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ENHANCING BUILDING MAINTENANCE EFFICIENCY THROUGH BIM-LIDAR INTEGRATION

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Abstract

Facility Maintenance Management constitutes a significant portion of building costs, emphasizing the need for innovative approaches to enhance efficiency. This paper introduces a novel methodology for transforming point cloud data into Industry Foundation Classes (IFC) models. This method involves a meticulous point cloud classification and a subsequent conversion into a visually appealing mesh representation. This mesh is then linked to IFC entities, enabling the creation of comprehensive and semantically rich BIM models. A case study on the Civil Engineering Building at the University of Cambridge demonstrates the methodology's effectiveness, showcasing improved visualization and supervision of maintenance tasks. The contribution lies in the refined point cloud classification, mesh conversion, and seamless integration with IFC, providing a novel and efficient solution to existing challenges. The results underscore the potential for revolutionizing maintenance practices in existing buildings.

Introduction

The aging of buildings accentuates the imperative for effective maintenance, constituting over 65% of total building costs (Matos *et al.*, 2020; Alavi, Bortolini and Forcada, 2022). Despite this, facility managers frequently depend on conventional methods which can be inefficient and time-consuming (Juricic, Krstić and Čulo, 2021; Alavi and Forcada, 2022).

The integration of BIM with various technologies allows for the creation of 3D information models for facility maintenance and administration work, ultimately enhancing productivity. However, one major challenge in utilizing BIM for maintenance activities is the lack of a BIM model for existing buildings (Alavi and Forcada, 2019). This paper addresses this gap by introducing a novel "Scan-to-BIM" methodology. The implementation of LiDAR technology confidently converts point cloud data into a mesh format, providing a solid foundation for creating extremely accurate as-built BIM models (Antah *et al.*, 2021). The proposed methodology aims to enhance maintenance activities in existing buildings where there is no BIM model available. The paper aims to outline the utilization of LiDAR technology to obtain point cloud data of existing buildings and convert it into a mesh format, which can serve as a foundation for assigning relevant Industry Foundation Classes (IFC) information to different building components.

This method enables the development of an as-built BIM model that precisely depicts the current state of the building. Once created, this model can be integrated with a Computerized Maintenance Management System (CMMS) to simplify maintenance tasks. Each maintenance request from the CMMS can be associated with the applicable components in the as-built BIM model, making it easy for maintenance personnel to find and evaluate maintenance needs.

Literature Review

To enable effective maintenance activities during the O&M stage, a diverse range of data is required in BIM (H. Alavi *et al.*, 2021; Fan *et al.*, 2023). Furthermore, Nicolle and Cruz (Nicolle and Cruz, 2011), emphasize the need for precise data on installed components in buildings to achieve effective BIM implementation in the O&M phase. These kinds of data might not be available in many existing buildings due to imperfect and deficient, obsolete, or disintegrated building information (Gursel *et al.*, 2009). The significant difference between enabling BIM for FM in new buildings and existing buildings is the lack of as-built, CAD files as well as insufficient and outdated information of the buildings (Becerik-Gerber *et al.*, 2012; Hamidreza Alavi *et al.*, 2021). Missing this kind of information might lead to ineffective building management, uncertain process results and time loss or cost increases in facility management processes (Alavi and Forcada Matheu, 2022).

In recent years, the integration of BIM and LiDAR has emerged as a promising approach to create as-built BIM models for existing buildings and maximize building maintenance efficiency (Shin and Cha, 2023). This integration offers a robust framework for capturing detailed building information and leveraging it for effective maintenance processes. One of the key advantages of this integration is the ability to create 3D information models for facility maintenance (Wang, Guo and Kim, 2019; Liu, 2022). By integrating LiDAR data in BIM, it becomes possible to enhance the productivity of maintenance and administration work in facilities. This approach allows for a more rapid detection of faults or potential faults and a significant reduction in maintenance costs.

