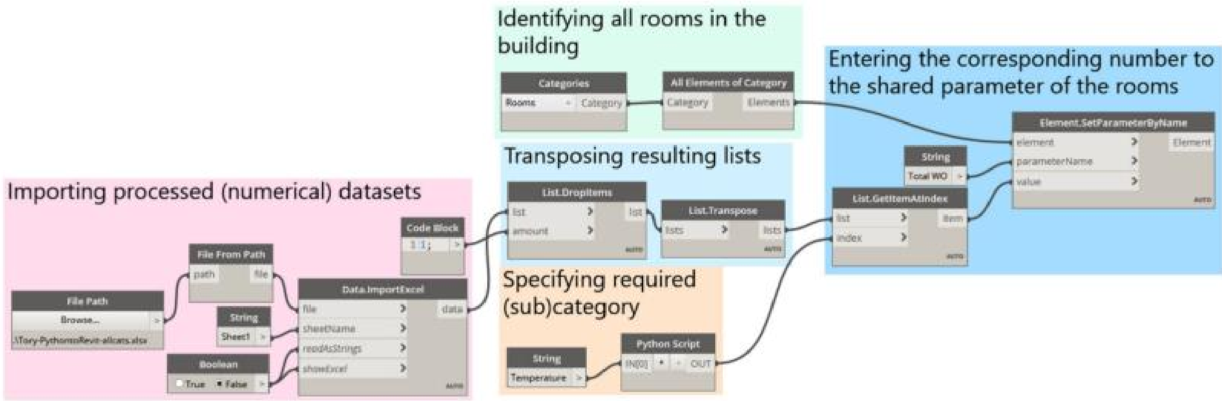


Figure 30: Tool 1, data extraction from excel and exporting it to BIM[92]

In this instance, an example of an algorithm created using visual programming is depicted in the preceding figure. This figure showcases a portion of the visual programming developed on the Dynamo BIM software interface.

In the methodology being explored, Microsoft Office Excel is employed as an auxiliary tool for the characterisation of parameters. Two methods are available to establish a connection between Excel and Revit: the first involves the reapplication of Dynamo, while the second utilises a plug-in that is compatible with the BIM software, which will be discussed in the following stage.

To activate a bidirectional link between Revit and Excel, an additional visual programming algorithm is required to ensure the successful importation of data from the Excel file to Revit, as illustrated in the subsequent figure. This process necessitates the deployment of two distinct scripts: one for exporting the schedules developed in Revit to an Excel

Element	Type	Build Up	Thickness - mm	Volume of Material / m² of area	Total Area (m²) - From MAT 01	Volume A - From MAT 03	Volume - From MAT 04	Supplier	Product
External Walls	Rainscreen Cladding on SFS	High Pressure Laminate	0.01		561.6	5.616		Trespa	Meteon Panel
		Rigid Insulation	0.09		561.6	50.544	50.544	Kingspan	K15 Rigid Board
		Cement Particle Board	0.012		561.6	6.739		Cembrit	Cempanel Cement Particle Board
		SFS		0.001	561.6	0.562			
		Vapour Barrier	0.002		561.6	1.123		DuPont	Tyvek AirGuard Reflective
		2 x Plasterboard	0.015		561.6	8.424		Siniat	GTEC dB Board & GTEC Universal Board
	Metal Cladding Projection	Metal Cladding	0.0012		56.8	0.068		Kalzip	Kalzip FC Rainscreen System
		Rigid Insulation	0.09		56.8	5.112	5.112	Kingspan	K15 Rigid Board
		Cement Particle Board	0.012		56.8	0.682		Cembrit	Cempanel Cement Particle Board
		SFS		0.002	56.8	0.114			
		Vapour Barrier	0.002		56.8	0.114		DuPont	Tyvek AirGuard Reflective
		2 x Plasterboard	0.015		56.8	0.852		Siniat	GTEC dB Board & GTEC Universal Board
	Metal Cladding Projection (External Only)	Metal Cladding	0.0012		37.5	0.045		Kalzip	Kalzip FC Rainscreen System
		SFS		0.002	37.5	0.075			
	Brick Cladding on SFS	Face Brickwork	0.1125		236.8	26.640		Ibstock	Brunswick Autumn
		Rigid Insulation	0.06		236.8	14.208	14.208	Kingspan	K12 Rigid Board
		Cement Particle Board	0.012		236.8	2.842		Cembrit	Cempanel Cement Particle Board
		SFS		0.001	236.8	0.237			
		Vapour Barrier	0.002		236.8	0.474		DuPont	Tyvek AirGuard Reflective
		2 no Plasterboard	0.015		236.8	3.552		Siniat	GTEC dB Board & GTEC Universal Board
	Brick Block Cavity Wall	Face Brickwork	0.1125		50.2	5.648		Ibstock	Brunswick Autumn
		Rigid Insulation	0.06		50.2	3.012	3.012	Kingspan	K12 Rigid Board
		Blockwork	0.1		50.2	5.020		Plasmor	Stranlite Paint Grade
		2 x Plasterboard	0.015		50.2	0.753		Siniat	GTEC dB Board & GTEC Universal Board
	Retaining Wall	Bitumen DPM	0.001		15	0.015		Visqueen	Gas Resistant Self Adhesive Membrane
		Concrete Retaining Wall (Concrete)	0.3			45.000			
		Concrete Retaining Wall (Steel)		0.0189	15	0.284			

Figure 31: maintenance plan exported from Revit.

spreadsheet, and another for re-importing the data from Excel back to Revit.

