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Research about semi-automation solutions that generate the BIM model from point cloud data

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BIM A+ European Master in Building Information Modelling

Master Dissertation
European Master in Building Information Modelling

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

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G. Sơn

Nguyễn Giang Sơn

RESUMO

Esta dissertação explora a aplicação de soluções de semi-automatização na criação de modelos de Building Information Modeling (BIM) a partir de dados de nuvens de pontos. O objetivo é aumentar a eficiência e a precisão do processo Scan-to-BIM, aproveitando software específico combinado com processos usuais em BIM. Esta pesquisa investiga a transição das práticas BIM convencionais para Scan-to-BIM, destacando a incorporação da tecnologia de digitalização a laser 3D e dados de nuvem de pontos no fluxo de trabalho BIM. O estudo examina os desafios, benefícios e direções futuras da utilização da semi-automatizaçã no processo Scan-to-BIM. Ele estudo concentra-se nos fatores que afetam a qualidade dos dados, incluíndo a preparação na sua recolha, técnicas de aquisição e métodos de processamento de dados. Além disso, este trabalho analisa o papel da definição do Nível de Desenvolvimento (LOD) antes de iniciar o processo Scan-to-BIM. Os resultados contribuem para o desenvolvimento de melhores práticas, metodologias e diretrizes para profissionais de arquitetura, engenharia e construção, permitindo que estes otimizem o fluxo de trabalho Scan-to-BIM na criação de modelos BIM com maior precisão

Palavras chave: Semiautomação, BIM, Nuvem de pontos, Scan to BIM, Digitalização a laser 3D, nível de desenvolvimento (LOD),

ABSTRACT

This thesis explores the application of semi-automation solutions in generating Building Information Modelling (BIM) models from point cloud data. The aim is to enhance the efficiency and accuracy of the Scan to BIM process by leveraging advanced software combined with familiar BIM processes. The research investigates the transition from conventional BIM practices to Scan to BIM, highlighting the incorporation of 3D laser scanning technology and point cloud data into the BIM workflow. The study examines the challenges, benefits, and future directions of utilizing semi-automation in the Scan to BIM process. It focuses on factors affecting data quality, including data collection preparation, acquisition techniques, and data processing methods. Additionally, the research discusses the role of defining the Level of Development (LOD) before initiating the Scan to BIM process. The findings contribute to developing best practices, methodologies, and guidelines for architecture, engineering, and construction professionals, enabling them to optimize the Scan to BIM workflow and generate accurate as-built BIM models.

Keywords: Semi-automation, BIM, point cloud, Scan to BIM, 3D laser scanning, Level of Development (LOD), construction.

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1. INTRODUCTION

1.1. Generalities and scope

This research scope focus on finding semi-automation solutions for generating Building Information Modelling (BIM) models from point cloud data. The scope of the study will focus on exploring potential software that can support this semi-automation process and provide preliminary explanations of the main algorithms, and techniques that are usually employed to classify and recognize the different BIM object types through point cloud data.

The research starts with a literature review, which will provide a general definition of BIM, Scan to BIM, and how it effects the AEC industry. It will highlight the high demand for creating As-built BIM models from point cloud data, emphasizing the need for semi-automation solutions to enhance efficiency, accuracy and save time.

As can be seen, machine learning algorithms, pattern recognition techniques, and feature extraction methods can aid in automating the BIM modelling process. It is already integrated into software from third parties and is easy to perform interoperability with commonly used BIM tools. Thus that, the study will delve into the semi-automation approaches by combining the common BIM tools with this software as it is the fastest way for learning and application on a large scale.

The research will also assess the limitations and potential drawbacks of semi-automation solutions in generating BIM models from point cloud data. Factors such as the quality of data input, missing objects by the scanning process, software techniques, and interoperability of BIM tools will be considered to provide a comprehensive evaluation.

The research scope will be restricted to the application and evaluation of semi-automation solutions for generating BIM modelling from point cloud data in specific case studies provided by a company that commonly uses scan to BIM. It will not encompass an explanation of algorithms of automated processes or the detail of manual modelling techniques.

The study will conclude by presenting findings and recommendations for the implementation and future development of semi-automation solutions in the context of the workload of generating the as-built BIM models from point cloud data growing higher and higher. The research outcomes will contribute to the advancement of knowledge and practices in the automation topic of the scan-to-BIM field.

The main result of this research is to help the BIM modeler or everybody who does not have strong knowledge of complex algorithms or programming techniques, to understand the Scan to BIM process, in addition to comprehending the benefits of application of semi-automation solutions in creating BIM model through point cloud data.

1.2. Main focus

This work focus on the semi-automation procedures to apply scan to BIM. For that purpose, it begins with the definition of BIM, Scan to BIM, and an introduction to some current popular applications. The application of Scan to BIM is then investigated, considering its relevance in different contexts, such as infrastructural projects and heritage building, focusing on the challenges and considerations specific to each context. The study also delves into the automation aspects of Scan to BIM, examining the advancements in automated algorithms, machine learning techniques, and artificial intelligence that contribute to faster and more accurate BIM model generation from point cloud data. Additionally, it covers the crucial steps involved in data collection preparation, including selecting appropriate scanning devices and identifying special objects for accurate data acquisition. The data acquisition process is discussed, addressing scanning equipment setup, techniques, and strategies for comprehensive coverage. Furthermore, the post-processing phase is explored, encompassing point cloud registration, data alignment, noise reduction, and outlier removal.

Lastly, the importance of defining the Level of Development (LOD) is emphasized, which establishes the required level of detail, accuracy, and completeness for different elements of the BIM model, considering project requirements and industry standards. The LOD is proposed according to the user's needs and assuming the current semi-automation solutions.

1.3. Structure of thesis

The dissertation is divided into six main chapters, each addressing crucial elements of the research study and providing valuable insights for practitioners and researchers in the field.

Chapter 1 sets the stage for the research by providing an introduction to the work's context. It establishes the scope of the study, identifies the problem statement, and defines the research objectives and overall purpose. This chapter lays the foundation for the subsequent chapters, offering a comprehensive understanding of the research focus and its significance in the broader context of Scan to BIM implementation.

Chapter 2 delves into a thorough literature review, examining existing research related to the main topics discussed in this dissertation. It explores the concepts of Scan to BIM, automation, and other relevant research surrounding Scan to BIM methodologies. By reviewing and synthesizing the existing body of knowledge, this chapter establishes a theoretical framework and contextual background for the subsequent chapters.

Chapter 3 presents the methodology developed for this research, taking into consideration various factors that can influence the Scan to BIM process and the implementation of semi-automation solutions. It outlines the research approach, data collection methods, and analytical techniques employed to achieve the research objectives. This chapter provides a systematic framework for conducting the research study, ensuring its validity and reliability.

Chapter 4: Briefly introduces the BIM tools from third parties that will be applied to the case study. Providing concise guidelines for these BIM softwares in the context of the study showcases implementation of methodology in two case investigations a small house project and an MEP

(Mechanical, Electrical, and Plumbing) project. It demonstrates how the developed methodology and semi-automation tools can effectively apply in real-world scenarios. Through these case studies, the chapter highlights the practical implications and outcomes of the research, providing empirical evidence of the effectiveness of the proposed approach.

Finally, Chapter 5 draws the dissertation to a closure by presenting a comprehensive conclusion. It summarizes the significant findings and conclusions derived from the research, Adding to the existing body of understanding in the subject matter of automation in Scan to BIM. The chapter also discusses the limitations of the study and proposes potential areas for future research and development based on the insights gained from this dissertation.

By following this structured framework, the dissertation aims to shed light on the potential of semi-automation solutions in the Scan to BIM process, offering practical guidance and theoretical contributions to the field of BIM methodologies and practices.

1.4. Problem Discussion and Research Questions

One of the primary challenges is ensuring the quality and accuracy of the as-built BIM model generated from point cloud data obtained through 3D laser scanning. The use of semi-automation techniques in the generation of BIM models from point cloud data has gained attention as a potential solution. However, a number of variables can influence the data's quality and the efficiency in the semi-automation procedure.

Research Questions:

- How can implementation of Scan to BIM contribute to the improvement of precision and efficacy in as-built BIM model creation?
- What are the main factors that affect the data fidelity of the Scan to BIM, and how can they be effectively managed and controlled?
- What are the potential benefits and drawbacks of applying semi-automation techniques in generating BIM models from point cloud data?
- How can semi-automation applications in the Scan to BIM process be optimized to enhance efficiency and accuracy?
- What are the future directions and potential advancements in the field of Scan to BIM and the application of semi-automation techniques?

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2. LITERATURE REVIEW

2.1. The introduction about Scan to BIM

The term BIM was first time mentioned by (Eastman, 1975; Campanelli et al., 2016) in his research about using computers to create the drawings for construction projects, that activity is well known today with the explain Building information modelling. Along with the development of the BIM process for a new building, using BIM for an existing building is necessary for the activities of maintenance, quality control, and assessment (Volk et al., 2014). Especially, for historic buildings creating the as-built model by scan to BIM is a base information for the management of conservation (Brumana et al., 2020). On a larger scale like a cultural heritage site, scan to BIM maybe successful when it can build a 3D GIS environment by capturing the whole area with point cloud data and high-resolution photo format and accurate with the actual dimension (Pepe et al., 2021). For MEP works, using scan to BIM provided tracking progress and the quality of existing work in the construction site by comparing the model from laser scan with the BIM model (Bosché et al., 2014). Therefore, investment in scanning to BIM is the new direction are deployment by the consultant and construction teams to increase labour productivity. (Esfahani et al., 2021). For example, construction progress monitoring can be more automated by improving point cloud quality and appropriate scanning solutions (Rebolj et al., 2017).

2.1.1. Scan to BIM

Scan to BIM is usually used to describe the process of collecting or recreating the as-constructed model via point cloud data (Son et al., 2015). The term Scan in "Scan to BIM" is the application of non-invasive imaging and long-range tools such as laser scanning (Suchocki and Katzer, 2018) or photogrammetry to capture and present this data with high precision in three dimensions (Rocha et al., 2020).

In the Architecture, Engineering and Construction (AEC) sector besides existing survey solutions, the integration between photogrammetry or laser scanning with the BIM process is a promising research direction. They are effective strategies for documenting the starting or existing conditions, maintaining an up-to-date record of the building site, detecting potential construction problems, evaluating changes over time, and producing as-built documentation. This is especially true for existing buildings because the site's variables may not be understood in advance. It is usual for new relevant information to come up during an intervention in an existing building. Furthermore, the initial design may be forced to adapt with all of the associated ramifications, as well as update project documents. In a BIM setting, this can be done rapidly and within a controlled environment (Barbosa et al., 2016).

Photogrammetry and scanning with lasers are surveying techniques applicable to multiple levels or dimensions of elements (Brumana et al., 2018; Mateus et al., 2019). Both are regarded as mass data collection methods (Boardman and Bryan, 2018). The advantage of photogrammetry and 3D laser scanning is that they can reduce the repetitive procedures of conventional survey operations, thereby freeing up time for other crucial process phases such as construction modelling or structure analysis (Mateus et al., 2013; Rocha et al., 2020). Both strategies show the captured shape of the complete building as the outcome of a point cloud file. The photogrammetric method is effective when completing architectural surveys with other specific tools is time-consuming or not possible and when laser scanning is less appropriate due to the size of the site or inaccessible areas, such as high rooftops (Barbosa, 2018). The photogrammetric survey must be carried out properly to ensure that all geometry is captured by images with sufficient information overlap and to prevent excessive gaps between photos. Additionally, it is essential to have suitable weather conditions and uniform illumination. Lastly, additional notes and dimensions must be collected on-site in order to position and size the model accurately. (Waldhäusl and Ogleby, 1994). On the surfaces of things and sites, laser scanners acquire and record geometry and, in certain circumstances, texture information (Vosselman and Maas, 2010). The laser scanner vocabulary encompasses a wide range of devices with varying principles and functions designed for a variety of situations, applications, and levels of accuracy and precision (Boardman and Bryan, 2018). It needs to be done to account for obstructions and inaccessible regions, to ensure that all of the surroundings is apparent or sufficiently clean to scan, to collect sufficient scan points within the equipment's range, and to guarantee adequate connectivity between all of the building's rooms, floors, and interior and exterior spaces. All of these stages are required to guarantee that when the raw files undergo processing, the programme can identify pertinent features and accurately align each scan. (Rocha et al., 2020).

Few examples of detailed workflows for creating 3D models with scanning lasers and photogrammetry for BIM purposes exist. Some authors used manual and automatic experiments to create models for certain construction aspects (Fryskowska and Stachelek, 2018; Lopez et al., 2017; Rodríguez-Moreno et al., 2018). Others have investigated the potential of wall construction (Macher et al., 2017; Ochmann et al., 2016), while others have concentrated on developing parametric and nonparametric families to populate existing databases (Baik, 2017; Murphy et al., 2013).

2.1.2. Application of Scan to BIM to build As-Is BIM model

The as-is BIM models produced by scan-to-BIM have been used in various applications and can be used in a broader range of applications in the future. The existing and possible applications of as-is BIM are described in Table 1 and shown in the following subsections based on distinct project phases.

Table 1 – The reference research about the application of Scan to BIM to build As-Is BIM

Project phase	Application of As-Is BIM	References
Design phase	Create a 3D site model	(Aydin, 2014)
Construction phase	Quality Assurance vs Quality Control	(Wang et al., 2016; Bosché and Guenet, 2014; Tang et al., 2007; Bosché, 2010)
	Construction progress monitoring	(Kim et al., 2013; Son and Kim, 2010; Turkan et al., 2012)
	Virtual assembly and installation	(Nahangi et al., 2015; Rausch et al., 2017)

	Safety management	(Zhang et al., 2013; Wang et al., 2015)
	Digital reconstruction	(Xu et al., 2017)
Operations and Maintenance phase	Documentation	(Yastikli, 2007; Rüther et al., 2009)
	Building evaluations (including, for example, energy consumption analysis, connectivity evaluation, and structural evaluation)	(Ham and Golparvar-Fard, 2013; Balado et al., 2017; Riveiro et al., 2011)
	Features for facility management	(Becerik-Gerber et al., 2012)

2.1.2.1. Design Phase

During the planning stage, as-is BIM models of the construction site's terrain, neighbouring structures, and environment help designers better understand the site conditions and make more informed building design decisions. (Aydin, 2014), For instance, laser scan data from existing buildings was utilised to evaluate a building facade's visual architectural elements.

2.1.2.2. Construction Phase

Existing BIM models of on-site construction projects or prefabricated elements are commonly used for quality assessment/quality control (QA/QC) throughout the construction phase. The as-is BIM is frequently compared to the as-designed BIM to discover any differences, which is then compared to the tolerance limits specified in relevant rules and regulations. Various forms of QA/QC have been studied, including dimensions disagreement (Wang et al., 2016), surface flatness and distortion (Bosché and Guenet, 2014), surface spalling flaws (Tang et al., 2007), and positioning inaccuracy (Bosché, 2010).

Another common implementation of as-is BIM during the construction phase is progress monitoring (Son and Kim, 2010; Turkan et al., 2012). The as-is BIM models are developed and compared to the as-designed 4D BIM models comprising project schedule information by scanning the on-site construction works at a given project milestone. In order to monitor construction progress and identify construction operations that are ahead of schedule, the actual project schedule is compared to the expected timetable in the BIM environment. Scan-to-BIM enables virtual installation and assembly of construction assemblies using precise as-is BIM models (Nahangi et al., 2015; Rausch et al., 2017). Scan-to-BIM can be used to make as-is BIM models of premade building parts so that the installation and assembly process can be re-created in a virtual world. With virtual installation and assembly, any potential problem or difficulty, such as the wrong size of a component or a clash between prefabricated elements and other construction work, can be found before the real installation and assembly, which saves time and money and speeds up the building process. As it is, BIM can improve the way building safety is managed.. (Zhang et al., 2013) created a rule-based machine for automatic safety checking that could figure out what safety steps need to be taken before construction to avoid accidents caused by falls. (Wang et al., 2015) examined laser scan data from dug pits to detect and pinpoint fall hazards, then used a previously built rule-checking system to recommend installing safety devices. Although earlier studies did not use scan-to-BIM, it is a feasible study direction to use scan-to-BIM to develop as-is BIM models for construction and building sites for the identification of safety threats and safety measure planning.

Additionally, scan-to-BIM can be used to digitally construction component (Xu et al., 2017). The created as-is BIM models of an item can be loaded into a construction 3D printing machine, such as a concrete printer, to create a high-precision copy of the component. Reproduction with scan-to-BIM is particularly effective for complex-geometry building components present in older structures that lack a blueprint or 3D model.