Multiple studies have explored the benefits and limitations of using LiDAR technology in combination with BIM for facilities management. These studies have highlighted the importance of accurately capturing the existing building conditions through LiDAR scans and converting them into BIM models (Brilakis *et al.*, 2010; Juan, Hwang and Kim, 2020; Liu, 2022). The study conducted by Hong Kong researchers focused on utilizing Scan-to-BIM, which combines terrestrial laser scan data with BIM, to perform quantity take-offs for estimating building maintenance costs (Sing *et al.*, 2022). This demonstrates the potential of LiDAR technology and BIM integration in enhancing maintenance activities by providing precise information for cost estimation and planning. Additionally, another study emphasizes the automation of the Scan-to-BIM process through semantic labeling. This study proposes an integrated system called Auto-Scan-To-BIM that automates the generation of a complete BIM model from scanned point cloud data. The Auto-Scan-To-BIM system utilizes region segmentation methodology and enhanced plane boundary line detection methods to accurately identify and analyze building elements from the point cloud data (Suprun *et al.*, 2022). Furthermore, research has also focused on the integration of BIM and LiDAR technology for quality management during the maintenance phase (Begić and Galić, 2021). Moreover, scan-to-BIM technology supports the creation of accurate as-built models that can be used by facility managers and stakeholders in maintenance operations. The integration of scan-to-BIM technology extends the value of BIM to the lifecycle of buildings, contributing to improved facility management and maintenance practices. The practicality of implementing the Scan-to-BIM approach in maintenance projects for existing buildings has not been widely explored, despite its potential benefits for creating accurate as-built models and improving facility management practices (Sing *et al.*, 2022). To address these limitations, this article proposes a methodology for enhancing maintenance activities in existing buildings using LiDAR technology and the scan-to-BIM process.

Methodology

The methodology involves utilizing LiDAR technology to capture point cloud data of the existing building. It is important to note that when processing point clouds, several challenges arise, including occlusions, misclassification, and identifying hidden elements. Occlusions occur when objects obstruct parts of the building, leading to incomplete or distorted point cloud data. Misclassification refers to the incorrect labeling of point cloud points, which can result in inaccuracies in subsequent modeling processes. Similarly, identifying hidden elements, such as structural components obscured from view, poses challenges in capturing comprehensive building information. To address these challenges, innovative approaches, such as deep learning and machine learning algorithms, were used to improve the identification of hidden elements and enhance the overall accuracy of the resulting BIM model.

The existing point cloud data is then processed and converted into a mesh representation of the building. Then, the methodology oversees creating IFC instance models to store building components created out of a laser scan. It is divided into four parts, as illustrated in Figure 1: (i) point cloud classification; (ii) point cloud conversion; (iii) the IFC model creation; and (vi) CMMS integration and visualization.

The first step in the methodology is point cloud classification. During this step, the point cloud data is classified and labeled to identify different building elements such as walls, floors, ceilings, doors, windows, and some MEP elements. Models created using the data contained in point clouds can be used for constructing an accurate representation of existing facilities by measuring their geometry and appearance.