In cases where the data to be incorporated is already available and merely needs to be inserted within Revit's shared parameters, only the second Dynamo script is required. The commands used for this purpose include File Path, File from path, and Data.ImportExcel.

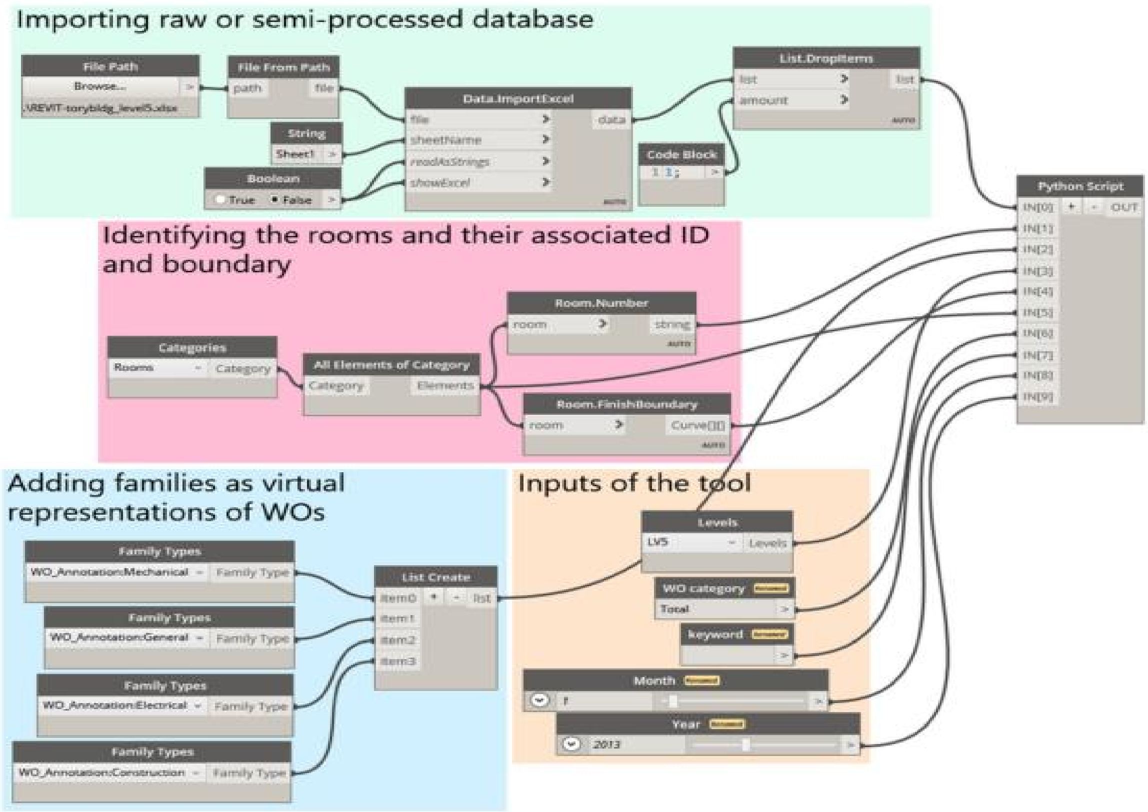


Figure 32: Tool 2,visual programming in Dynamo for the data importation from Excel to Revit.[92]

The initial segment of the script designates the Excel sheet to be processed. The components marked in blue represent the data fields from Excel that are slated for importation into Revit. The elements highlighted in orange are utilized to define the shared parameters of the model that are intended for an input.

6. **SheetLink Testing**:

Visual programming is recognized as a process that requires substantial time investment. This type of programming is comprehensive and inherently involves the development of schedules in Revit.

Therefore, in this section different plug-ins will be discussed which will help to introduce the utilization of the SheetLink to forge a bidirectional connection between Revit and Excel, contrasting this technique with the prior method. The SheetLink tool was tested to further enhance the bidirectional interaction between Revit and Excel, offering an alternative for data synchronization.

Step	Description
Select Elements by Category	Categories is the default choice when creating an Excel file. You must select an elemental category. For instance, you can choose the category of doors.
Adjust the Selection Option	By default, the generated Excel file will contain all of the model's doors. The Selection option at the top of the menu can be changed. You can choose to choose all doors from the current active view by switching to Active View instead of Whole Model.
New Selection Option	Alternatively, you may select the New Selection option, which enables you to make a selection window to choose particular parts.
Select the Parameters	SheetLink will prompt you to select the parameter you wish to export when your selection is complete. To add particular characteristics, use the arrows.
Use an Existing Schedule	Rather than choosing individual components and settings, you may just choose a pre-existing Revit timetable. From the Type dropdown box, choose the Schedules option on your left. Next, choose a particular timetable inside your Revit model.
Export to Excel	To save a.xlsx file after choosing elements and parameters, select "Export to." Open the file with any spreadsheet viewer, such as Excel.