2.1.2.3. Operations and Maintenance phase

The most fundamental application of scan-to-BIM in the maintenance and operation phase is the documentation of building geometry and texturing. It is widely used to preserve historical sites such as the Fatih Mosque in Istanbul (Yastikli, 2007) and the Wonderwerk Cave in South Africa (Rüther et al., 2009). BIM-based documentation allows for improved protection of historical heritage and easier maintenance and restoration.

The scan-to-BIM as-is BIM was additionally used for building performance analysis, such as energy performance analysis (Ham and Golparvar-Fard, 2013), accessibility testing (Balado et al., 2017), and structural evaluation (Riveiro et al., 2011). Scan-to-BIM generates accurate as-is BIM models, allowing for thorough BIM-based building evaluations to investigate and enhance building performance in terms of energy consumption, accessibility, and structural dependability. Scan-to-BIM is expected to be used for a variety of analyses and simulations in the future, such as emergency evacuation simulation, spatial program validation, daylight simulation, and so on.

Because of the improved 3D visualization capabilities and the extensive and well-organized building information in BIM, as-is BIM models of existing buildings are also advantageous to many Operations and Maintenance phase functionalities. Operations and Maintenance phase space management, refurbishment planning and execution, emergency management, and personnel training and development are all potential applications of BIM-enabled facility management (Becerik-Gerber et al., 2012). For example, a BIM-based procedure can improve building component O&M since BIM provides efficient localization of building components and real-time access to essential facility data, lowering maintenance operations' costs and time (Becerik-Gerber et al., 2012). Scanning-to-BIM has the potential to be used to generate as-is BIM models for existing buildings without BIM models, easing the deployment of BIM-enabled facility management (Volk et al., 2014).

2.1.3. The process of scanning to BIM

2.1.3.1. Scan to BIM in the usual way

The usual method for application Scan to BIM was proposed by (Badenko et al., 2019), where the following steps are provided:

(1) Classification of elements to be considered when developing an as-built BIM-model for an existing building/asset;

(2) Determination of required degree of details for elements examined, including geometry accuracy and attributes information fullness;

(3) Definition of scanning parameters, including scanner type, optimization of scan position number for scan-to-BIM procedures, and acquisition of laser scanning data;

(4) These acquired scans (several specific point clouds) must be combined and registered in the same coordinate system to obtain the complete united point cloud, which is a point model of a real building/asset;

(5) Processing of this laser scanning point cloud, including information about the 3D coordinates of the points, the intensity of the reflected laser beams, and RGB color, for the generation of as-built BIM-models using a variety of specific software;

(6) Analysis and use of the obtained BIM-model.

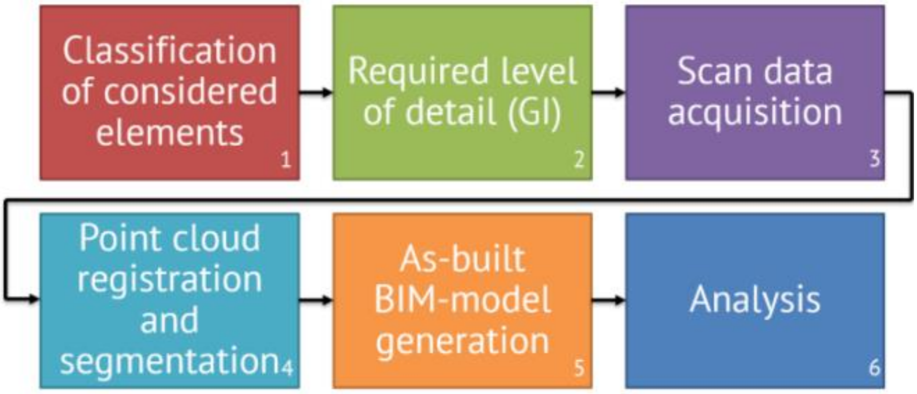


Figure 1 – Six steps of the proposed methodology (Badenko et al., 2019)

It is 6 main steps for creating the as-built model from the point-cloud data and gave guidance for the analysis of this model in the main aspects which are structure analysis, insolation analysis, and collision detection.

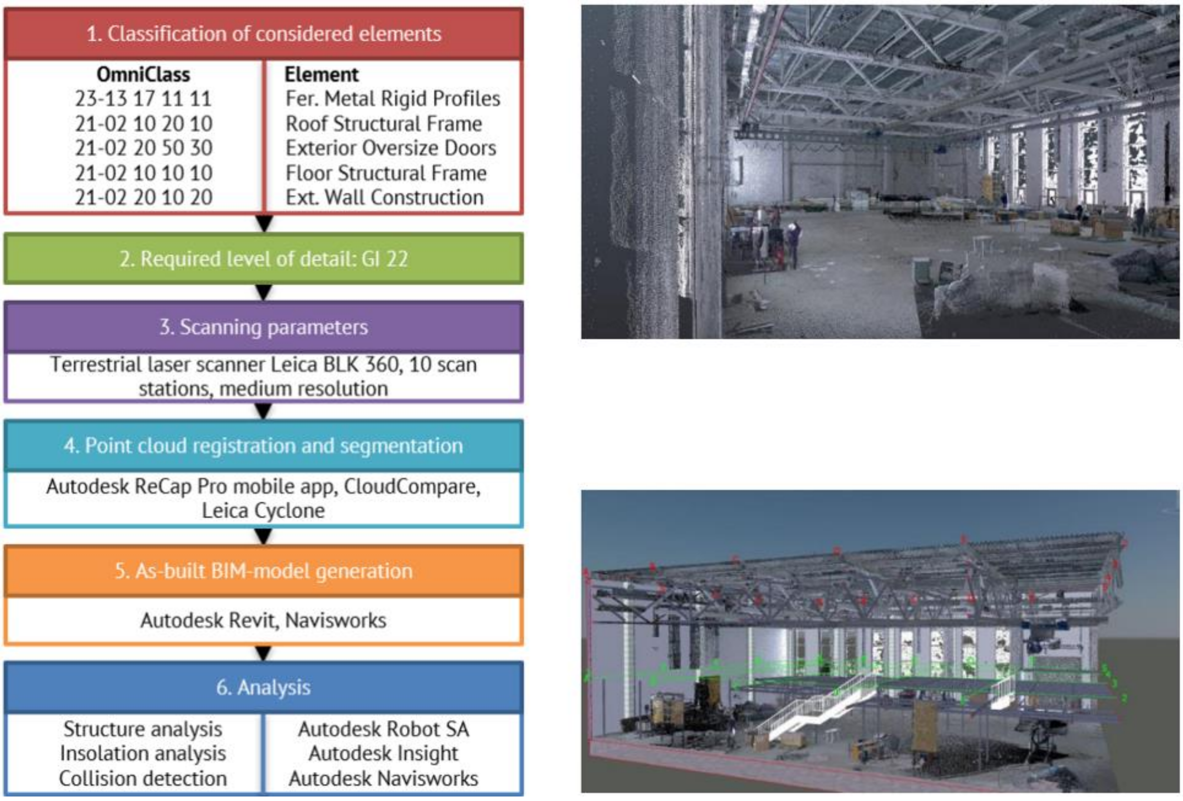


Figure 2 – Scheme of the proposed methodology, which is tuned for the case study for existing industrial sites and the as-Built model (Badenko et al., 2019)

2.1.3.2. Scan to BIM in Heritage Building

The process for application Scan to BIM in heritage building was proposed by (Rocha et al., 2020). Besides similar things to regular construction projects, the historical project usually has a bigger scale and small details for decoration. The survey workflow here requires more steps and equipment, such as GPS tools and geo-referenced. The following steps are creating BIM model following the typical way of any project: standard models, creating families, and automatic creation of simple objects.

(Rocha et al., 2020) the procedure entailed generating a BIM model that is ready to have its degree of detail raised if necessary, in the future. Some elements were modelled in more depth, reaching LOD 350 (trusses, doors, and windows), while others remained at LOD 300 (walls and floors). This was owing to the inability to test the materials that make up the core of various elements. As a result, their model was limited in terms of dimensions, size, positions, orientation, and finishing materials, but there was no distinction between the inner layers. Aside from the geometric reconstruction of the structure, the final model includes all the elements classified according to their use, as well as their finishing materials and structural and support elements when possible. The BIM model is not static; at any time, geometric and non-geometric information (such as physical and material performance characteristics, costs, manufacturers, compositions, and others) can be updated to enhance the LOD.

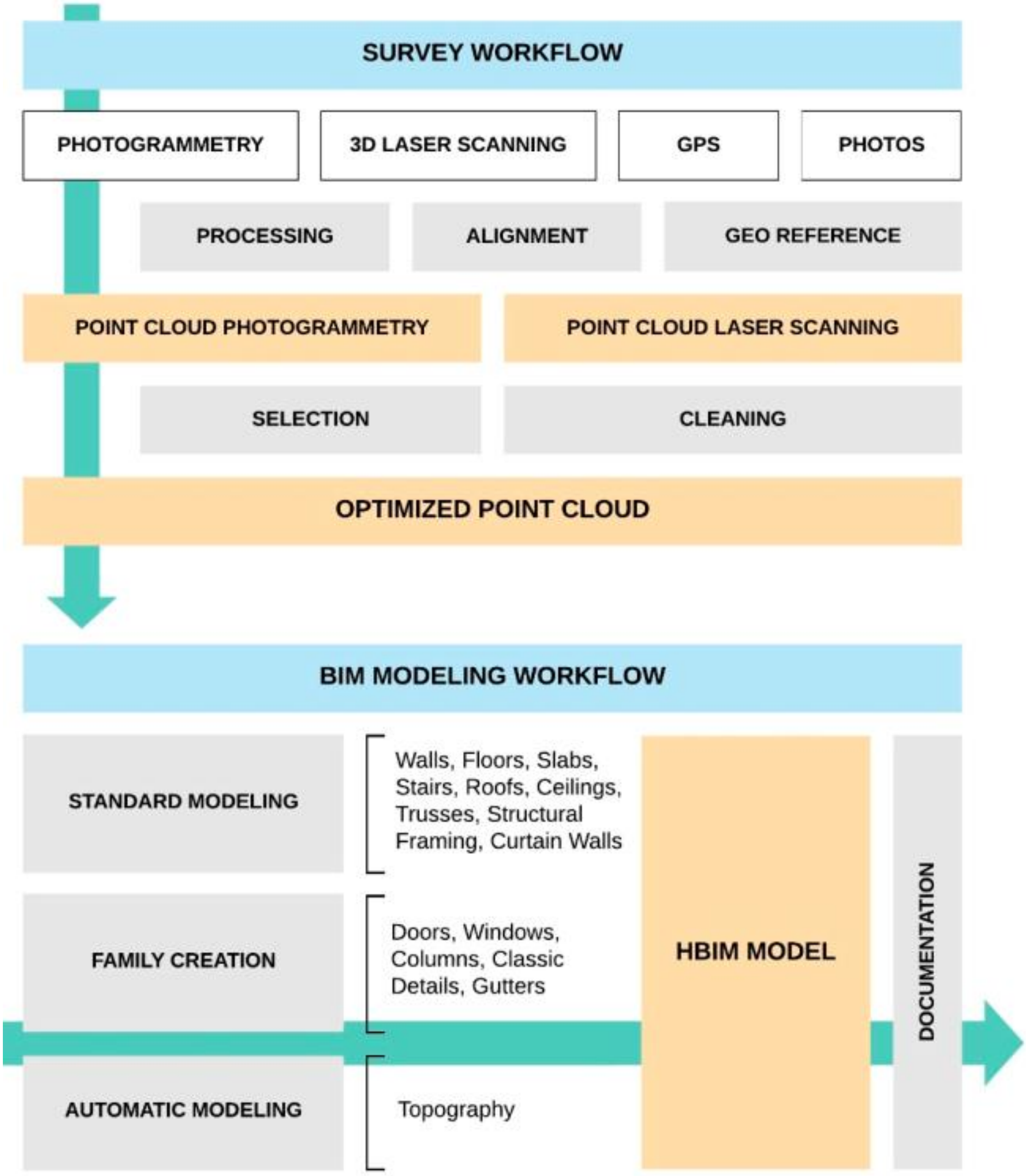


Figure 3 – The workflow of Scan to BIM in Heritage Building (Rocha et al., 2020)

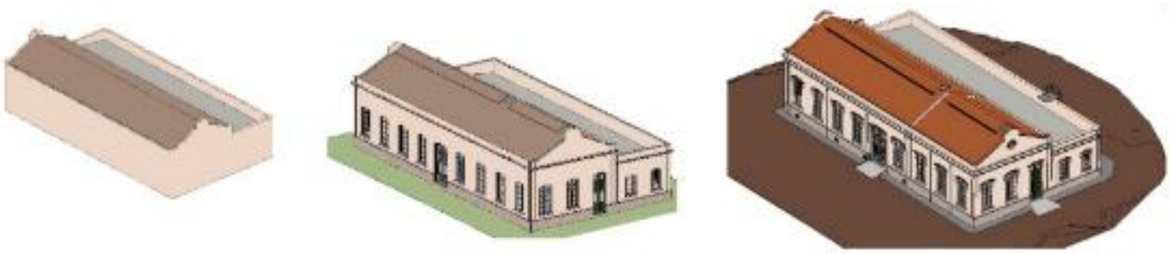


Figure 4 – The increasing of LOD in this project(Rocha et al., 2020)

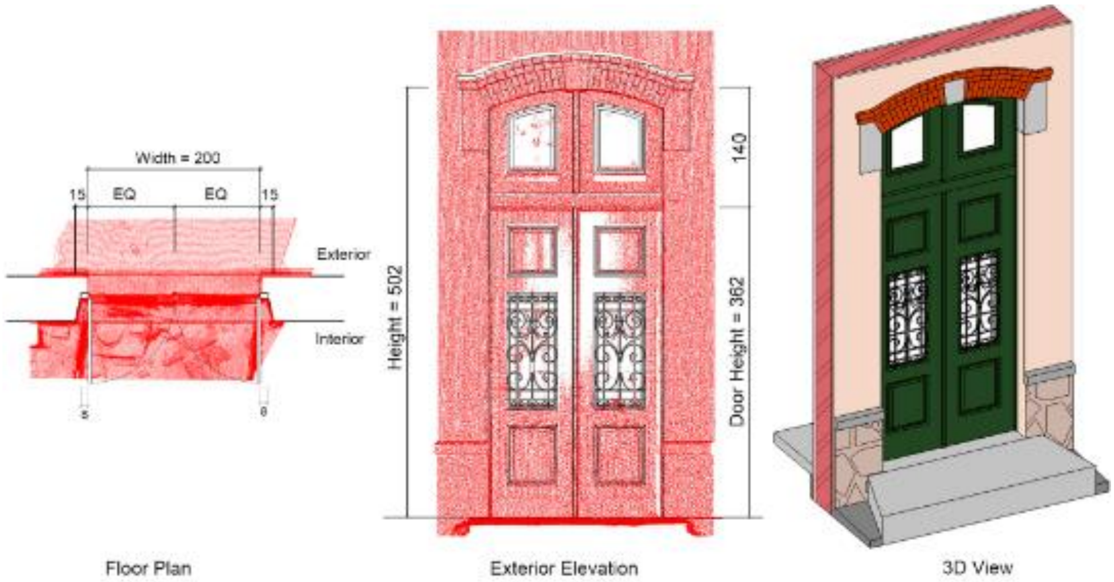


Figure 5 – Creating the BIM model by referring the point cloud data (Rocha et al., 2020)

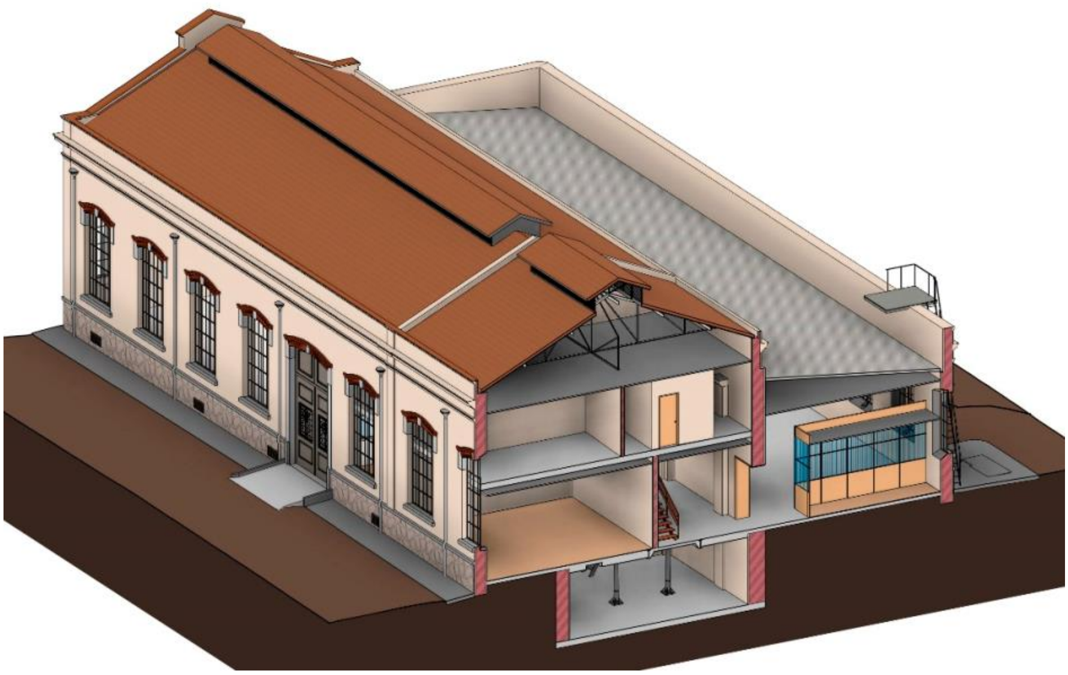


Figure 6 – Completed rebuilding the BIM model of this historical project (Rocha et al., 2020)

2.1.3.3. Scan to BIM for infrastructure project and application

The application scan to BIM for real-time tracking of the progress of the bridge project (Jiang et al., 2022). The main idea is the comparison of the as-design BIM model in a specific time with the real progress to figure out the issues of schedule.