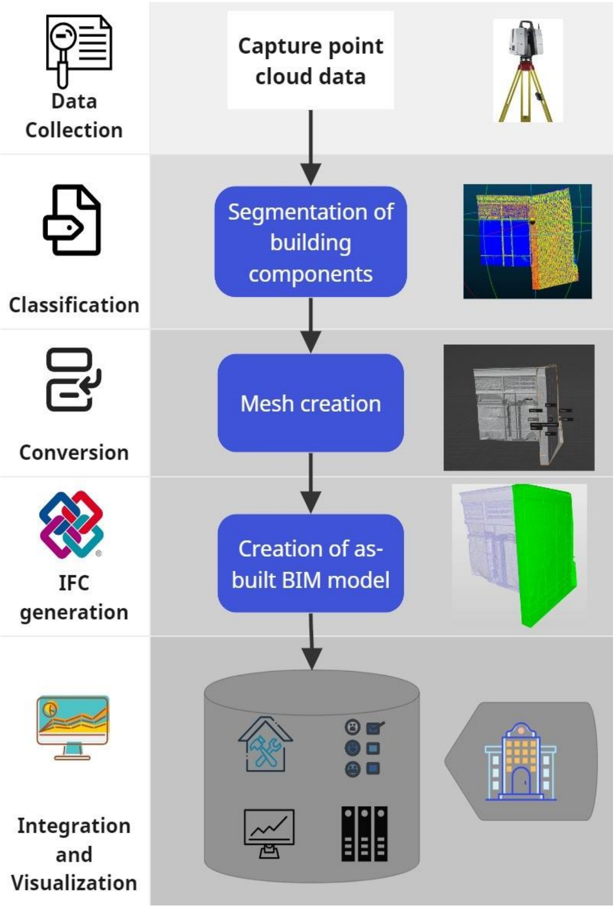

Figure 1. Methodology

The second step is point cloud-to-mesh conversion. During this step, the classified point cloud data is converted into a mesh representation of the building. This mesh representation allows for a more visually appealing and interactive view of the building, making it easier for maintenance workers to identify different elements and their locations. The third step in the methodology is the generation of an IFC model. During this step, the mesh representation of the building is assigned relevant Industry Foundation Classes entities. This involves mapping the building elements identified in the point cloud data to their corresponding IFC entities, such as walls, floors, doors, and windows. Once the relevant IFC entities are assigned, a complete IFC model is generated for the entire building. This IFC model contains all the necessary information about the building, including its geometry, spatial relationships, and attributes. The final step in the methodology involves using Dynamo in Revit to link maintenance requests from the building maintenance management system to the IFC model. By integrating the building maintenance with the generated IFC model, each maintenance request can be linked to the corresponding element in the building model. A filter can be applied to visualize the priority of each maintenance request on the model, dynamically representing their level of urgency or importance with different colors or indicators.

Case Study Implementation

To demonstrate the effectiveness of this methodology, a case study was conducted on the Civil Engineering Building in University of Cambridge, United Kingdom. The Cambridge University Engineering Department's (CUED) Civil Engineering Building, completed in 2019, stands as a pioneering example of modular and flexible laboratory and research infrastructure on the eastern fringe of the University's West Cambridge Campus. Encompassing approximately 5000m², the facility seamlessly integrates laboratory, research, and office spaces. LiDAR technology was utilized to capture a detailed and accurate point cloud of the building, shown in Figure 2.

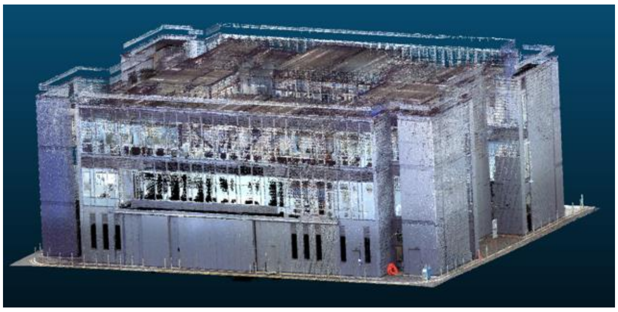

Figure 2. Point Cloud of the Civil Engineering Building

Point Cloud Classification

The point cloud data was then processed and classified to identify various building elements. The classification of the point cloud data enabled the identification of different building elements such as walls, floors, ceilings, doors, windows, and some MEP elements. Once the point cloud was segmented and the noise omitted, the next step involved the conversion of the classified point cloud data into a mesh representation of the building.

Point Cloud Conversion

The point cloud was converted into a mesh representation of the building. Using the innovative Python Ball Pivoting Algorithm, we were able to convert the raw point cloud data into a detailed mesh structure. This algorithm effectively handles challenges such as occlusions and hidden points, guaranteeing that the resulting mesh-based geometry accurately portrays the intricate details of the building's structure. The mesh representation provided a more intuitive and visually appealing view of the building, making it easier for maintenance workers to understand and interact with the model. Figure 3 shows the created mesh based on the point cloud data.

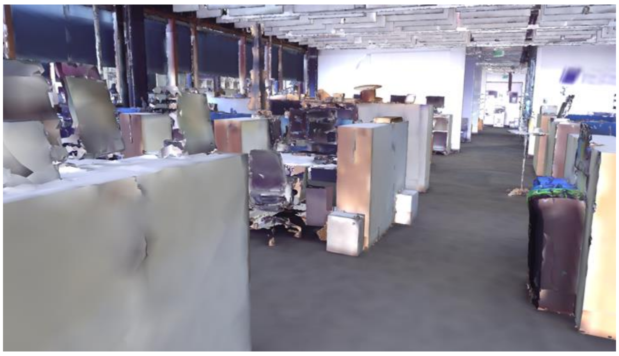

Figure 3. Mesh of the building

IFC Creation

Next, the classified point cloud data was mapped to relevant IFC entities, such as walls, floors, and doors. The IFC model was created using the ifcopenshell package in Python. This package allows for the manipulation and extraction of data from IFC files, enabling the assignment of relevant IFC entities to the classified point cloud data. The ifcopenshell library provides a set of tools and functions for working with IFC files, including the ability to create, read, and modify IFC models programmatically. Using the ifcopenshell package, the classified point cloud data was mapped to their corresponding IFC entities, such as walls, floors, doors, and windows. This process involved creating IFC elements for each building component, ensuring that the IFC model accurately represented the geometry and attributes of the existing building. The ifcopenshell package facilitated the generation of a complete IFC model that contained all necessary information about the building, allowing for spatial relationships and properties to be incorporated into the model.