Table 2: Steps for Table 2: Steps bidirectional interaction between Revit and Excel[93]

A software add-in created by Diroots called SheetLink is already included in the Revit version 2022. As seen in the previous table, this add-in enables a two-way data transfer between a Revit model and an Excel file. All produced parameters that have been allocated to different objects can be extracted by it.

With SheetLink, you may use well-organized and structured Excel files to provide smooth synchronization between Revit and Excel through import and export options. Moreover, any changes made are immediately reflected on both platforms. By ensuring data quality and consistency, this improves the efficiency of the modeling and architectural design processes.

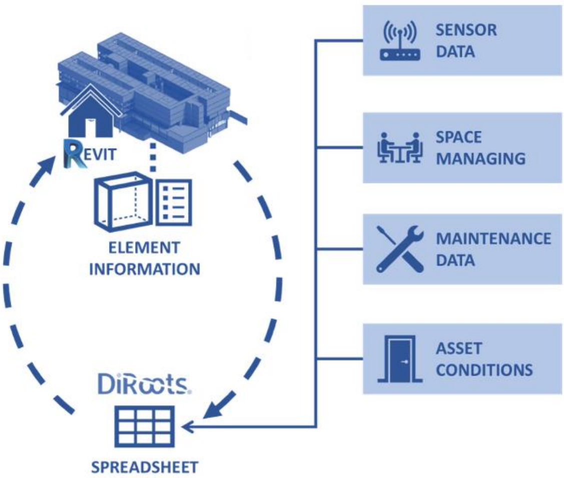


Figure 33: the interface for BIM data using DiRoots plug-in[94]

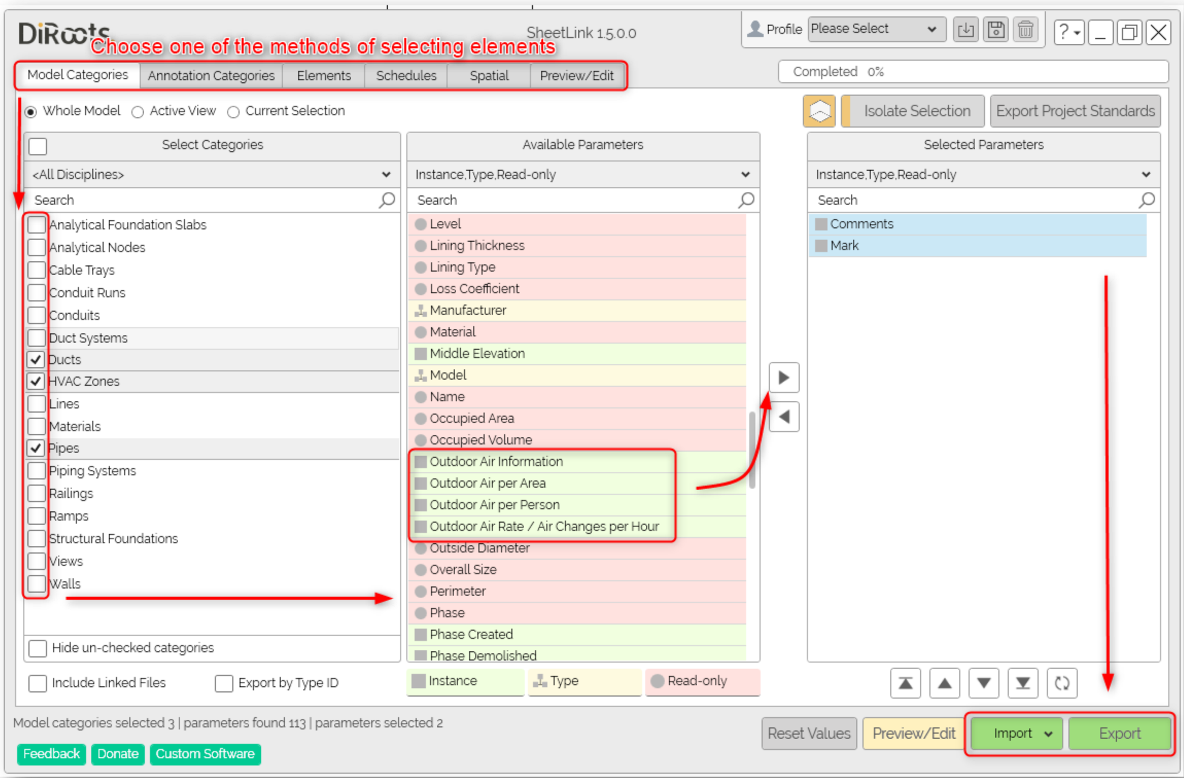


Figure 34: layout and selection of the parameters to extract from Revit

	B	C	D	E	F	G	H	I
2	Element ID Custom Parameter	NO. String Instance Identity Data	FROM ROOM Schedule Parameter	TO ROOM Schedule Parameter	TYPE String Type Identity Data	HEIGHT Double Type Dimensions	WIDTH Double Type Dimensions	MATERIAL String Instance Materials and Finishes
3	309292	99			P1	2100	1800	
4	366919	100	001		P2	2134	750	
5	366954	101	109		P2	2134	750	
6	366991	102	108		P2	2134	750	
7	367103	103	107		P2	2134	750	
8	367157	104	106		P2	2134	750	
9	367424	105	105		P2	2134	750	
10	367735	106	101		P2	2134	750	
11	367847	108	102		P2	2134	750	

Figure 35: Excel Spreadsheet created for Maintenance

The Excel spreadsheet acts as a dynamic platform where information is organized in a methodical manner and may be modified in order to be imported again into Revit 2022. It is clear that SheetLink improves synchronization efficiency by streamlining the procedure and removing the need for post-exportation data modifications. By ensuring a smooth data management experience, this raises the efficiency of architectural design and modeling operations overall.