The workflow tries to calculate the percentage completion of the components. The evaluation of the construction progress of infrastructure elements involves four processes. First, an as-design (virtual) point cloud will be constructed using the as-design BIM technology by Autodesk Civil 3D. The coarse and fine registration methods are then used to align the as-designed (virtual) point cloud with the as-built point cloud.

Following registration, segmentation and filtration are used to eliminate noise and ascertain the as-is state. Finally, the building progress will be calculated by dividing the numerical results of the as-is and as-design point clouds by their geometric statuses.

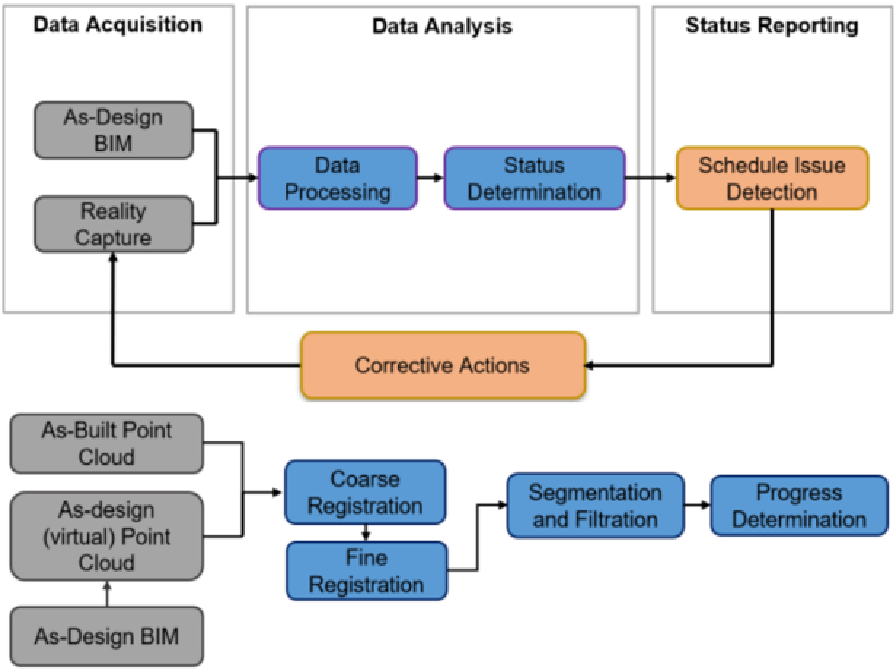


Figure 7 – The modules of proposed system and the developed framework (Jiang et al., 2022).

2.2. Automation in scan to BIM

2.2.1. Related research about automation and semi-automation in scan to BIM

The simple objects inside the existing building, such as walls, slabs doors and windows, can be reconstructed and opened in BIM tools by semi-automation process (Macher et al., 2017) or also can be different method segmentation, refinement, boundary mapping, object recognition (López Iglesias et al., 2020). In the analysis of the point cloud data of the facade of the building, the windows on it were recognized automatically by comparing the colour, the radiometric and the geometric feature (Macher et al., 2021), the . The map of the MEP system pipeline can be automatically built by using scan to BIM combined with AI and Deep Learning algorithms (Kang et al., 2020).

Based on the research paper of (López Iglesias et al., 2020), the objects can be a plane, such as the essential element of indoor modelling (walls, floors, and ceilings), and the facades of outdoor modelling usually use algorithms to classify them before drawing their boundary completely. Besides, the doors and windows will be defined based on the gaps of the segmented plane and the comparison with the database.

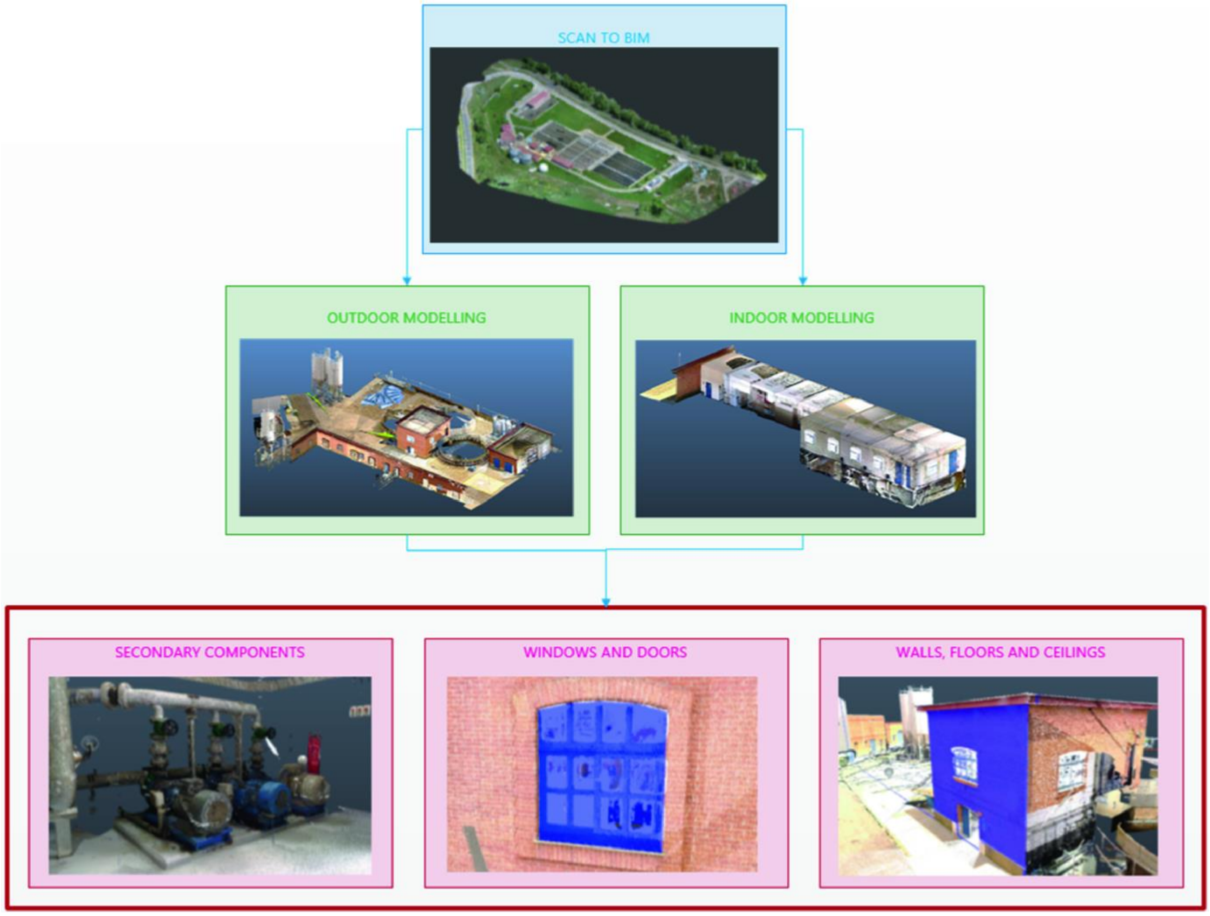


Figure 8 – Automation generating BIM elements based on their indoor/outdoor properties(López Iglesias et al., 2020)

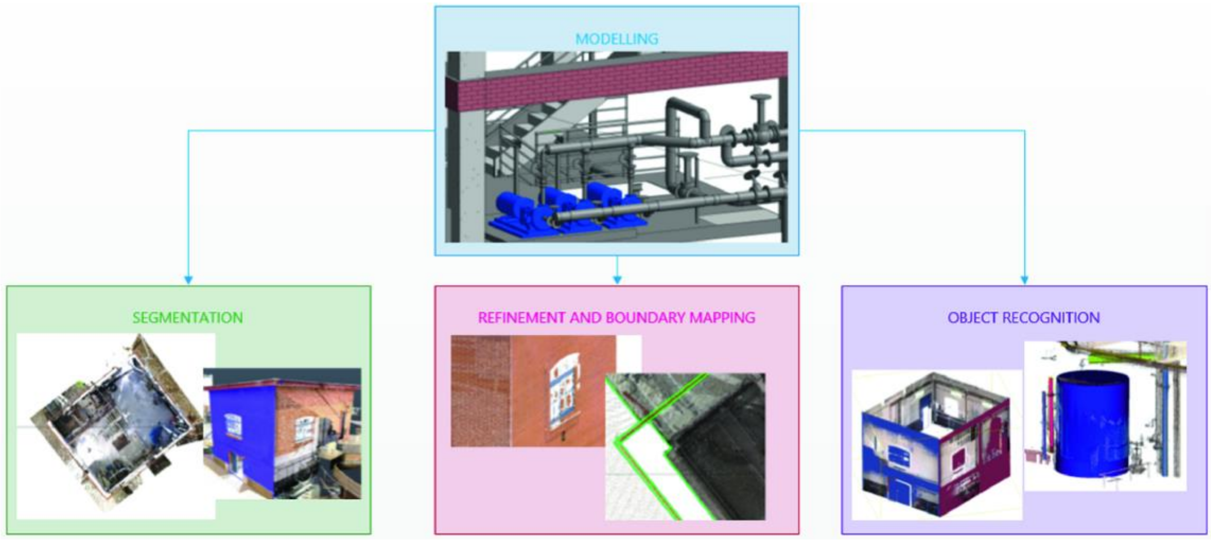


Figure 9 – Detecting the object boundary and recognizing the object (López Iglesias et al., 2020)

2.2.1.1. Segmentation

Segmentation in the field of 3D geometric models understanding is dividing the original set of points into subsets, such that the subsets contain only points taken from a particular natural surface (Varady et al., 1997). The popular algorithm for this task is RANSAC, which uses to identify the planes containing the points of a single structure element and filter the outlier points (Romero-Jarén and Arranz, 2021), (Schnabel et al., 2007); However, this also uses together with the algorithm Principal Component Analysis (PCA), (Dimitrov and Golparvar-Fard, 2015) to improve the result.

2.2.1.2. Refinement and boundary mapping

After finishing the segmentation step, the algorithm refinement and boundary mapping are applied to reduce the noise points, and prevent the rest points will belong to the wrong class or misleading before labelling for this plane. The noise points are also can be eliminated by using ray-tracing labelling (Huber et al., 2011), (Previtali et al., 2014), (Xiong et al., 2013). To extract the boundary lines of the walls, floors, among other, they use the algorithm that creates the boundary based on the corners of the planes and the line between them (Douglas and Peucker, 1973).

2.2.1.3. Object Recognition

Object recognition is the most crucial method for the automatic modelling process. However, it may only be possible after the segmentation process is finished. It leads to most methods trying to label the element when reconstructing the geometric (López Iglesias et al., 2020). (Nguyen et al., 2005) proposed a solution that automatically deduces the element (walls, ceiling, floors) by its topological information.

2.2.1.4. Secondary Components

Current approaches focus on modelling main components in buildings, while secondary components like switches and extinguishers can distort segmentation. To detect these, an algorithm uses colour and depth information from 4D orthoimages, separating them into colour and depth images (Adán et al., 2018). For depth, the Canny algorithm identifies potential regions of interest based on geometric discontinuities, comparing detected objects to a database (Canny, 1986). For colour, discontinuities define potential interest regions, transforming the colour image into binary to find compact pixel sets. These regions are compared with the database using global descriptors. However, the method has limitations, being less accurate for inclined walls or cluttered indoor spaces.

2.3. Summary

In summary, the literature review above has examined the automation and semi-automation of the Scan-to-BIM process, an increasingly important approach in the Architecture, Engineering, and Construction (AEC) industry. The Scan-to-BIM process, which involves converting point cloud data acquired through 3D laser scanning into Building Information Models (BIM), has shown significant potential for improving the management and visualization of building projects, particularly in the context of heritage buildings and infrastructure projects.

Throughout this review, an overview of the Scan-to- BIM process and its application was provided an overview of the Scan-to-BIM process and its applications, highlighting its use in various project types, including preserving heritage buildings and developing infrastructure projects. Discuss common methods were provided for automating and semi-automating the Scan-to-BIM process, such as segmentation, object recognition, and secondary component extraction. These methods have enabled the more efficient and accurate conversion of point cloud data into BIM models, streamlining the overall process.

Automation and semi-automation of the Scan-to-BIM process offer several advantages, including increased efficiency, reduced human error, and the ability to handle large datasets. These benefits can lead to more accurate and comprehensive BIM models, which are invaluable for project management and decision-making. However, there are also challenges and limitations associated with automation, such as the complexity of algorithms, the potential for misinterpretation of point cloud data, and the need for manual intervention in certain situations.

In light of the reviewed literature, it is evident that the automation and semi-automation of the Scan-to-BIM process hold great promise for the future of the AEC industry. Further research and development in this area, particularly in the context of advanced algorithms and machine learning techniques, will likely lead to even more sophisticated and accurate BIM models, ultimately enhancing the management and preservation of built environments. As technology advances, it is crucial to explore the potential of automation and semi-automation in the Scan-to-BIM process and address the challenges and limitations that remain.

3. FRAMEWORK FOR SEMI-AUTOMATION PROCESSES

3.1. Objective

This research's scope is to capture as-built models in some specific categories. These include residential or smaller-scale projects, structural projects, or MEP (Mechanical, Electrical, and Plumbing) projects.

The proposed methodology for this research is rooted in an extensive analysis of the existing Scan-to-BIM process, deployed widely across various projects. The aim is to identify specific stages in the process that hold the potential for automation. Once these stages are singled out, the next step would involve identifying the software tools best suited to automate these stages, considering factors like ease of use, scalability, and integration capabilities with other platforms, such as the IFC standard.

One of the key aspects of this research will be to address and consider every significant element that could potentially affect the quality of the point cloud data and, ultimately, the project's overall outcome. These factors will be discussed in detail within the methodology, providing clear guidelines on mitigating any issues and optimizing the data quality.

In terms of the object detailing in BIM, the Level of Detail (LOD) will be carefully considered based on the unique requirements of each specific project. Additional steps needed for modifying these objects, in line with the evolving project requirements, will also be addressed meticulously, ensuring the BIM model remains accurate and useful throughout the project lifecycle.

This chapter will provide a comprehensive validated methodology for semi-automating the Scan-to-BIM process using selected software tools. This methodology will be backed by rigorous testing and validation through case studies representing each of the four types of projects. The goal is to create a new process universally applied framework, helping industry practitioners adopt and benefit from semi-automated Scan-to-BIM processes.

3.2. The framework/roadmap of research plan

In the Scan to BIM process, the crucial steps include preparing the construction site, selecting scanning devices, and defining the main requirement for each object, such as the Level of Detail (LOD). These factors collectively substantially influence the quality of the resultant As-built BIM model.

In the task post-processing of point cloud data. This research used specific software that supported automating or semi-automate the translation of this data into BIM models in the widely used Revit format. This process makes the automatic generation and swift editing of simple objects such as walls, floors, and ceilings possible.

The methodology considers elements such as windows, doors, and other Revit family components moving forward to secondary objects. These objects are automatically recognized and positioned by the software, thus relieving the user of these tasks and enabling them to input the correct family type data.

In the case of more complex or unique objects, such as those associated with Mechanical, Electrical, and Plumbing (MEP), structural elements, and infrastructure components, the software steps up to handle the intricate task of classification. Once the automation process is completed, users are tasked with the relatively simplified job of placing the correct Revit family in the designated, referenced locations.