By leveraging the capabilities of ifcopenshell in Python, the methodology successfully assigned relevant IFC entities to the classified point cloud data, resulting in the creation of a comprehensive and semantically rich IFC model for the existing building. Figure 4 illustrates ifcopenshell package for assigning relevant IFC to segmented mesh.

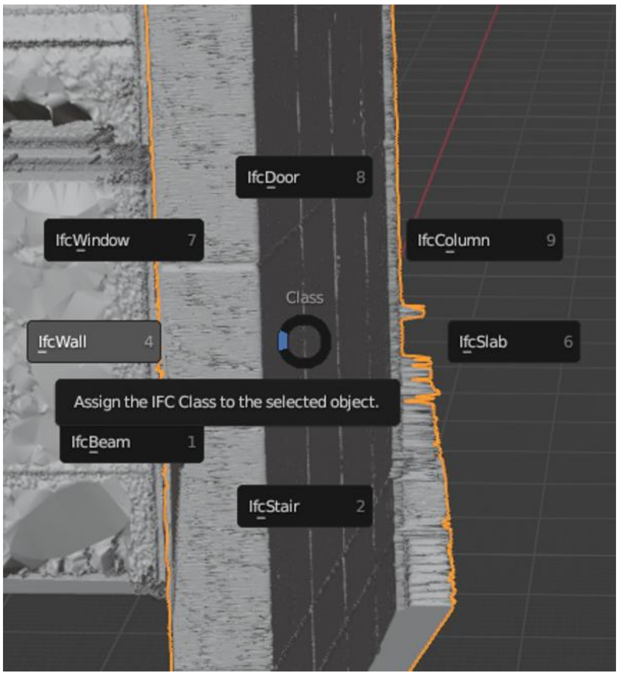

Figure 4. Process of assigning relevant IFC to mesh

CMMS Integration and Visualization

The process of linking maintenance requests from the CMMS to the generated IFC model involved several steps. First, the maintenance data obtained from the CMMS in an Excel file format was imported into Dynamo, a visual programming extension for Autodesk Revit as shown in Figure 5. Each row in the Excel file represented a different maintenance work order, with columns containing specific information such as issue, priority, and equipment codes. Table 1 shows examples of maintenance requests received by facility management department of west campus.

In this study, the shared parameter was utilized to allow BIM models to contain EquipmentID and Priority parameters. The shared parameter is a Revit term that can be added to the Revit family for custom data fields. It can also be accessible for any project due to holding parameters in a separate file. This enables the integration of maintenance data from the building maintenance management system with the BIM model, allowing for better coordination and planning of maintenance activities.

Table 1. Examples of maintenance requests for West Campus

Issue	Date reported to Facilities	Priority
Air Conditioning is still playing up	07 March 2023	Medium
remove alarm on back door	08 August 2023	low
repaint bike shed & compounds where w/shop exit is and where skips are	09 August 2023	low
The gas boiler in the plant room wont switch on	18 October 2023	medium
AC not working in the workshop	20 October 2023	medium
light inside study room not working	23 October 2023	medium
A leaking pipe in office	30 October 2023	high

To map maintenance requests to the BIM model for visualization, the following steps can be taken. First, the Excel file obtained from CMMS is imported in Dynamo, a visual programming extension for Autodesk Revit. In this file, each row corresponds to a different maintenance work order, and each column contains specific information such as issue, priority, and equipment codes. The parameters from the file are then grouped by type and mapped to each equipment (depending on the code) using the SetParameterbyName node in Dynamo. This step