This methodological approach provides insightful information for future study and applications while highlighting the potential of BIM and associated technologies to revolutionize infrastructure maintenance.

Standalone software used for Maintenance and Control in Construction

The standardization of maintenance procedures emerges as a potent strategy to enhance operational efficiency, reduce maintenance costs, and bolster the overall effectiveness of maintenance operations. The absence of standardized procedures within an organization can led to inconsistencies, potential risks, and irregularities during maintenance operations. These irregularities can compromise the quality of work, shorten the lifespan of assets, and in severe cases, pose safety hazards to employees and the public.

In response to these challenges, an increasing number of companies, particularly medium to large-scale enterprises, are turning to specialized software to augment their facility management activities. A growing trend has been observed in recent years where companies are transitioning from traditional methods to digitalized activity management. This transition allows companies to exert greater control over their operations, including maintenance, which is viewed in this context as maintenance process management.

Once the objectives and budget have been defined, the selection of appropriate software becomes a critical and intricate step. This complexity arises from the vast array of software options available in the market, each offering different functionalities and objectives. Therefore, the choice of software becomes a pivotal decision in the pursuit of operational efficiency and effectiveness.

Advancements in Construction Management: A Focus on Maintenance and Control

In the dynamic world of construction, the need for efficient maintenance and control is paramount. Standalone software solutions have emerged as game-changers, offering specialized functionalities that cater to various aspects of construction project management. This article delves into the advantages of some commonly used software in the construction industry, focusing specifically on their benefits in the domain of maintenance and control.

PlanGrid

PlanGrid revolutionizes real-time collaboration, management, and updating of project plans, blueprints, and documents. Its standout feature is the ability to create and track punch lists, manage RFIs (Request for Information), and generate progress reports. This aids in maintaining control over project progress and ensuring timely completion. Moreover, PlanGrid's mobile apps provide on-site access to project information, enhancing field-level collaboration and control.[95]

PlanGrid is a construction management software that facilitates real-time collaboration. It offers several advantages:

- Streamlined Document Management: PlanGrid allows teams to manage and update project plans, blueprints, and documents in real-time.
- Enhanced Collaboration: The software provides a platform for teams to collaborate effectively, reducing the risk of miscommunication and errors.
- Mobile Accessibility: With its mobile apps, PlanGrid ensures on-site access to project information, enhancing efficiency and productivity.

Procore

As a cloud-based construction management platform, Procore excels in managing project documents, schedules, budgets, and communication. It offers modules for project management, quality and safety, financials, and field productivity, providing comprehensive control over various project aspects. Procore's integrations with third-party software solutions enable specialized functions like BIM coordination and equipment management, further enhancing maintenance capabilities.[96]

Procore is a cloud-based platform that offers a comprehensive suite for managing construction projects. Its benefits include:

- Project Management: Procore helps teams manage project documents, schedules, budgets, and communication.
- Quality and Safety: The platform includes modules for quality and safety management, ensuring high standards are maintained throughout the project.

- Integration Capabilities: Procore can integrate with various third-party software solutions, facilitating specialized functions such as BIM coordination and equipment management.

Fieldwire

Designed for field collaboration, task management, and document control, Fieldwire allows users to create and assign tasks, track progress, and share files and documents with team members. Its features such as plan viewing and markup, issue tracking, and daily reporting are instrumental in maintaining control over field operations and ensuring effective task management.[97]

Fieldwire is designed for field collaboration, task management, and document control. Its advantages are:

- Task Management: Fieldwire allows users to create and assign tasks, track progress, and share files and documents with team members.
- Real-time Collaboration: The software facilitates real-time collaboration, ensuring all team members are on the same page.
- Offline Functionality: Fieldwire works offline, ensuring work can be done even without an internet connection.

BuildingConnected

This preconstruction platform streamlines the bidding process, manages subcontractors, and tracks project opportunities. It facilitates sending and receiving bids, comparing subcontractor proposals, and tracking project costs and budgets, thereby providing control over preconstruction activities. BuildingConnected’s integrations facilitate data exchange and workflow automation, enhancing overall project control.[98]

BuildingConnected is a preconstruction platform that streamlines the bidding process. Its benefits include:

- Streamlined Bidding Process: The platform helps contractors manage subcontractors and track project opportunities.