The methodology concludes with an exhaustive re-evaluation phase. During this stage, the quality of the Revit model is systematically compared against the initially determined LOD. Alongside this, an assessment of the effectiveness of the automation process facilitated by the software is conducted, setting it against traditional, less automated processes. This comparative analysis serves a dual purpose: highlighting the advantages of the automation process and pinpointing areas of potential improvement.

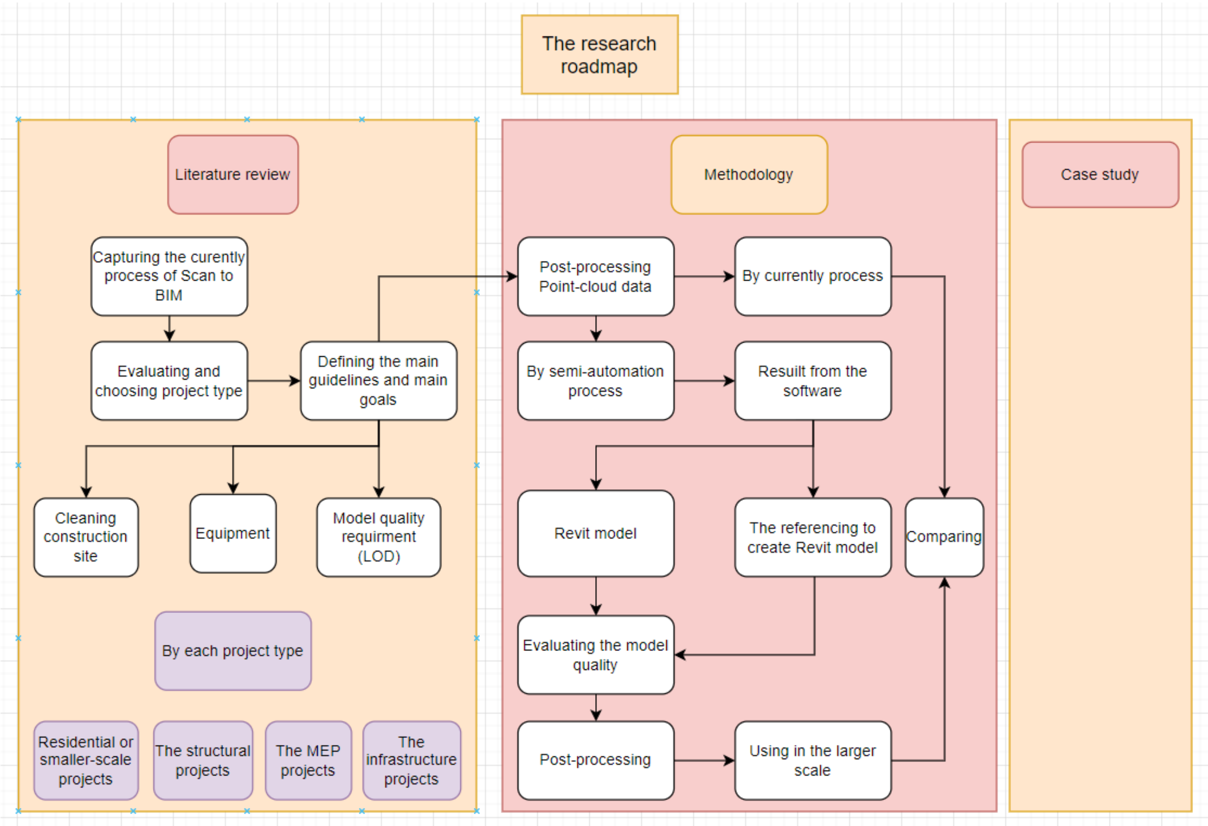


Figure 10 – The research road map that navigated for every task of this dissertation.

3.3. Preparation for data collection

3.3.1. Scan Device

The scanning device, the scan station, and the construction site affect the quality of point cloud data. The scanning device is the laser scanner. It is used for capturing and delivering the object's information, that is 3D geometry of its shape, the appearance (colour and material texture), context with the surrounding environment, and GPS coordination. According to the actual condition and the circumstances, these can be:

Stationary scanners: the devices that stand at some place to capture the maximum area and object around. There was classified into two sub-groups (Angelopoulou and Wright Jr, 1999): Stationary scanners: the devices that stand at some place to capture the maximum area and object around. There were classified into two sub-groups: the first is 'phase-based', used for mid-range distances from 0-100m, often to capture interiors and facades of standard construction. The second is 'time of flight' used for long distances beyond 100m, often to capture larger construction sites and infrastructure projects.

Terrestrial Laser Scanner (TLS): TLS devices shoot laser beams and time how long it takes for the beams to return to the scanner. This information is utilized to generate a high-resolution point cloud of the scanned area. TLS devices are frequently used to capture large-scale exteriors, building facades, and intricate architectural features. They are highly accurate and capable of capturing millions of points per second.

Mobile Laser Scanners (MLS): the devices can be mounted on mobile tools (a person or machine) to move along the scanning place. Technology and the algorithms inside portable scanners are more complex to process and contain 3D information, and they can be used in tiny places with no experience (Cadena et al., 2016). MLS collects georeferenced point clouds by combining laser scanning technology with GPS and inertial measurement units (IMUs). These scanners are useful for collecting large-scale settings like motorways, bridges, or entire neighborhood.

Handheld 3D Scanners: Handheld 3D scanners are manually controlled portable devices. They collect 3D data of objects or small regions using various technologies like as laser or structured light. Handheld scanners are multifunctional, allowing them to capture fine details as well as conduct close-range scanning jobs. They are frequently employed in the capture of architectural elements, sculptures, or minor construction components.

Photogrammetry Scanners: Photogrammetry scanners reconstruct a 3D model from a series of images taken from various angles. Photogrammetry software calculates position and depth information from overlapping photos to build a point cloud or a mesh model. This approach is widely used to capture interiors of buildings, furniture, or things where high accuracy is not required.

Unmanned aerial vehicle (UAV) scanners or aerial lidar scanners: It allows for effective and speedy data collecting, covering huge areas from an aerial perspective and requiring less time and effort than older methods. Using high-resolution point clouds, they produce realistic and accurate depictions of building exteriors, terrain, and surroundings. Drone scanners are adaptable and portable, allowing them to reach inaccessible or hazardous regions and collect complete data. Drone scanners help with construction monitoring, progress tracking, site planning and analysis, as well as enhancing safety, cost savings, and decision-making processes. Before starting the scan process, crucial factors such as flight planning, data accuracy, and regulatory compliance are required to ensure reliable and accurate results.

3.3.2. The precision and tolerance in measurement of device

Following the ISO 5725-1:1994 (Normalització, 1994), the accuracy was described as a trueness and precision parameter combination.

- The trueness data was collected by Terrestrial Laser Scanning (TLS) machine (or photogrammetric techniques). Its value is the 3D coordinate points closer to the correct values, identified by the average value of the group of precision points. The quality of the device scanners (cheap or high-cost) impacts the precision. In contrast, the trueness can maintain the accuracy in acceptable value by frequently calibrating as manufacture standard.

- So precision is the most crucial parameter to decide the quality of point cloud data (Campanelli et al., 2016). The picture below illustrates the definition of the trueness and precision value. And the different values of them when using two kinds of devices (Valero et al., 2022).

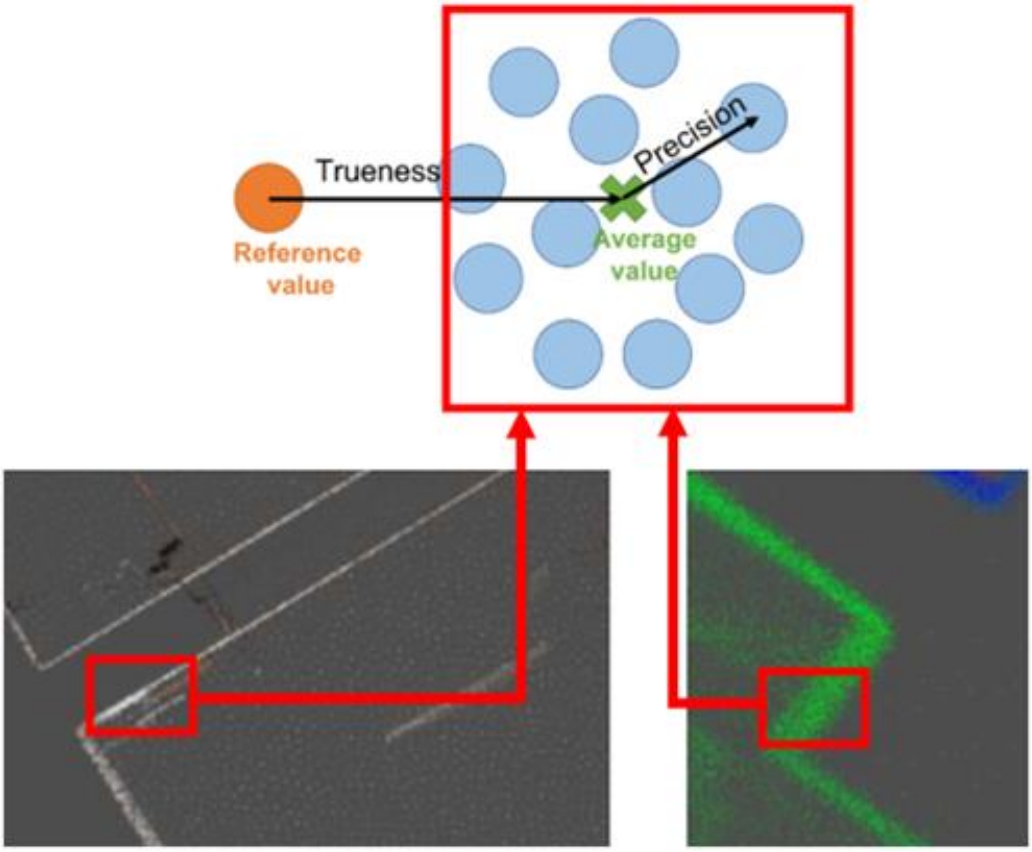
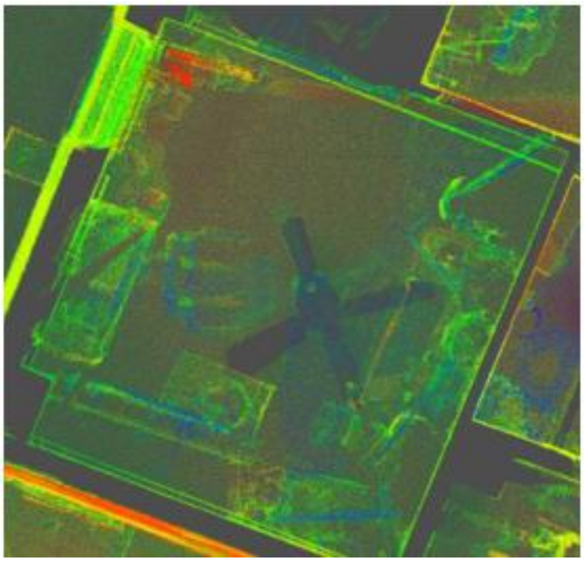


Figure 11 – The group of precisions points was collected by two different devices (Valero et al., 2022)

3.3.3. Scan station

The completion of object recognition or detection depends much on the result completeness of point cloud data. Holes in the data collection, for example, the wall in FIG can be realized and fixed by modelers with their experience. However, the missing data can significantly reduce the effectiveness of the automation recognition algorithms (Adán and Huber, 2010) (Valero et al., 2022).



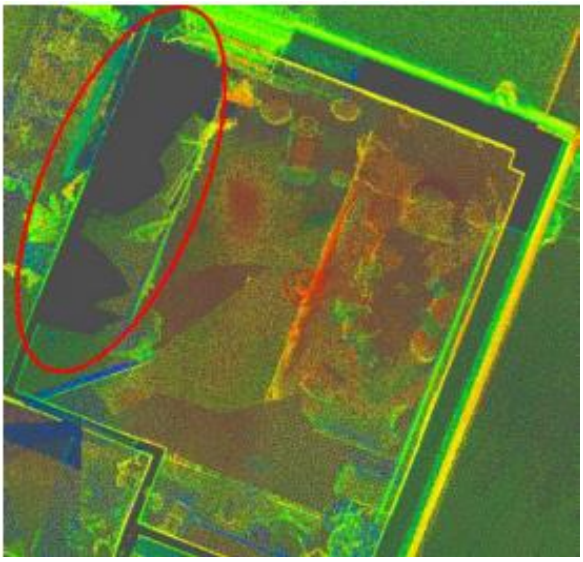


Figure 12 – The complete of the point cloud data (LEFT) and the incomplete (RIGHT), (Valero et al., 2022)

To improve the automation process of Scan to BIM, the scan station should keep in mind the advice below (Macher et al., 2017):

- The scan stations should be organized with a careful plan. To make sure it can capture every object with the minimum number of devices and overlap area.
- With indirection georeferencing, that should be scanned by more than one scan station.

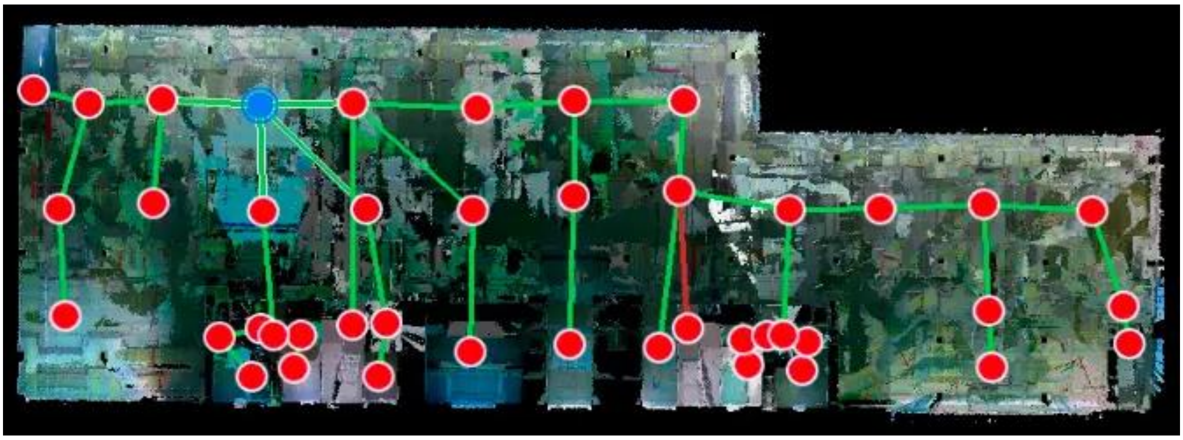


Figure 13 – The illustration for scan station planning (Siraj, 2021)

3.3.4. Special objects

3.3.4.1. Opening

In the construction project, the opening has many crucial roles. They can be the doors and the windows to create the way for people, light and wind to enter or exit the building. However, capturing their exact size is usually the hard work of the scanning process. For instance, in figure 14, the door is covered by the drawn curtain, all of them preventing the detection of the device and the fluent of data. From the research of (Díaz-Vilariño et al., 2015), (Assi et al., 2019), to reach high accuracy in the automation of object recognition the input point cloud data need to be clear without noise point and unclear object. However, various algorithms and strategies have been developed for the occluded opening (Quintana et al., 2018), (Nikoohemat et al., 2018). In addition, the segmentation algorithms cannot work perfectly with the closed curtain in front of the windows because it looks like a wall with different colours. Similarly, the opening size can be wrongly detected if air conditioning, blinds and furniture are nearby (Quintana et al., 2018). Scanning doors and windows when they open is not mandatory, but it facilitates finding the opening easier and improves the overlap while executing consecutive scans, and consequently easier for the registration process. (Valero et al., 2022).

Figure 14 – The windows with closed curtain (Valero et al., 2022)

3.3.4.2. Mirrors

The term "Through the looking-glass" is used to call everything reflected in a mirror. For instance, figure 15 and the consequence is the mirrored scene displayed as the real thing. Similarly, the same issue may occur to any object with a reflexed material, such as metal or glass (Valero et al., 2022). Some solution has been developed to identify the rectangular mirror to ignore its reflected scenic (Käshammer and Nüchter, 2015). Nevertheless, the best solution is to remove or cover every high-reflection object if possible. If it is impossible, the erroneous point must be deleted before working (Gao et al., 2022).