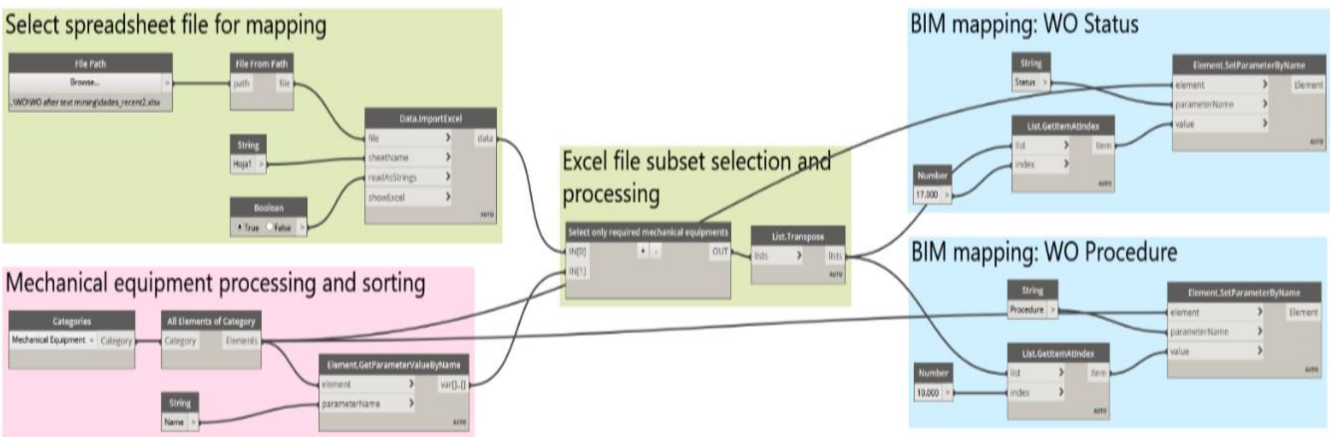

Figure 5. Dynamo code to import the maintenance requests to the mechanical equipment of the IFC model

involves linking the maintenance information to the corresponding elements in the BIM model. Using a Dynamo script, the information from the selected columns of the file can be saved in each parameter. This script contains two key Python code blocks. The code block "Reorganize room objects into Revit ordering" creates a list of all rooms and their room numbers, which are then organized to match the element numbering set by Revit. Developing custom Dynamo scripts specifically for this purpose made integrating maintenance activities into the BIM model easier. These scripts, using unique Python code blocks, showing our dedication to creating solutions that meet the specific needs of maintenance tasks in facility management. By using these custom scripts, we ensured that maintenance information was accurately mapped to corresponding rooms in the BIM model, improving the efficiency of maintenance planning and execution.

This integration allowed for the linking of each maintenance request to the corresponding element in the building model, with the ability to visually represent the priority of each maintenance request on the model. By dynamically indicating the urgency or importance of maintenance requests with different colors or indicators, the maintenance team gained an efficient and effective tool for managing and prioritizing maintenance activities.

Results and Discussion

The use of the proposed methodology for enhancing maintenance activities in existing buildings without a BIM model can greatly improve efficiency and accuracy. By utilizing LiDAR technology to capture point cloud data, maintenance workers can have access to detailed and accurate information about the building's geometry. This data is then transformed into a mesh representation using the Python Ball Pivoting Algorithm to ensure precise modeling that includes intricate details, such as holes in walls, thus enhancing the fidelity of the resulting BIM model. This BIM model can then be linked to the CMMS, enabling maintenance requests to be directly connected to the corresponding elements in the model.

The methodology involves using the ifcopenshell package in Python to convert the mesh representation into an IFC file. Unlike conventional approaches, ifcopenshell offers a versatile and general solution, providing greater flexibility in manipulating and extracting data from IFC files. This contributes to advancing the field by offering a more accessible and adaptable framework for generating IFC models from point cloud data.

In addition, we have developed custom Dynamo scripts designed to integrate maintenance tasks into Revit, enhancing the usefulness of BIM models in facility management. The unique Python code blocks within these scripts, especially the "Reorganize room objects into Revit ordering" code, demonstrate our dedication to creating solutions tailored for maintenance activities. This customization enables accurate mapping of maintenance information to respective rooms in the BIM model, leading to significant improvements in maintenance planning and execution efficiency.