- Cost Tracking: BuildingConnected allows users to track project costs and budgets, facilitating better financial management.
- Integration Capabilities: The software integrates with various construction management and accounting software solutions, facilitating data exchange and workflow automation.

e-Builder

e-Builder assists owners and contractors in managing project schedules, budgets, documents, and contracts. Its features for capital planning, procurement, cost control, and reporting provide robust control over project finances and schedules. e-Builder's customization options and integrations meet the specific needs of construction projects, ensuring effective maintenance and control.[99]

e-Builder is a construction program management software that offers several advantages:

- Project Management: e-Builder helps owners and contractors manage project schedules, budgets, documents, and contracts.
- Capital Planning: The software includes features for capital planning, procurement, cost control, and reporting.
- Customization Options: e-Builder offers customization options and integrations with other software systems to meet the specific needs of construction projects.

Bluebeam Revu

his PDF-based collaboration software aids construction professionals in creating, marking up, and sharing project documents and drawings. Its tools for reviewing and commenting on PDF files, measuring quantities, and creating custom markups and annotations enhance document control. Bluebeam Revu's features for document organization, version control, and real-time collaboration further bolster maintenance capabilities.[100]

Bluebeam Revu is a PDF-based collaboration software with several benefits:

- Document Review: Bluebeam Revu includes tools for reviewing and commenting on PDF files, measuring quantities, and creating custom markups and annotations.

- Real-time Collaboration: The software offers features for document organization, version control, and real-time collaboration.

Autodesk BIM 360 Ops

Designed for building owners and operators, this mobile-first maintenance management software enables users to create and assign maintenance tasks, track asset performance, and generate reports on maintenance activities. Its integration with Autodesk's BIM 360 platform ensures seamless handover of building data from construction to operations, enhancing control over building maintenance.[97], [99]

Autodesk BIM 360 Ops is a mobile-first maintenance management software. Its advantages include:

- Maintenance Management: BIM 360 Ops allows users to create and assign maintenance tasks, track asset performance, and generate reports on maintenance activities.
- Integration with BIM 360: The software integrates with Autodesk's BIM 360 platform for construction project management, enabling seamless handover of building data from construction to operations.

These software solutions offer specialized functionalities for various aspects of construction project management, maintenance, and control. They are transforming the construction industry, making it more efficient, productive, and cost-effective.

Discussion

In the construction industry, maintaining buildings and structures properly is essential to their endurance, general performance, and safety. As technology becomes more and more important, new techniques for infrastructure management and maintenance control have been developed. Let's discuss the comparison between two such approaches:

- Building Information Modeling (BIM)-based optimized methods.
- standalone software solutions.

We'll examine how these approaches compare to one another in addressing the intricate problems associated with structural maintenance in the building sector. We'll explore further into the many elements, including how they manage data, their visualization capabilities, customization possibilities, and even how they interface with other systems. We hope to give construction experts useful information by highlighting the advantages and disadvantages of each method, enabling them to choose the best course of action for their projects.

Aspect	BIM-Based Optimized Method	Standalone Software
Interoperability	Integrates seamlessly with various BIM software platforms using open standards like IFC, facilitating the exchange of detailed maintenance data among different systems. This reduces the need for manual data entry, saving time and reducing errors in maintenance records.	Limited interoperability with other software, potentially requiring manual data transfers and conversions, leading to data loss or inconsistencies in maintenance information. This manual effort can result in increased labor costs and delays in maintenance tasks.
Approach	**Preventive**: Proactively identifies maintenance needs based on BIM data and RFID tags.	**Corrective**: Reactive approach, addressing issues after they occur.
Data Consistency and Integration	**Comprehensive**: Combines BIM data, sensor information, and maintenance records. Provides a unified platform for storing and managing maintenance data, ensuring consistency and integrity throughout the maintenance lifecycle. Maintenance data is integrated with building	**Limited**: Typically handles specific maintenance tasks without holistic integration. Relies on standalone databases, which may result in isolated maintenance data silos, making it challenging to integrate maintenance information with broader facility management

	information, enabling comprehensive analysis and decision-making. This integrated approach streamlines data management, reducing duplication of effort and minimizing the risk of errors in maintenance records.	systems. This fragmented approach can lead to increased labor costs associated with manual data reconciliation and reduced data accuracy.
Benefits	- **Efficiency**: Reduces time, cost, and effort compared to traditional methods. - **Predictive**: Anticipates maintenance needs before failures occur. - **Holistic**: Considers the entire building lifecycle.	- **Task-Specific**: Tailored to specific maintenance functions (e.g., HVAC, electrical). - **Familiarity**: Widely used but lacks BIM integration.
Visualization and Analysis	Offers advanced visualization capabilities, such as 3D models and interactive dashboards, allowing maintenance teams to visualize structural components, identify issues, and plan maintenance activities effectively. This visual representation enhances understanding and facilitates proactive maintenance planning, reducing downtime and maintenance costs.	Typically provides basic visualization features, limiting the ability to analyze maintenance data comprehensively and make informed decisions regarding maintenance activities. This limited visualization capability can result in longer troubleshooting times and increased maintenance costs.
Customization and Automation	Enables the creation of custom scripts and workflows using platforms like Dynamo, allowing for automation of maintenance tasks, such as scheduling inspections or generating work orders, improving efficiency and accuracy in maintenance operations. This automation reduces the reliance on manual processes, optimizing resource allocation and reducing labor costs associated with routine maintenance tasks.	Limited customization options may hinder the ability to tailor maintenance workflows to specific requirements, leading to manual and time-consuming maintenance processes. This manual effort can result in increased labor costs and delays in maintenance activities.
Lifecycle Management	Supports the entire maintenance lifecycle of a structure, from planning and scheduling to execution and monitoring, ensuring proactive maintenance strategies	Primarily focuses on reactive maintenance tasks without integration with broader facility lifecycle processes, potentially resulting in increased