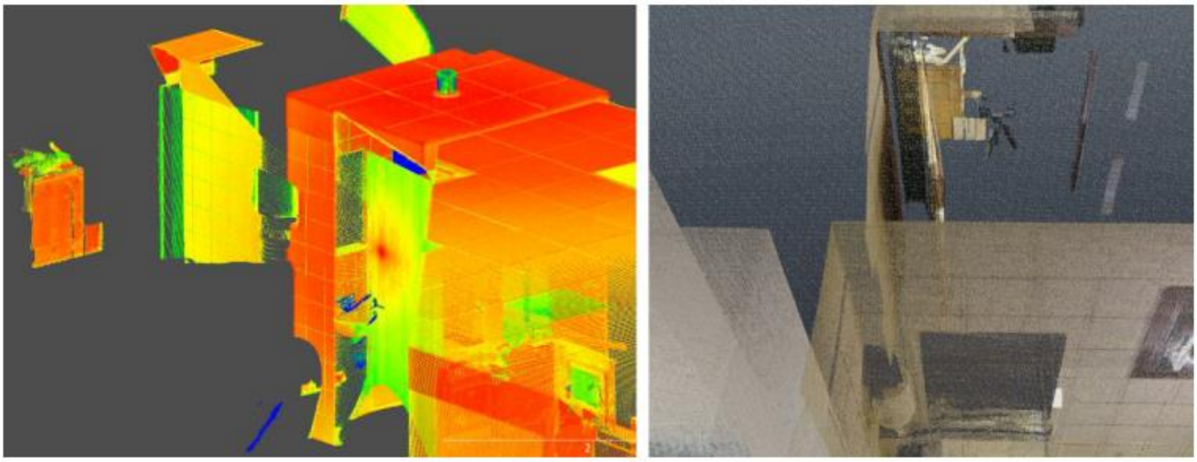


Figure 15 – The consequence of uncovering the mirror when scanning (Valero et al., 2022)

3.3.5. Data acquisition

3.3.5.1. Resolution

The resolution is the first parameter to be set up before the scanning process starts. The horizontal and vertical angular gaps between successive scanned sites define resolution. Resolution is also typically stated as the distance between consecutive cloud spots at a particular distance from the scanner, such as "x millimetres @ y metres" (Faro, 2022). It's worth noting that the horizontal and vertical scanning resolutions are frequently set to the same value (Valero et al., 2022).

Point clouds with higher resolution angles are sparser. This allows for more precise scanning of tiny objects, but it can also have a negative influence on data processing performance. To ensure adequate resolution of a given target item (enough but not too high), the surveyor must know or estimate the scanning distance in order to select the appropriate resolution settings. However, it should be noted that the incidence angle of the laser beam on the scanned surface influences the resolution of the produced point cloud. The higher the resolution, the smaller the incidence angle (i.e., the scanning path is more perpendicular to the scanned surface). Surveyors may also need to consider this while scanning structures that are high above the ground, such as the upper parts of high-rise buildings (Valero et al., 2022).

3.3.5.2. Colour

The surveyor must determine whether or not colour will be necessary for subsequent stages. This is because, depending on the scanning technology utilized, colour acquisition can impede overall data acquisition.

Colour is acquired from the scanning equipment using adequate, but not necessarily high-quality cameras. If high-quality imagery is required, scanning may need to be complemented by additional image acquisition, and the colour information transferred to the point cloud via texture mapping, for example, through alignment with photogrammetric reconstructions (Alshawabkeh et al., 2021; Valero et al., 2019).

3.3.5.3. Overlapping

As mentioned in "3.3.2. The precision and tolerance in measurement of device" Completeness and Occlusions, obtaining a comprehensive point cloud of an environment requires a well-designed scanning plan. However, the scanning locations chosen must ensure not only that the target objects are scanned with the appropriate levels of quality and completeness, but that the resulting scans can be properly registered together in a unified point cloud. Many research papers argue that appropriate overlap between subsequent clouds is required (Ahn and Wohn, 2016; Aryan et al., 2021; Chen et al., 2018; Huang et al., 2021; Li et al., 2021).

When scanning indoors, as shown in figure 16, positioning the scanner in doorways see a green point cloud here allows for data capture from the two connected rooms and helps co-registration of additional point clouds gathered in those two neighbouring spaces and beyond. When scanning a building exterior outside, it is critical to connect the separate clouds representing the facades. When using stationary scanning devices, positioning the device at the building's corners will produce a cloud including data from two (or more) connected facades, allowing co-registration of other point clouds gathered from those facades (Valero et al., 2022).

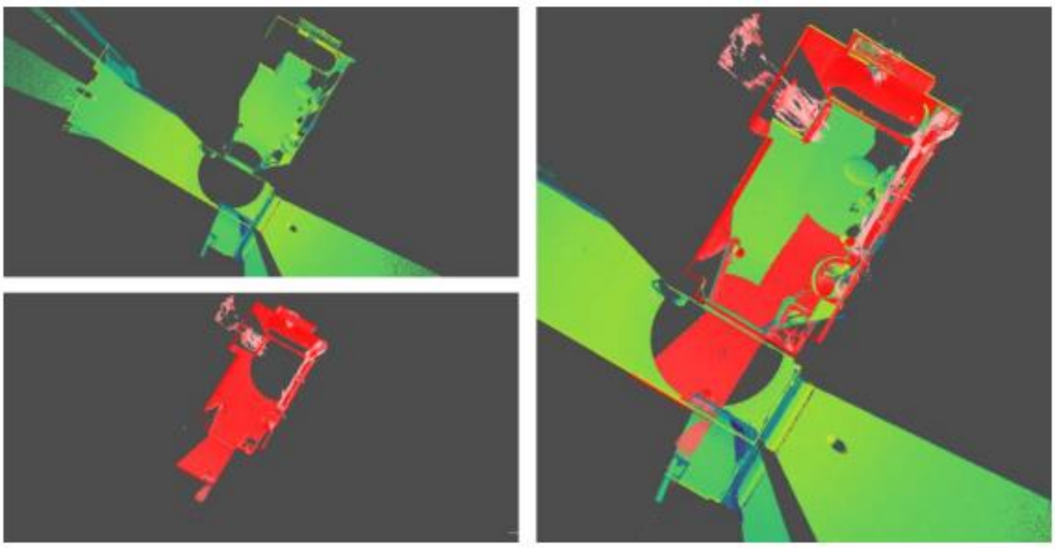


Figure 16 – Point clouds that overlap. The Benefits of Putting an equipment in a doorway (Valero et al., 2022)

3.3.6. Data processing

3.3.6.1. Cleaning

As mentioned in "3.3.4.2. Mirrors" Mirrors, reflecting surfaces, and transparent surfaces will add bogus points to a cloud. Figure 17 depicts a scanned bathroom in which objects were scanned by reflection on glass and plastic surfaces, resulting in 'ghost' 3D points (Gao et al., 2022). Furthermore, during scanning, the scene may contain moving items, such as people. To avoid confusion, these points should be deleted as much as possible before co-registering the individual scans, especially when executing automatic procedures (Cheng et al., 2021).

Furthermore, points pertaining to non-study items should ideally be deleted to optimize processing performance (in terms of both time and quality). Such cleaning efforts may necessitate human intervention, which can be time-consuming and error-prone. Thus, the amount of cleaning should be evaluated using a cost/benefit analysis.

Figure 17 window and a mirror on the adjacent wall generate a similar effect (highlighted in green), as does the washing machine door (highlighted in red).

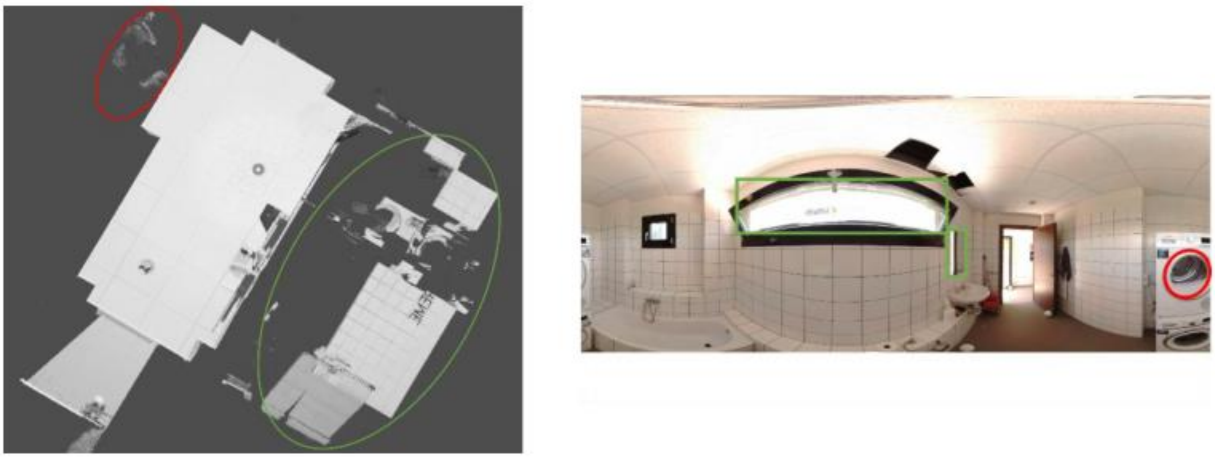


Figure 17 – Plastic and glass surfaces produce incorrect points (Valero et al., 2022).

3.3.6.2. Registration

It is critical to carefully register successive point clouds in order to generate a complete cloud that precisely depicts the scanned environment. Care must be taken in this process, especially if the point cloud is to be used in automated processes. Indeed, registration mistakes can cause misalignment, which can have significantly more of an impact on processing than single point precision and accuracy - for example, overlapping scans of a wall that are appropriately co-registered will result in two close but separate planes. Despite the fact that most software processing point clouds work automatically.

For example:

Faro Scene: https://www.faro.com/en/Resource-Library/Tech-Sheet/techsheet-faro-scene

Cyclone: https://leica-geosystems.com/products/laser-scanners/software/leica-cyclone

Autodesk ReCap: https://www.autodesk.co.uk/products/recap

Can register point clouds automatically and robustly using natural and artificial attributes as well as internal sensor data (e.g., IMU) (Ridene, 2013). It is critical to validate the results, including ensuring that overlapping scans of items of interest (such as walls) are appropriately aligned (Mora et al., 2021).

If the automated registration of consecutive clouds is insufficient (see walls in Figure 18 Left), a human registration should be performed by selecting at least three (but preferably four or more) pairs of matching spots as shown in Figure 18 Left (Aiger et al., 2008; Brumana et al., 2020; Li et al., 2021). Figure 18 right depicts a manual correction of mis-registration. It should be noted that geometric characteristics other than points, such as planes, can also be used (Forstner and Khoshelham, 2017; Kim et al., 2018; Bueno et al., 2018; Valero et al., 2022). It should be noted that geometric features utilized for registration (e.g., points) should be distributed throughout the space and should not be on the same plane. This strengthens the registration process.

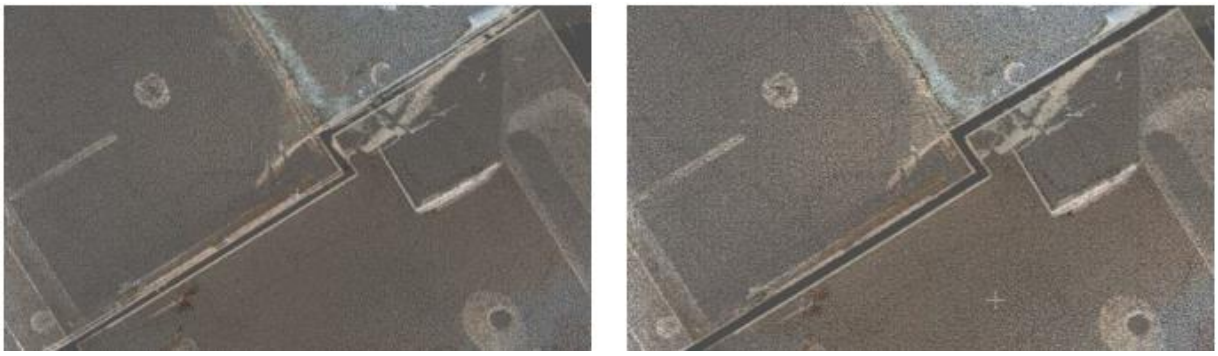


Figure 18 – Automatically and manually registered consecutive point clouds (Valero et al., 2022)

3.3.7. Defining the main goal

3.3.7.1. Information requirement identification

Distinct BIM applications necessitate the storage of distinct sets of information in the as-is BIM models. Too much information is a waste of time and effort, while inadequate information results in a BIM model that is unusable for the intended purpose (Tang et al., 2010). As a result, before gathering scan data, it is vital to establish the relevant information for each unique BIM application. The information needs are identified in three ways:

- Requirement of the construction element
- Requirement of Level of detail - LOD
- Requirement of Non-Geometric characteristics

3.3.7.2. Elements Required for Construction

The needed building elements are the elements that must be modelled in the as-is BIM. Using a specific building element classification system, a list of required building elements should be identified. The

OmniClass Construction Classification System (also known as OmniClass or OCCS) is a construction classification system (Gelder, 2013) is one example that has been widely used in the construction business. The OmniClass is made up of 15 tables that represent various sorts of building information, and it has been used in some research projects. (Messner et al., 2019) for example, used OmniClass Table 21 (representing building Elements) to specify information sharing. And Table 23 (representing building Products) was adopted by (Pishdad-Bozorgi et al., 2018) to designate facility assets to be tracked via BIM. Other well-known classification systems besides OmniClass include the (MasterFormat) from the United States and Canada and the Uniclass (NBS) from the United Kingdom.

Table 21 - Elements	**Definition:** An **Element** is a major component, assembly, or *"constituent of a construction entity with a characteristic function, form, or position"* (ISO 12006-2:2015). Predominating functions include, but are not limited to, supporting, enclosing, servicing, and equipping a facility. Functional descriptions can also include a process or an activity.
	Examples: Structural Floors, Exterior Walls, Storm Sewer Utility, Stairs, Roof Framing, Furniture and Fittings, HVAC Distribution

Figure 19 – Table 21 of OmniClass

Table 23 - Products	**Definition: Products** are components or assemblies of components for permanent incorporation into construction entities.
	Examples: Concrete, Common Brick, Door, Metal Window, Junction Boxes, Pipe Culverts, Cast-Iron Boiler, Curtain Walls, Textured Paints, Vinyl-Coated Fabric Wall Covering, Demountable Partitions, Pre-Engineered Manufactured Structures

Figure 20 – Table 23 of OmniClass

3.3.7.3. LOD required

The required modelling LOD of each architectural element that needs to be modelled should be established. In this paper, LOD refers to "level of detail," while in the building business, this phrase is frequently used interchangeably with another term, "level of development." The phrase "level of development" refers to the gradual evolution of the BIM model from the conceptual design stage to the completion of construction. However, the term "level of detail" refers to the degree to which the element model is detailed and specific. Both phrases are commonly used in the construction of BIM models for new buildings, where they express the same model development process but from distinct perspectives. In the industry, various model LOD specifications have been suggested and used, and a typical LOD specification consists of five levels: conceptual (LOD 100), approximate geometry (LOD 200), accurate geometry (LOD 300), manufacturing (LOD 400), and as-built (LOD 500) (Reddy, 2011). The comprehensive descriptions of the customary five levels of model LOD specification are included in Table 2

Table 2 – The explanation for the LOD requirement in each level

LOD	Description	Model
100	Conceptual	A symbol or another type of generic representation
200	Approximate geometry	Estimated number, size, form, position, and orientation
300	Precise geometry	Quantity, size, form, position, and orientation must all be specified.
400	Fabrication	Detailing, manufacturing, assembly, and installation details, as well as specific size, shape, location, quantity, and orientation
500	As-built	Size, shape, position, quantity, and orientation were all checked in the field.

Because this study is aimed at creating as-is BIM for existing buildings, existing LOD requirements cannot be immediately adopted. According to the existing LOD specifications, all as-is BIM models should be LOD 500 due to their "as-built" character. Furthermore, the current LOD specifications do not explicitly define the quantitative threshold for each level. The line between approximation and precise geometry is unclear and subjective. As a result, in the proposed scan-to-BIM framework, the model LOD is divided into three levels: "conceptual", "approximate geometry", and "precise geometry". The needed modelling accuracy of the element amount, size, form, location, and orientation should be defined in addition to the required LOD wherever relevant. For example, the needed LOD for a wall could be "precise geometry" with 10 mm modelling precision in terms of size, form, and position.

3.3.7.4. Non-Geometric characteristics are required

While the model LOD focuses on the required geometric properties of an element, the required non-geometric attributes for each element should also be established to meet the objectives of the intended BIM application. For example, spatial linkages between architectural elements are critical for BIM-based spatial reasoning for diagnosing a building's water distribution system (Tang et al., 2010). Aggregation relationships, topological relationships, and directional relationships are examples of spatial relationships. The materials of building elements and thermal properties of building materials are required for BIM-based building energy modelling. Surface qualities (e.g., colours and reflectivity) of building elements, mechanical properties of structural elements, acoustic properties of walls, technical specifications and warranty information of equipment, and so on are examples of non-geometric attributes. It should be noted that the scan-to-BIM method can only capture a few of the non-geometric features stated above, such as spatial relationships between building elements, materials, and surface qualities. However, identifying all of the necessary non-geometric features in this step is still useful so that the needs are adequately defined, and alternative data sources may be deployed later to supply the required data.