The proposed visualization tool aligns with the case study's findings, illustrating how the seamless integration of LiDAR technology with BIM models effectively facilitates more efficient and accurate maintenance practices. By implementing the visualization tool, Facility Management and Maintenance teams can better organize and prioritize maintenance tasks. The clear visualization of maintenance requests directly on the 3D model of the building enables FMM personnel to assess the urgency and allocate resources effectively. Figure 6 illustrates examples of two maintenance requests on the West Campus of Cambridge University. As shown in the figure, each maintenance request is depicted by a colored marker on the BIM model. For instance, a red marker indicates a high-priority maintenance request, while a yellow marker represents medium-priority requests. A leaking pipe in the office is an example of a high-priority maintenance request and is represented as a red marker in the BIM model. On the other hand, a light in the study room constitutes a medium-priority request and is symbolized by a yellow marker. This color-coded representation not only improves the efficiency of maintenance workers in addressing urgent issues promptly but also allows for better planning and allocation of resources to address less urgent maintenance requests. In addition, this integration provides maintenance workers with a clear understanding of the location and status of each maintenance request, facilitating their decision-making process and streamlining the overall maintenance workflow.

The process of implementing the visualization tool involves the utilization of LiDAR technology to capture comprehensive point cloud data, enabling the creation of a detailed and visually rich BIM model. This model, integrated with the CMMS, enhances the clarity and accessibility of maintenance requests, streamlining the overall maintenance workflow while ensuring accurate documentation and spatial representation of the building's elements.

The comparison of the current maintenance management approach, where maintenance work orders are received in Excel files, with the proposed visualization tool clearly demonstrates the potential for improvement. The visualization tool provides a more intuitive way to manage maintenance tasks, moving away from traditional tabular data towards a spatially enriched representation of the building's elements. This transition can significantly enhance the FMM's ability to plan, coordinate, and execute maintenance activities effectively.

The implementation of the visualization tool, as evidenced by the successful integration of LiDAR technology, point cloud data, and BIM models in the case study, presents a compelling opportunity to revolutionize the management of maintenance tasks in existing buildings.