	and optimizing the performance and longevity of structural components. This comprehensive approach minimizes downtime and extends asset lifespan, reducing long-term maintenance costs and maximizing return on investment.	maintenance costs and decreased asset lifespan due to inadequate planning and monitoring. This reactive approach can lead to higher labor costs associated with emergency repairs and unplanned downtime.
Integration with External Systems	Integrates seamlessly with external systems and data sources, such as IoT sensors and predictive maintenance platforms, enabling the incorporation of real-time maintenance data into maintenance workflows, enhancing predictive maintenance capabilities, and optimizing maintenance strategies. This integration streamlines data acquisition and analysis, enabling proactive maintenance interventions and reducing overall maintenance costs.	Limited integration capabilities with external systems may hinder the ability to leverage real-time maintenance data and advanced analytics for proactive maintenance planning, resulting in reactive and inefficient maintenance practices. This lack of integration can lead to increased labor costs associated with manual data entry and analysis.
Collaboration and Communication	Facilitates collaboration among maintenance teams, contractors, and stakeholders by providing a centralized platform for sharing maintenance information, enabling effective communication, and coordination in planning and executing maintenance activities. This collaborative approach enhances team efficiency and reduces miscommunication, resulting in faster response times and reduced labor costs.	May lack collaborative features, resulting in communication gaps and delays in maintenance activities due to difficulties in sharing maintenance information and coordinating tasks among teams. This lack of collaboration can lead to increased labor costs associated with duplicated efforts and inefficient communication practices.
Operating Costs	**Optimized**: Reduces costs by streamlining interventions and minimizing downtime. Offers long-term cost savings through improved efficiency, reduced downtime, and optimized maintenance planning and execution, resulting in lower maintenance costs and increased asset lifespan. The initial investment in BIM-based methods is offset by long-term savings and improved	**Varies**: Depends on the specific software and its licensing model. Initial investment costs may be higher due to software licensing and training expenses, but long-term savings may be limited by inefficiencies in maintenance processes and increased maintenance costs resulting from reactive maintenance practices. The upfront cost savings may be outweighed by higher long-term

	asset performance.	maintenance expenses.
Decision-Making	- Helps stakeholders choose the appropriate method based on evaluation. - Encourages informed decisions.	- Requires manual assessment. - May not consider long-term implications.
Future Potential	- Can integrate with other emerging technologies for enhanced value. - Continues to evolve with BIM advancements.	- Limited scope unless integrated with broader systems. - May not adapt well to changing needs.

Table 3: Comparison between BIM based methodology and standalone software

Challenges and limitations of BIM adaptation

Building Information Modeling (BIM) has been defined as "Computer Aided Design (CAD) paradigm" producing "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life cycle".

Building Information Modeling (BIM) is useful for facilities management in addition to construction. Governments support BIM as a means of promoting cooperation and reducing fragmentation within the building industry. Adoption of BIM is still hampered, though. The objective is to promote cooperation among members of the construction design team and reduce industry fragmentation.[101]

The BIM maturity levels in the UK are described by the BIM Industry Working Group (2011). Global BIM objectives have been set, and national BIM deployments are still underway in the USA, Scandinavia/Europe, and the Far East. acceptance continues to encounter obstacles because of the drastic shift in working habits necessary for its acceptance, even in the face of strong pressure from the government, clients, and other sources.[102]

Lack of Senior Management Support: Senior managers' unwillingness or resistance to implementing new technology and procedures in their companies, for a variety of reasons, including uncertainty about return on investment, a lack of vision, or a fear of change .

Doubts about ROI/Lack of Vision of Benefits: The difficulty or uncertainty of quantifying and demonstrating the financial and non-financial benefits of BIM implementation, especially in the short term.

Cost of Implementation (Software and Training): The high upfront cost of purchasing, updating, and maintaining the BIM software and hardware, as well as training the staff in the use of BIM tools and processes.

Scale of Culture Change Required: The need for a radical shift in the organisational culture, business practices, and mindsets of the stakeholders involved in BIM projects, to foster collaboration, integration, and innovation.

Other Competing Initiatives: The presence of other ongoing or emerging initiatives that may divert the attention, resources, or priority of the organisations from BIM implementation, such as quality, health and safety, and environmental standards.

Lack of Supply Chain Buy-in: The challenge of securing the competencies, interoperability, and commitment of the supply chain partners, such as sub-contractors, fabricators, and suppliers, to adopt and use BIM in a collaborative manner.

Staff Resistance and ICT Literacy: The potential opposition or reluctance of the staff to learn and use new technologies and processes, due to various factors such as lack of training, skills, confidence, or motivation, or fear of job loss or redundancy.