3.4. The method used to compare and evaluate the case study

Objective: Objective: The next part applies the semi-automation process to two case studies to determine its effect. However, after the test, it should be evaluated carefully to determine the pros and cons and revised before applying on a larger scale. This part proposes the framework to evaluate the entire case study, from the point cloud data post-processing to the Revit model.

Break down the process to evaluate in detail: In general, generating the Revit model from the point cloud data is taken many steps. Therefore, every manipulation will be mentioned and clarified to ensure practical analysis.

Quantitative analysis: the LOD requirements of each case study, the quantitative analysis of the time-consuming, expensive, and accuracy of each element will be considered, following the list:

- Wall
- Window
- Door
- Stair
- Railing
- Roof
- Timber structure
- Pipe

Qualitative analysis: Consider qualitative factors such as the feeling of BIM modelers and project managers and variables such as simplicity of use, collaboration, adaptability, and general satisfaction.

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4. CASE STUDY

4.1. Semi-automation tools and BIM tools

4.1.1. Aurivus semi-automation tool

Aurivus is the Revit add-in used to assist the BIM modeler while creating the Revit model based on the point cloud data. This tool used AI technology to classify and segment the elements of the construction project in whole point cloud data. Regarding the object's type (the family in Revit), it automatically generates the Revit element or provides to modeler the reference view and dimension to easily create these elements. This add-in can work with various construction elements, such as furniture, structural, and MEP elements.

4.1.2. Recap Pro

Autodesk's ReCap Pro is a reality capture application. It allows users to create 3D models from point cloud and laser scan data. ReCap Pro facilitates the creation of precise as-built models for architecture, engineering, and construction applications by incorporating data processing, altering, and visualization features. It supports multiple file formats, efficiently manages large datasets, and offers tools for registration, alignment, and data analysis.

4.1.3. Revit

Revit is Autodesk's BIM software for the creation and management of intelligent 3D building models. In the architecture, engineering, and construction industries, it facilitates design, collaboration, and documentation processes. Revit's parametric modelling capabilities and data-driven approach enhance project efficiency and facilitate improved stakeholder coordination.

The case study will be created by Revit will ensure it has high interoperability with the popular software and is easy to use and update in the future.

4.1.4. Open IFC Viewer

Open IFC viewer software is a free and open-source application that allows users to view and explore Industry Foundation Classes (IFC) files. This software provides the ability to visualize 3D models and navigate through the BIM data contained within IFC files.

Its application for the next case study is checking the ability of interoperability of the BIM model in IFC format after creation by Revit.

4.2. Case study 1

4.2.1. Introduction

The first case study concerns a point cloud data of a small house with a 75m^2. This case study was selected as it comprises a typical existing structure where different structural elements can be observed and analysed. The house has 3 floors, including a basement and one roof. It was built with brick and gypsum, and the roof structure was made of timber. This type of house is very common in villages in Slovenia. The picture below is shown the current situation of this house. The option intensity colour was shown together to increase its detail.

A terrestrial laser scanner Leica RTC360 was used to obtain the cloud of points. It has a high scanning speed, a 360-degree field of view, and great precision. It provides detailed point cloud data for a variety of applications using HDR imaging and automated workflow. The scanner is portable and lightweight, and it works with applications such as Leica Cyclone and CloudWorx. It is employed in construction, surveying, and the preservation of cultural assets.

Figure 21 – Terrestrial laser scanner Leica RTC360

The main goal of to create a Revit model for this house with geometric information on a medium level. The first purpose is to use the cloud of points for illustrations of rendering video or the scene of the main project. Furthermore, it can be a reference if the building needs to be reconstructed. In that case, the LOD of its BIM model has to improve. Using Aurivus Revit add-in to demonstrate its effect, based on its result comparing the pros and cons of the common process and new processes.

The information on the point cloud data, and relevant it was obtained from Elea IC company. Firstly, the current situation of every part of this house is presented. Although the quality of these photos is not high, they provided enough information about this house for the purpose of this work

LOD requirement:

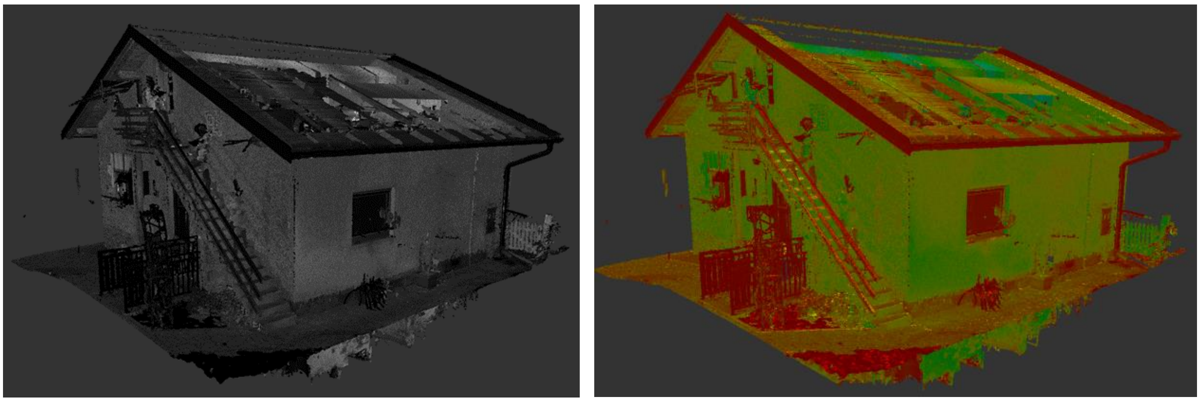
Regarding the main goal, the LOD of this case study is assigned at a low level, mainly focusing on the reconstruction of the Revit model of the building with medium accuracy.

Table 3 – LOD requirement for case study 1

Object types	LOD requirement	Description
Wall	200	Approximate thickness and material
Floor	150	Approximate elevation and material

Door	150	Approximate dimension and structural opening size
Window	150	Approximate dimension and structural opening size
Stair	100	Approximate riser height and treated depth
Railing	100	Approximate geometric shape
Roof	100	Approximate boundary and slope of the roof
Timber structure	200	Approximate section of the timber and location

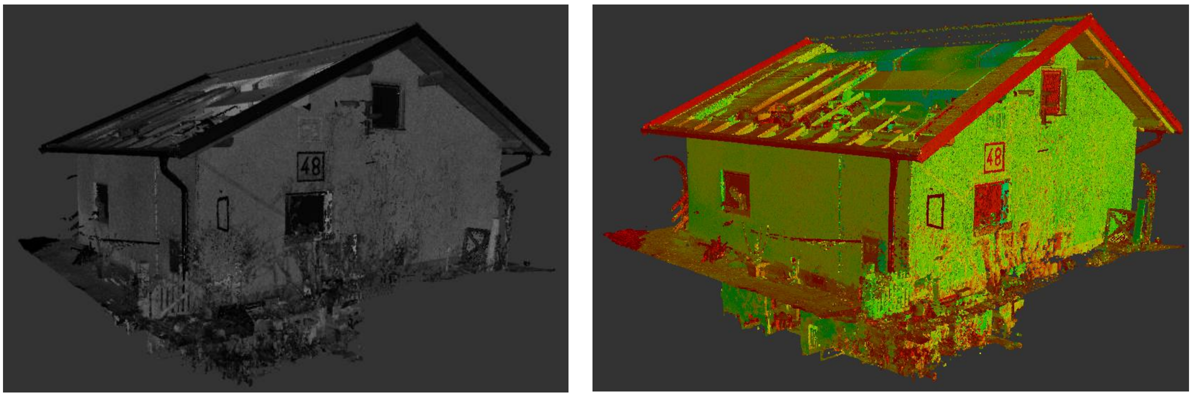
Figure 22 below shows the current state of the house from the front. The exterior includes 1 door and 2 windows and has 2 main stairs, one leading to the basement and one to the roof. Through this image, it can also be seen that the roof structure of the house has been partially damaged.



a) b)

Figure 22 – The facade of this house with two different colour modes: a) Normal image b) Intensity colour mode

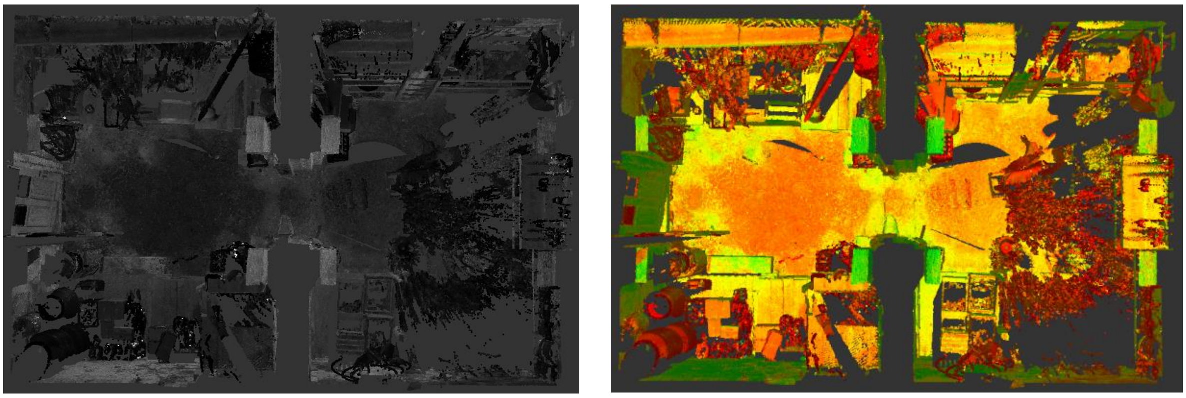
Figure 23 below shows the current condition of the house from the rear. On this side of the house, two windows are facing out. The damaged roof is also more visible in this figure. More specifically, some timber was broken or missing.



a) b)

Figure 23 – The back side of this house with two different colour modes: a) Normal image b) Intensity colour mode

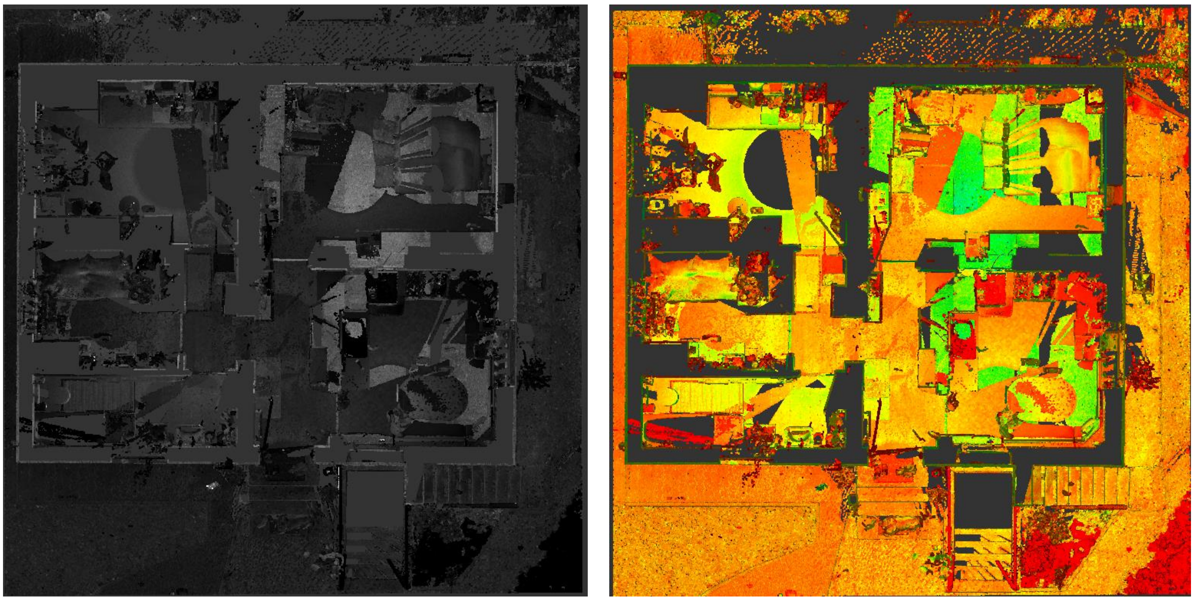
Figure 24 clearly shows the floor plan of the basement. It contains a lot of furniture, some located in the corner of the room's boundary areas, which reduces the quality of point cloud data. However, the size of the door in the middle of the house can still be seen clearly.



a) b)

Figure 24 – The floor plan of basement with two different colour modes: a) Normal image b) Intensity colour mode

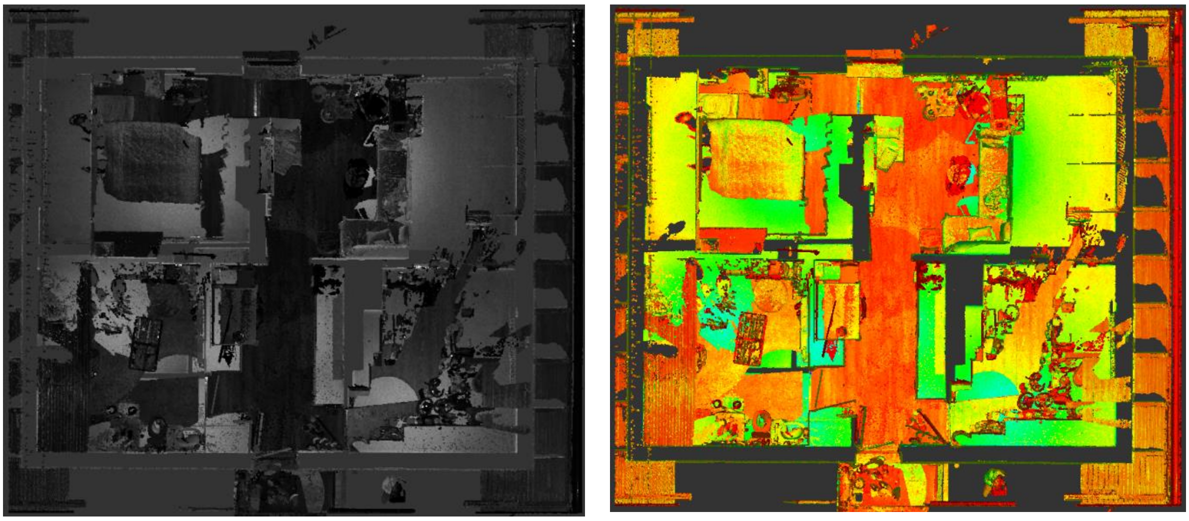
Figure 25 clearly shows the floor plan of the first floor. Based on this, the quality of point cloud data is average. Many tables, chairs and cabinets interfered with scanning, causing the floor and wall thickness data to be displayed indistinctly. Besides, cabinets and shelves close to the border can confuse data on wall thickness.



a) b)

Figure 25 – The floor plan of level 1 with two different colour modes: a) Normal image b) Intensity colour mode

Figure 26 below is the floor plan of the rooftop. From this figure, the data point cloud in this area is of poor quality but still shows the wall thickness. There is also a lot of noise here, which may result from a damaged roof, causing a lot of natural light to interfere with the scan data.

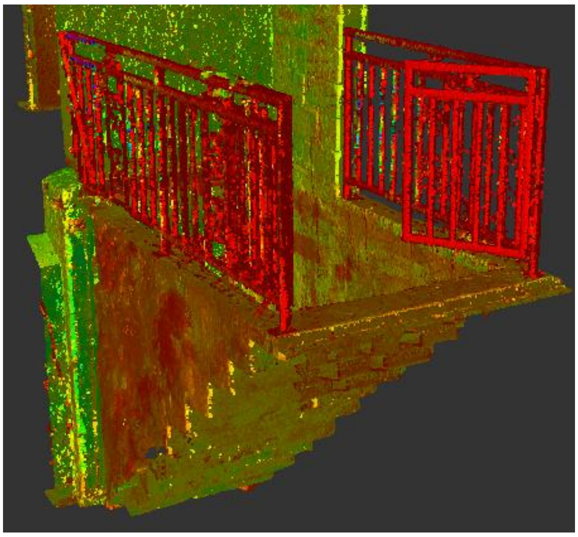


a) b)

Figure 26 – The floor plan of rooftop with two different colour modes: a) Normal image b) Intensity colour mode

The data in figure 27 shows the condition of the stairs leading down to the basement. The quality of the data point cloud here is quite good. It clearly describes the details of the railings and stairs. From this picture, it is also possible to see the door height and the old condition of the door.