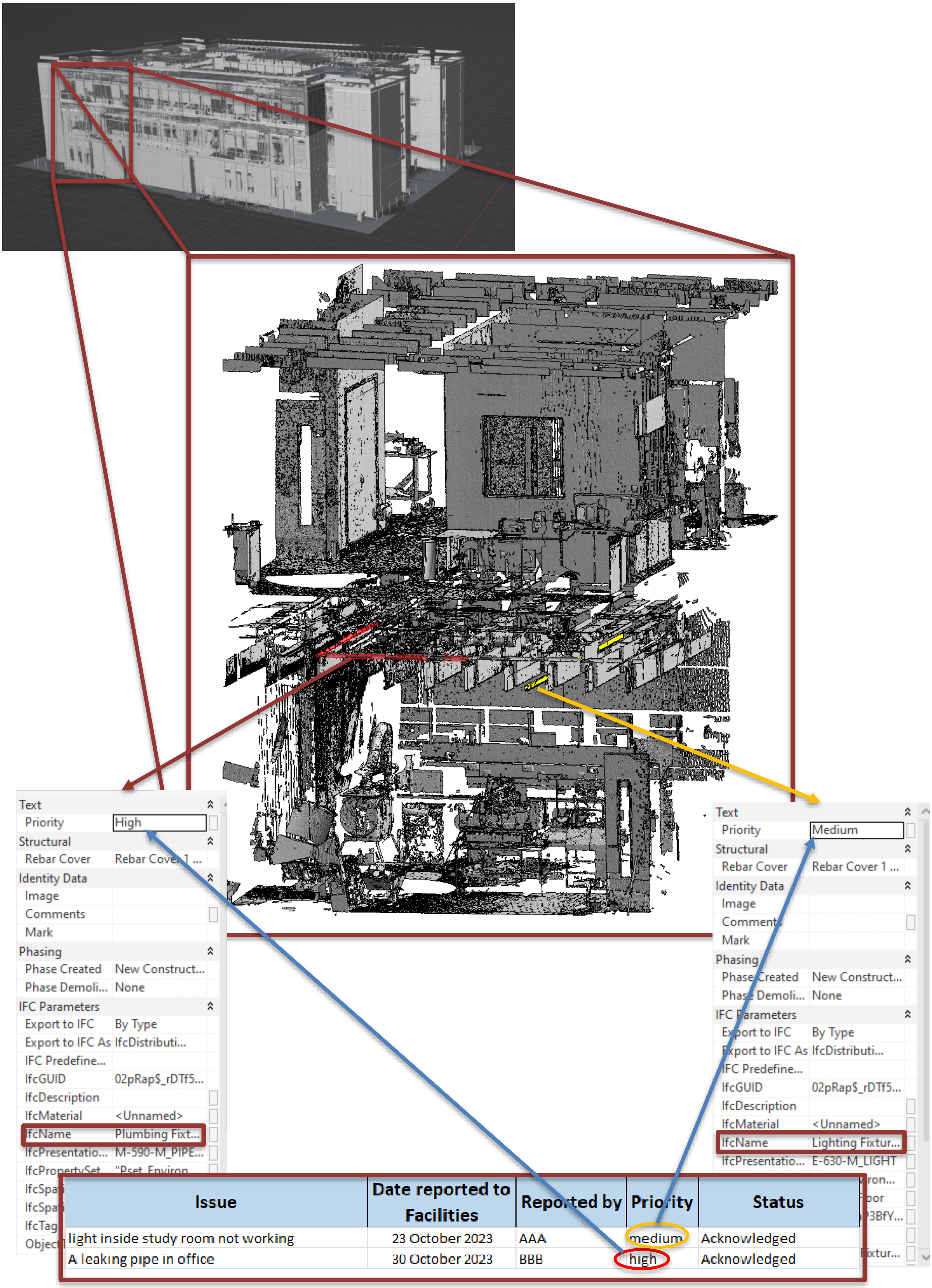

Figure 6. Example of the equipment visualization based on the priority of maintenance requests

The visualization tool not only fosters a more organized and informed approach to maintenance but also elevates the overall understanding of the building's conditions and facilitates well-informed decision-making for maintenance and rehabilitation efforts. This methodology not only improves the maintenance process but also enhances the overall management of the building. With the integrated system of LiDAR technology, point cloud data, and BIM models, facility managers can easily access and analyze important information about the building's condition, identify potential issues, and make informed decisions regarding maintenance and repairs. This approach also enables better communication and collaboration among stakeholders involved in the maintenance process.

Conclusion

The use of LiDAR technology and point cloud data to enhance maintenance activities in existing buildings without a BIM model offers significant advantages.

It allows for the creation of detailed and accurate as-built BIM models, which can be linked to maintenance management systems to streamline the maintenance workflow. By assigning relevant IFC entities and color-coding maintenance requests based on priority level, maintenance workers have a clear understanding of the location and status of each maintenance request, improving efficiency and effectiveness. Moreover, the integration of point cloud data and BIM models provides facility managers with valuable information for better decision-making and overall building management. For instance, various kinds of data can be linked to IFC models to improve maintenance activities. This includes information about equipment specifications, maintenance history, warranty details, and any other relevant data that can assist in planning and executing maintenance tasks. By leveraging the power of LiDAR technology and point cloud data, facility management teams can transform the way they approach maintenance in existing buildings. This innovative approach not only improves the accuracy and efficiency of maintenance tasks but also enhances the overall management of building conditions and facilitates informed decision-making processes. The combination of LiDAR technology, point cloud data, 3D models created with BIM in the context of maintaining activities for existing buildings presents a significant opportunity to revolutionize traditional approaches towards conducting property upkeep while improving their overall performance as well as longevity.

The development of custom Dynamo scripts highlights the potential of this methodology in the future. These scripts form the basis for potential projects, such as creating APIs for seamless integration with emerging digital twin platforms. Future work could focus on advancing the use of BIM and point cloud data in maintenance activities for existing buildings. One potential future direction is the refinement of automated algorithms and machine learning techniques to streamline the process of converting point cloud data into parametric BIM models. This advancement can significantly reduce the manual effort required, making the generation of BIM models from point cloud data more time-efficient and scalable. Additionally, future work in this area could explore the integration of Internet of Things data with BIM models to enable real-time monitoring of building components and systems. This integration would allow for proactive maintenance, where sensor data from IoT devices triggers maintenance alerts directly within the BIM model, enabling facility managers to address issues before they escalate. Moreover, the role of BIM in predictive maintenance can be explored in existing buildings. By leveraging historical maintenance data, sensor information, and building performance data within the BIM environment, predictive maintenance strategies can be employed to anticipate and plan for maintenance activities, maximizing the operational efficiency of existing buildings.

Acknowledgments

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