Legal Uncertainties: The concerns or risks associated with the legal aspects of BIM, such as ownership, liability, intellectual property, contracts, insurance, and evidence, which may not be adequately addressed or resolved by the current laws and regulations. [101], [102]

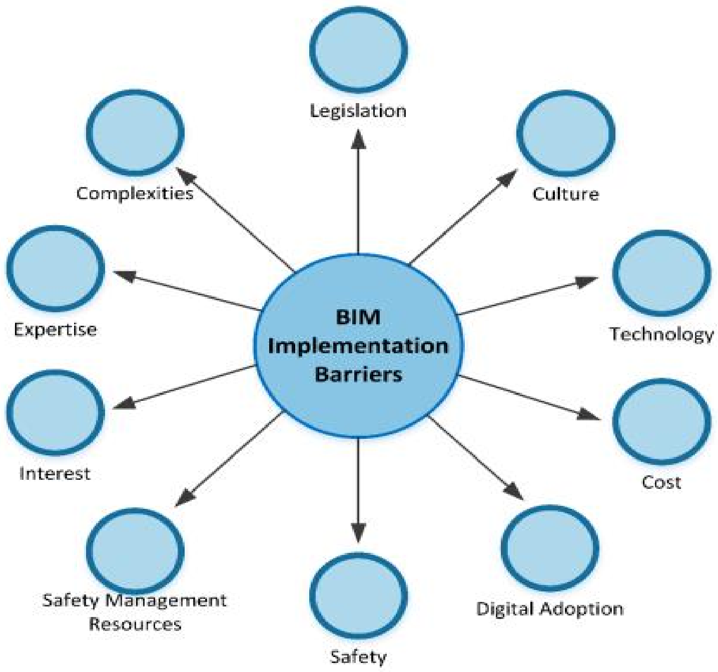


Figure 36: BIM implementation Barriers_Graphical representation.[102]

Let's create a concise table that specifically highlights the barriers related to maintenance and control in the context of building construction. These barriers can significantly impact the effectiveness of building maintenance practices:

Barrier Aspect	Description
Contracting Issues	BIM FM may not align with existing contracting methods commonly used in the industry. Compatibility challenges may arise when integrating BIM-based contracts with traditional approaches.
Interoperability Issues	Existing software tools utilized by FM stakeholders (such as computerized maintenance management systems) may not seamlessly integrate with BIM platforms. Lack of interoperability hinders data exchange and collaboration.
Proof of Effectiveness	Conservative mindsets or reliance on conventional methods may demand empirical evidence demonstrating the benefits of BIM for FM. Demonstrating its effectiveness becomes crucial for wider adoption.
Unknown Benefits	Awareness of BIM's potential advantages for FM might be limited. Clear communication about how BIM can enhance maintenance efficiency, cost savings, and overall building performance is essential.
BIM Marketing Focus	BIM marketing efforts predominantly target design and construction phases. Consequently, facility managers may not perceive BIM as directly relevant to their maintenance and control responsibilities.
Privacy Concerns	The use of digital software (including BIM) raises privacy and security questions. Facility managers need assurance that sensitive data (e.g., maintenance records, occupant information) remains protected.
BIM Continuity	If BIM was routinely applied throughout design and construction, it would be more likely to be adopted for FM. Effective FM is hampered by BIM data handover discontinuities.
BIM Familiarity	Facility managers who lack familiarity with BIM and associated technologies may face difficulties in navigating BIM models, interpreting data, and leveraging BIM for maintenance tasks.
Legal Framework	The absence of a well-defined legal framework specifically addressing BIM in the FM phase can create uncertainty. Legal

	guidelines are essential for contractual obligations, liability, and data ownership.
Research and Development Gap	While BIM has advanced significantly in design and construction, research and development specific to BIM for FM lags behind. Best practices, standards, and tools need further refinement.
Training Costs	Training facility management staff to effectively use BIM tools can be expensive. Adequate training ensures competent utilization of BIM data for maintenance purposes.
Software and Hardware Costs	Investing in BIM software licenses, hardware infrastructure, and maintenance systems can be financially demanding. Balancing costs against long-term benefits is critical.
Information Quality Issues	The accuracy, completeness, and reliability of information stored within BIM models impact FM decisions. Inaccurate or incomplete data undermines effective maintenance planning.
Best Practice Guidelines	While BIM standards exist, specific guidelines for BIM in FM are limited. Comprehensive best practices are essential to guide facility managers in leveraging BIM effectively.
Software Providers Landscape	Multiple private software providers offer BIM-related tools. This diversity can lead to confusion, inconsistency, and challenges in selecting the most suitable software for FM.
Fragmented Data Systems	BIM data may not be stored uniformly or in a centralized format. Fragmentation complicates data retrieval, updates, and synchronization across various FM tasks.
Regulatory Promotions and Incentives	Policymakers and regulatory bodies play a crucial role in promoting BIM adoption for FM. Lack of incentives or clear directives may hinder its widespread use.
BIM Training Availability	Availability of proper BIM training programs tailored for FM professionals is essential. Bridging the knowledge gap ensures effective utilization of BIM tools.
Reluctance to Change	Facility managers may resist adopting BIM due to reliance on existing operational methods. Convincing stakeholders of the

	benefits and managing the transition is challenging.
BIM Experience Gap	The lack of practical experience in implementing BIM for FM poses hurdles. Building expertise and confidence among facility management teams is crucial.