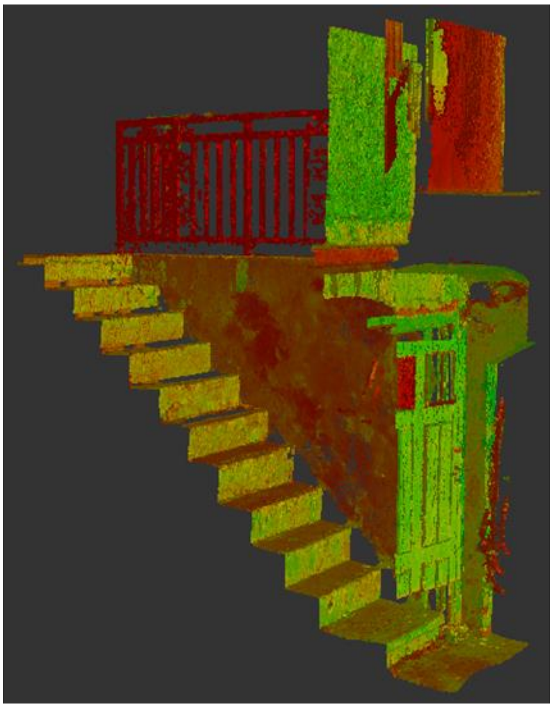
a)



b)

Figure 27 – The current situation of the stair for access basement with two different colour modes: a) Normal image b) Intensity colour mode

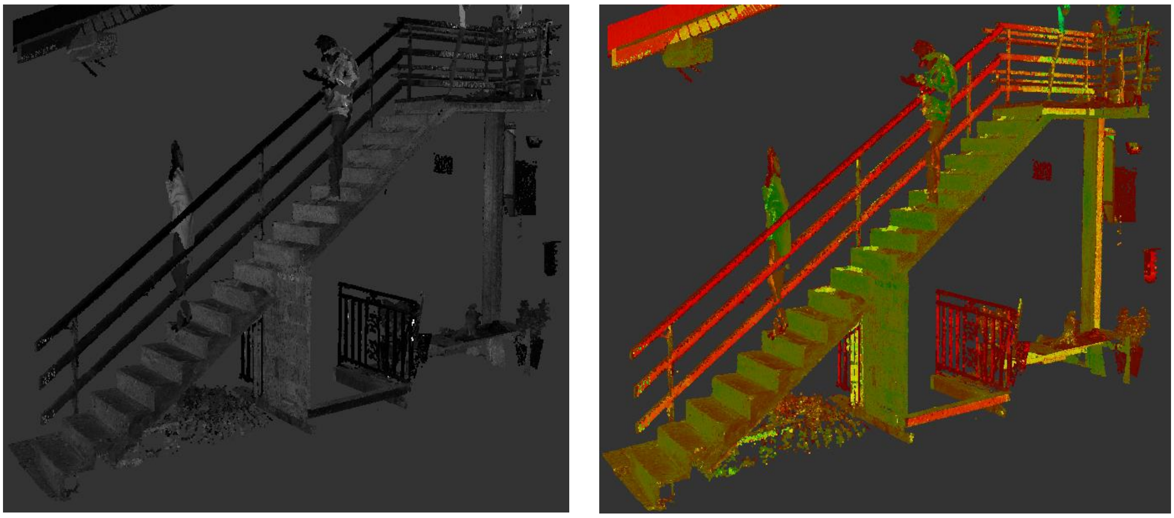
a)



b)

Figure 28 – The current situation of the stair for access basement – section view with two different colour modes: a) Normal image b) Intensity colour mode

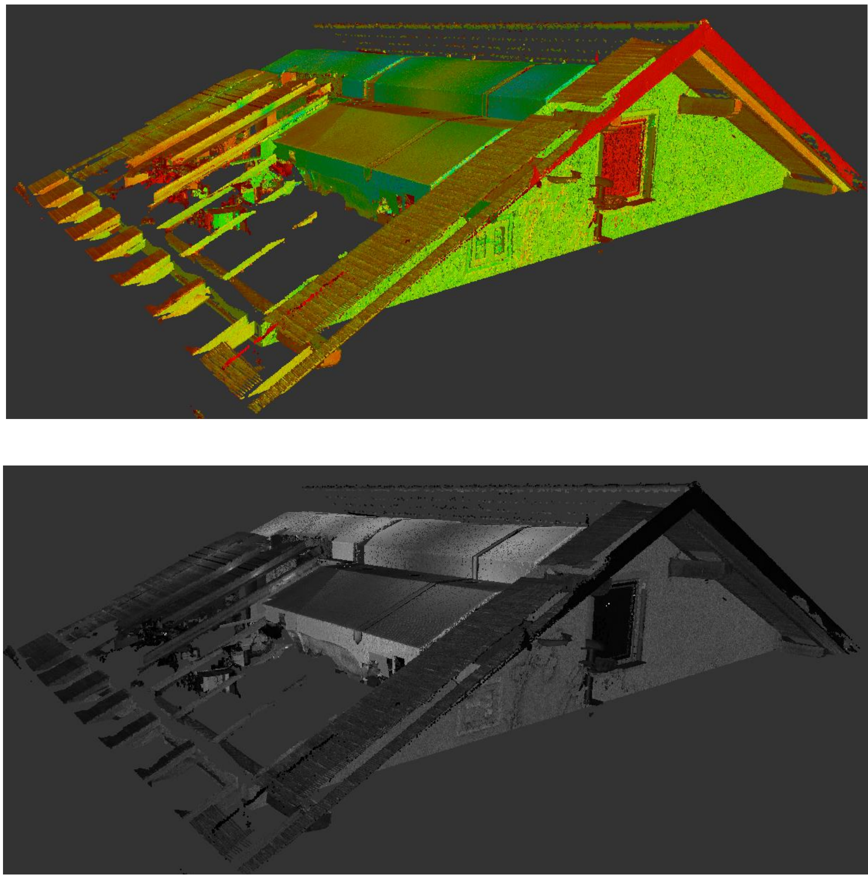
The data in figure 29 shows the condition of the stairs leading to the rooftop. The quality of the point cloud data here is quite good. The section of the stairs and the railing details can be seen. The railing on this staircase is old, and it can be seen at the top of it has been repaired.



a) b)

Figure 29 – The current situation of the stair for access rooftop – section view with two different colour modes: a) Normal image b) Intensity colour mode

The data in figure 30 shows the roof's current state and structure. However, because the quality of the data point cloud here is bad, it is easy to cause confusion, and it is difficult to distinguish between broken timbers and timbers that are blurred due to errors in the scanning process.



a)

b)

Figure 30 – The current situation of the rooftop structure with two different colour modes: a) Normal image b) Intensity colour mode

4.2.2. The approach workflow

Figure 31 below presents the typical workflow of the Revit modeler when generating a model with point cloud reference. The manual steps and the semi-automation are delivered parallel for an easier comparison basis. Time is considered dependant on the experience of the user. Indicatives values were provided, considering the author's experience, for comparison purposes.

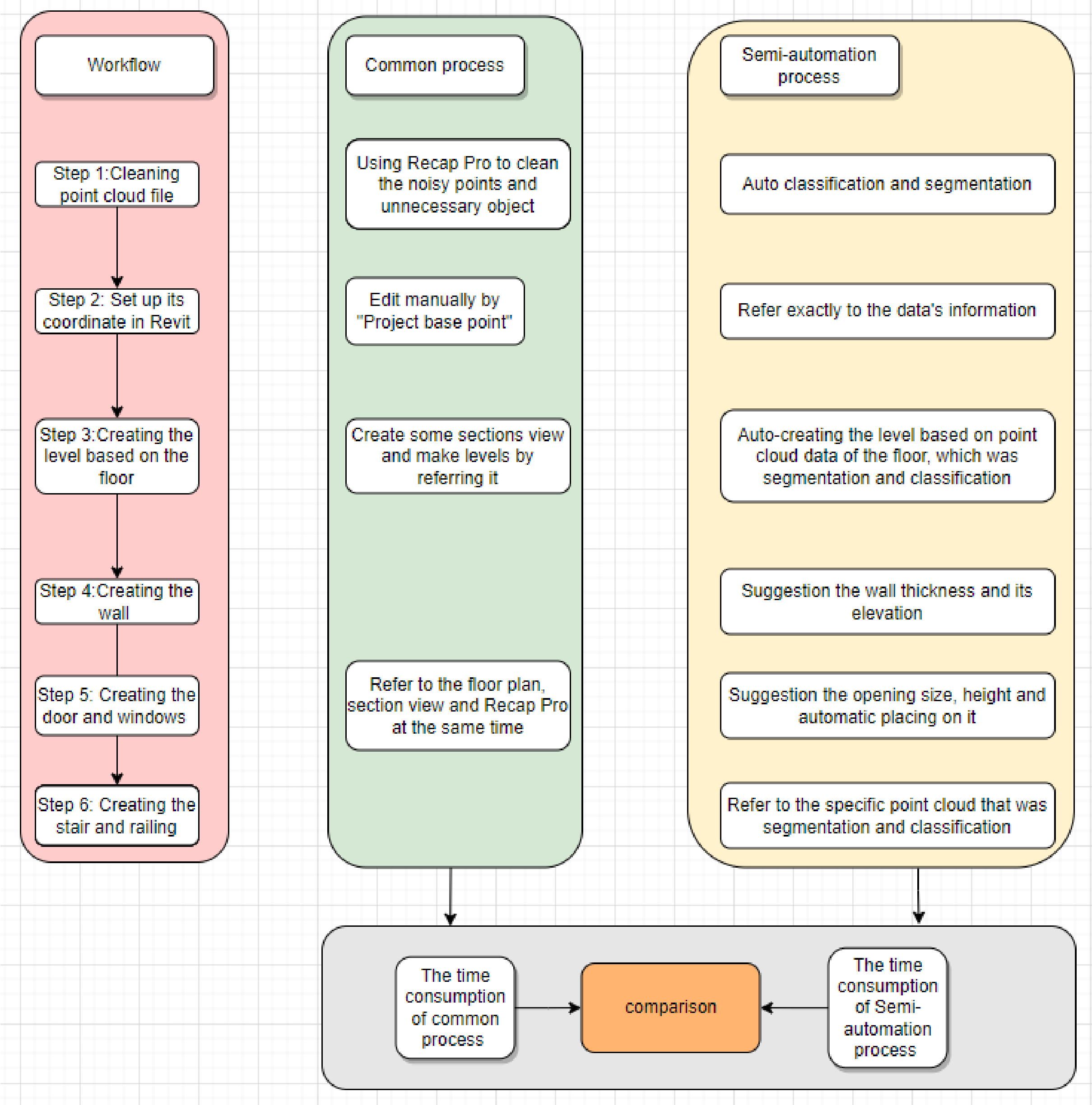


Figure 31 – The approach workflow for case study 1

4.2.2.1. Step 1: Cleaning the point cloud file:

Common process: Using Recap Pro to clean the noisy and unnecessary objects by manual step. In this step, the modeler's task is to remove all unnecessary objects, such as furniture, to make clear the necessary objects are walls, doors and floors. As can be seen in figure 33, in this point cloud file, a lot of furniture obscures the wall and floor areas, causing confusion when creating the model in the next step.

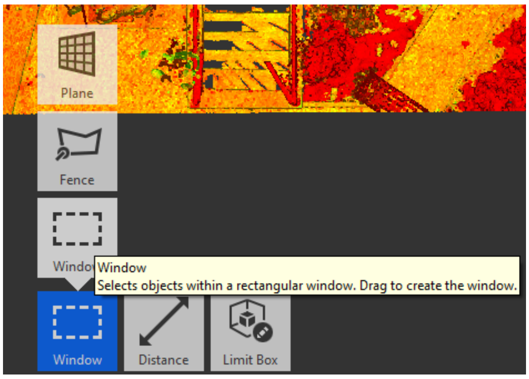


Figure 32 – Using the delete function manually

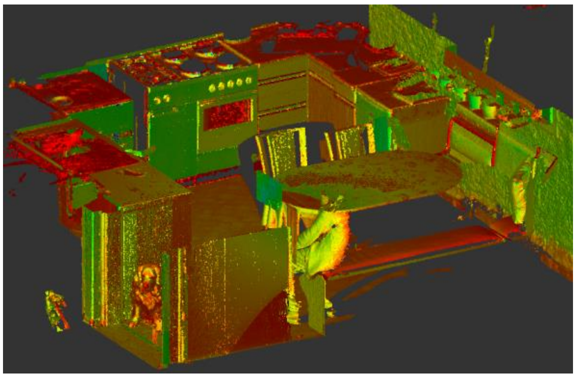


Figure 33 – Wall, floor mixing with furniture

Table 4 – Pros and cons of Cleaning the point cloud file in common process

Time: 60 minutes or can be more.
Pros: No
Cons: Take a lot of time, and sometimes it is impossible. For example, the picture shows the living room with a lot of furniture and equipment, and it is tough if the modeler removes them by hand or classification by eyes.

Semi-automation process: When using the Arivus add-in, the software will automatically classify key objects, including walls (gray colour), floor (purple) windows (yellow) and doors (green), with high accuracy. However, in this case study, because the quality of the point cloud data is average, many blurred wall areas confuse the software.

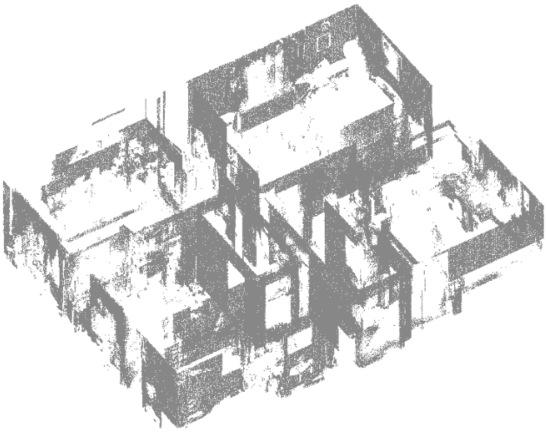


Figure 34 – Auto classification wall

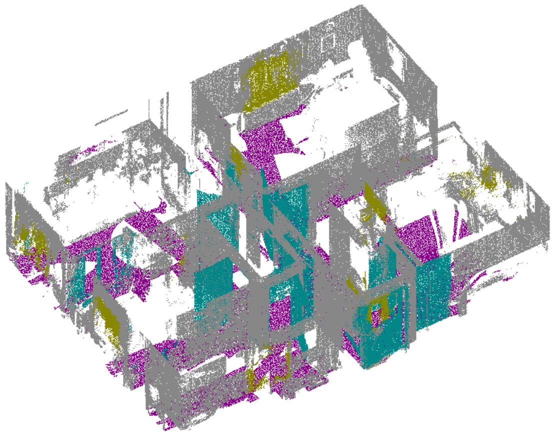


Figure 35 – Auto classification wall, floor, door and windows

Table 5 – Pros and cons of Cleaning the point cloud file in Semi-automation process

Time: 15 minutes
Pros: Saving time and very easy to use this add-in
Cons: The main object, such as walls, windows, and doors, can be missing if the big furniture of decoration covers it. The result of the classification process depends on the quality of point cloud data.

4.2.2.2. Step 2: Setup its coordinate in Revit:

This step does not have differences between both processes. However, by using the Aurivus add-in, the modeler can get the information of the point cloud file directly throw Revit.

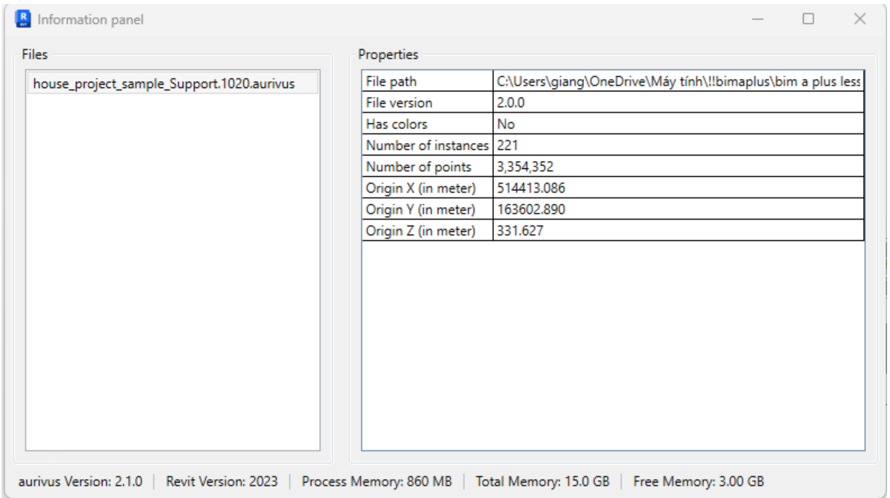


Figure 36 – The coordinate information of this house

4.2.2.3. Creating the level base on the floor:

Common process: Using section view and create the levels by referring it. Specifically, in this step, the modeler will create multiple section views to clearly determine the height of the floor and thickness, from which the level elevation can be determined.