Table 4: Represents the barriers aspect and its description in Facility Management[101], [102]

Conclusion

In this thesis, an attempt was made to conduct a comprehensive analysis and put forward strategies to improve building control and maintenance, with a focus on utilizing the optimum BIM-based methodology. The excursion started with a comprehensive overview of the BIM technique, exploring its foundational ideas and uses. We then went into great detail to examine the several advantages that come with using it in infrastructure management projects. By focusing on the field of building maintenance operations, we were able to hone down on the specifics of control management while still offering a wide picture.

The goal is to suggest a maintenance and control methodology grounded in BIM procedures. With these objectives in focus, we compared the utilization of licensed platforms and software tailored for facility management, which typically necessitate a license, against the adoption of freeware and BIM-based methodology.

Let's start by identifying the similarities across different workflows. Both maintenance software and free software typically begin by creating and organizing a digital model or adjusting an existing one if needed. Exporting the model in the IFC exchange format is also often a necessary step, regardless of the software used or its intended purpose.

It's clear that integrated Facility Management software provides helpful features, like automatically creating databases or linking seamlessly with BIM authoring software, which are missing in free software. As a result, to achieve similar results, the latter requires integrating functions through connected applications and extra external steps.

In our ongoing exploration of Facility Management (FM), a significant finding has emerged: the often-overlooked importance of Preventive maintenance. Despite its critical role in sustaining building performance, preventive maintenance has not received the attention it deserves within the Architecture, Engineering, Construction, and Operation sector. This gap has led to the development of a BIM-based optimized methodology tailored specifically for preventive maintenance. Without a structured maintenance plan, efficient building maintenance management becomes unattainable, jeopardizing the building's operational integrity. Leveraging BIM methodology, this approach consolidates comprehensive building life cycle information into a unified platform, fostering continuous updates and mitigating data fragmentation, ultimately reducing associated data collection costs. Moreover, it promotes interdisciplinary collaboration by facilitating the seamless exchange of digitally shared information among stakeholders. In essence, this research underscores the transformative potential of integrating preventive maintenance practices within a BIM framework, emphasizing the collaborative nature of this approach and its potential to optimize resource utilization and enhance overall project outcomes.

Several criteria for maintenance plans in BIM objects were presented by this study. It investigates a two-way connectivity between Revit and Excel using two techniques to improve information management for both BIM users and non-users:

- Developing a Dynamo Routine
- Using the SheetLink (Revit add-in developed by Diroots).

These techniques have clear benefits and drawbacks. The choice of approach is determined by the particulars and intricacy of the project. The first approach, which makes use of a Dynamo procedure, can be laborious and could produce intricate programming routines that could include mistakes. It entails making a timetable in Revit, exporting it, and maybe adjusting it by hand. It is required to be compatible with Revit versions, Dynamo, and the Bumblebee package. But this approach allows for more customization and flexibility with regard to extra instructions.

Using the free add-in SheetLink, which is compatible with Revit, is the second way. All data pertaining to BIM objects may be exported and imported with ease because to its user-friendly interface. Unlike the previous way, scheduling doesn't need to be made in advance in Revit. The extracted data is structured properly and doesn't need to be altered by hand. This improves automation and efficiency over utilizing the Dynamo procedure for the particular goal described in this study.

Given the project's specific nature, the freeware employed for control management proved sufficient for the process's requirements. This adequacy was achieved either through inherent program functions or integration with other software. However, if a more detailed or comprehensive approach had been desired, involving multiple activities simultaneously, the utilization of various software solutions might have been more suitable.

The research examines how Revit, Dynamo, and Excel can communicate with each other in both directions and shows how to modify, export, and import data for ongoing changes. It illustrates how readily methods or add-ins may be accessed across both platforms, allowing for seamless data extraction and manipulation in Revit or Excel. Furthermore, the approach which was first created for the upkeep of already existing structures can be modified for use in the maintenance of newly constructed buildings in the future. It may be used to a variety of building kinds and equipment that calls for thorough maintenance procedures.

This dissertation undertook a comprehensive comparison between BIM-based methodology and standalone software, with a particular emphasis on cost, time, and human resource training.

Cost is a crucial factor in choosing a methodology, with integrated management software often starting with free demos before transitioning to paid licenses. These costs, along with expenses for personnel training, should be seen as investments with potential long-term benefits. Careful consideration is needed in selecting the appropriate software, with cost analysis ideally integrated into the decision-making process.

In contrast, freeware offers a cost-saving alternative, but an overemphasis on prevention may inflate total costs without sufficiently reducing corrective maintenance expenses. Therefore, the choice of software is pivotal and must be tailored to budget constraints and specific circumstances.

It is proposed that the procedures shown with freeware can also handle more complex models with good results. Theoretically, the more specific a model gets especially with regard to operational timing the more advantageous it may be to use software that can create databases and handle control inside them. This is particularly important in situations when various sites and multiple models are involved in maintenance management.

Research highlights the value of BIM-based approaches for building maintenance and control by utilizing BIM capabilities throughout the building life cycle. Organizations may improve maintenance procedures, promote teamwork, and cut costs by utilizing BIM capabilities and investigating alternative software option.

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