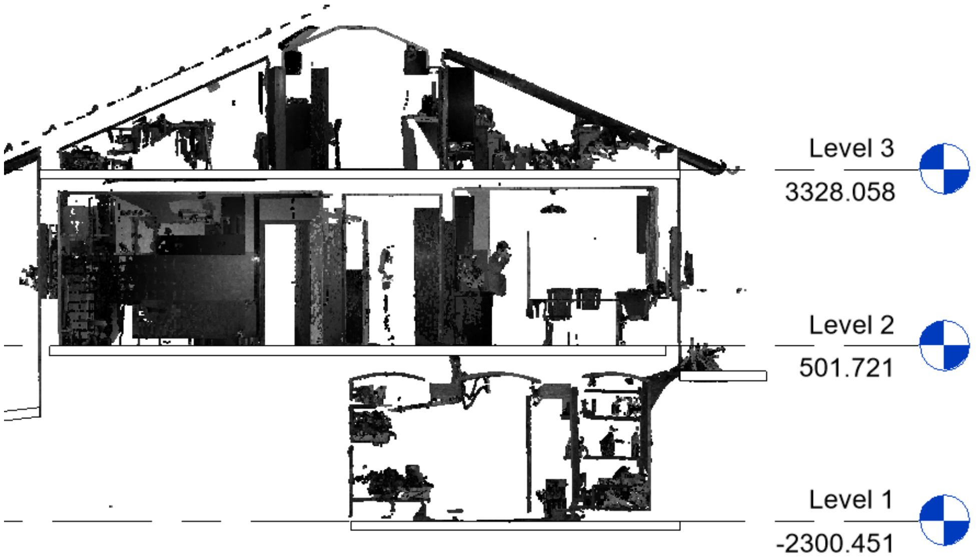


Figure 37 – Section view of this house

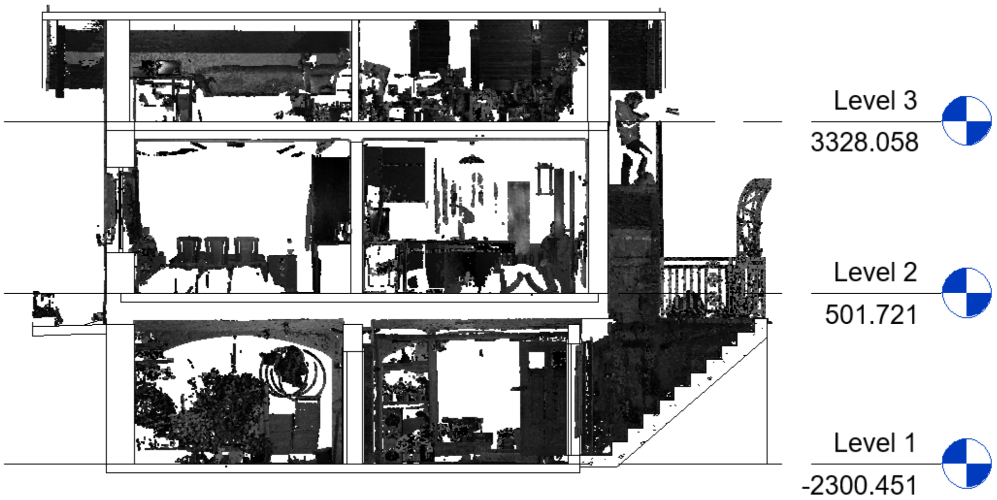


Figure 38 – Section view of this house

Table 6 – Pros and cons of Creating the level in common process

Time: 40 minutes
Pros: The tolerance is small and easy for the modeler to edit.
Cons: Takes time because the process needs to create some section views and compare the height level by different views

Semi-automation process: Using the Aurivus add-in, the level elevation is automatically generated based on the floor planes classified in the previous step. The software performs this step with great accuracy even when the point cloud data of the floor is not clear.

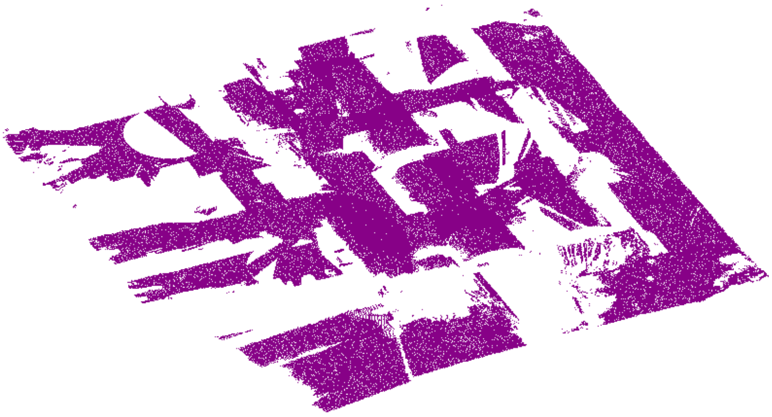


Figure 39 – Isolate only floor by using Aurivus add-in

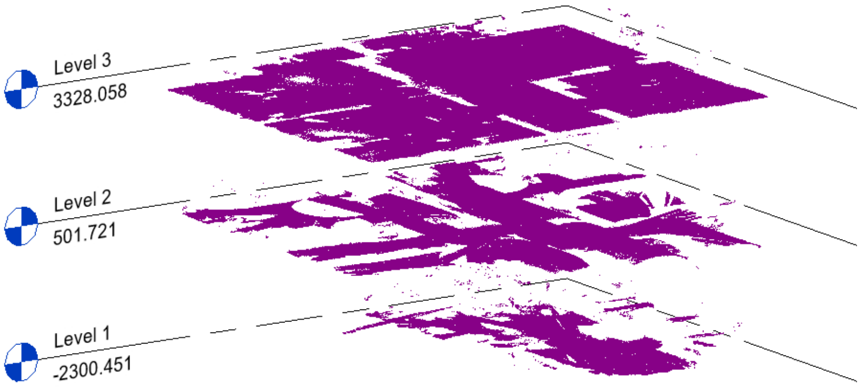


Figure 40 – Isolate only floor by using Aurivus add-in

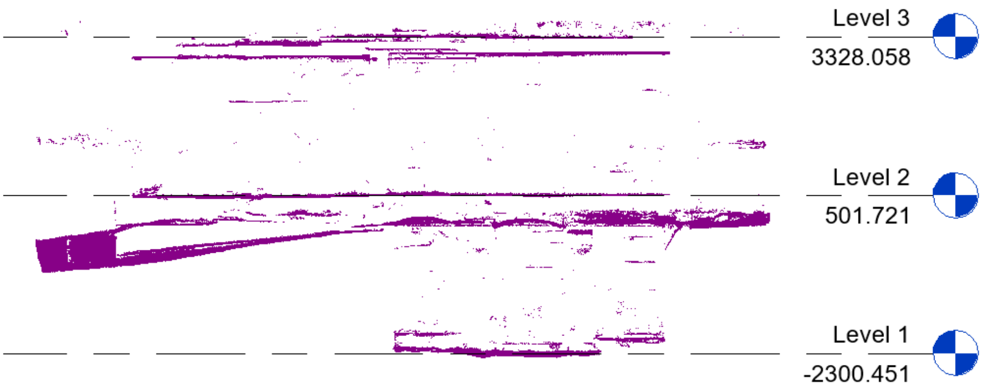


Figure 41 – The level was auto-created

Table 7 – Pros and cons of Creating the level in semi-automation process

Time: 3 minutes
Pros: Quickly and with high accuracy because the level was generated based on the floor's flat.
Cons: No

4.2.2.4. Creating the wall

Common process: When doing this step manually, the modeler relies on the floor plan to determine the wall thickness and position. Then select the height and check them against the scope box. This step usually takes a long time because the same wall has to check on multiple section views. Also, pay attention to the cabinets placed boundary here because it is easy to confuse the thickness.

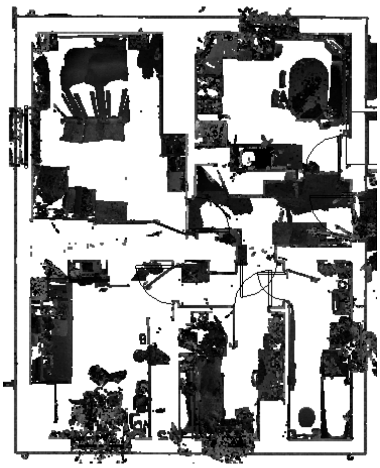


Figure 42 – Floor plan of this house

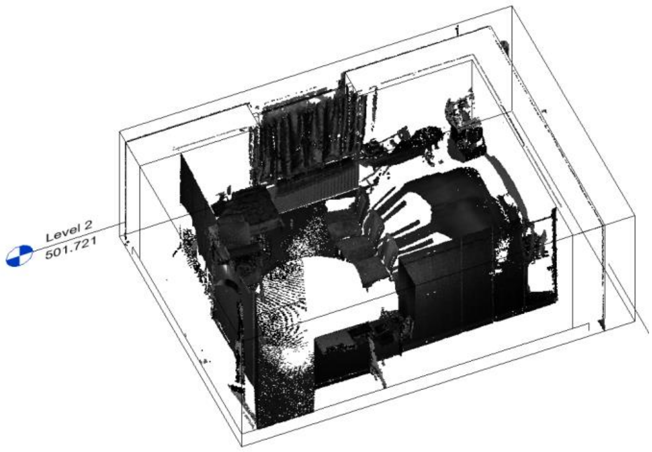


Figure 43 – Using the scope box to check the wall

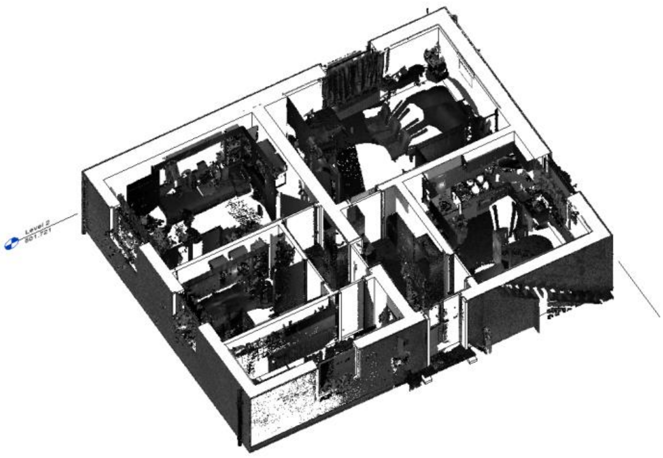


Figure 44 – The new wall created

Table 8 – Pros and cons of Creating the wall in common process

Time: 180 minutes
Pros: The tolerance is small and easy for the modeler to edit.
Cons: This process takes a considerable amount of time because it requires creating a new wall type and comparing the same wall in different views to ensure the dimension is true. The modeler has always to work with high concentration to avoid misinterpretations of the drawings.

Semi-automation process: In this step, using the Place wall model function, the software will automatically generate wall types with thickness based on the floor plan, then their height will be determined based on the elevation of this level. This function has high accuracy in the walls that are clearly displayed and not obscured by furniture. The blurred wall segments still need the modeler to check with the scope box.

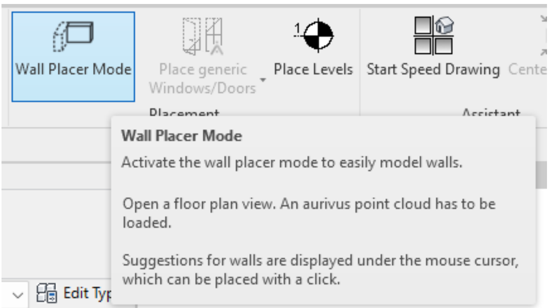


Figure 45 – Using wall place mode

Figure 46 – Auto-creating the wall based on the point cloud data

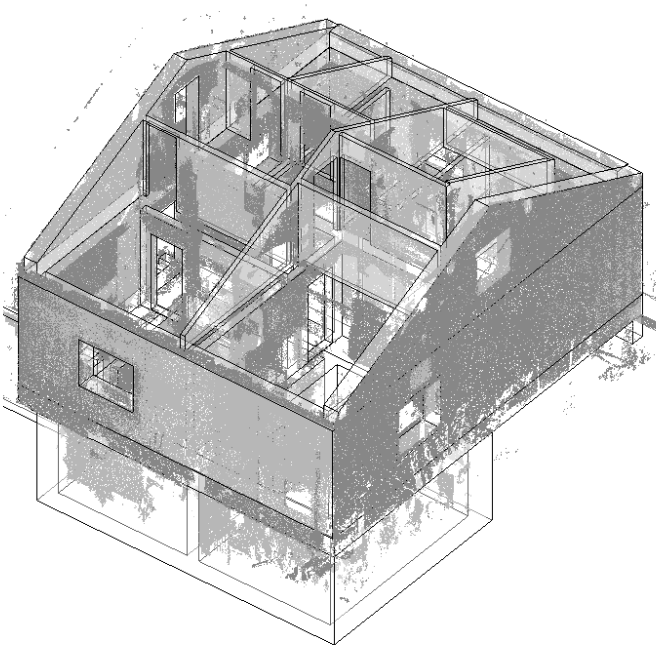


Figure 47 – The wall was created, which has medium accuracy in thickness and elevation.

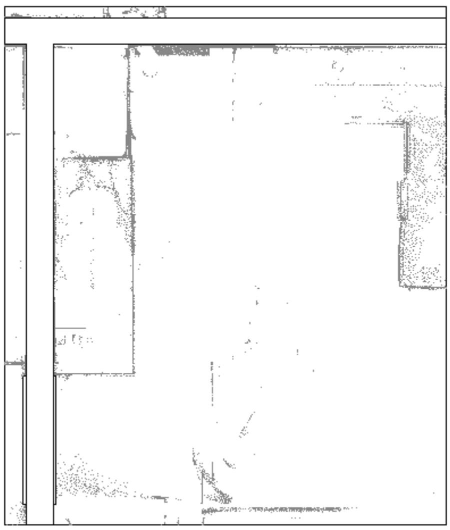


Figure 48 – The cabinet was identified wrongly as the wall

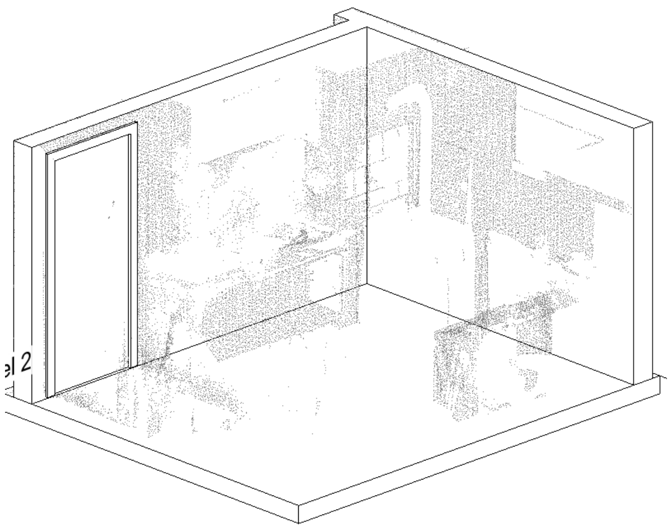


Figure 49 – The cabinet was identified wrongly as the wall

Table 9 – Pros and cons of Creating the wall in semi-automation process

Time: 15 minutes
Pros: Quickly and with medium accuracy

Cons: The accuracy of the wall depends on the quality of the model. For example, the software identifies the kitchen cabinets as the wall because it has a large vertical surface.

4.2.2.5. Step 5: Creating the door and window

Common process: In this step, the modeler usually relies on the openings of the wall segments to determine the width of the window and door and then determines the height from the other section views. In this way, the height and width of the door are highly accurate.

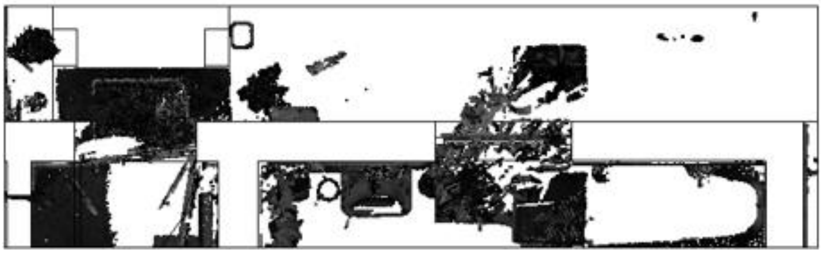


Figure 50 – Using section view to create the door and window

Figure 51 – Using section view to create the door and window

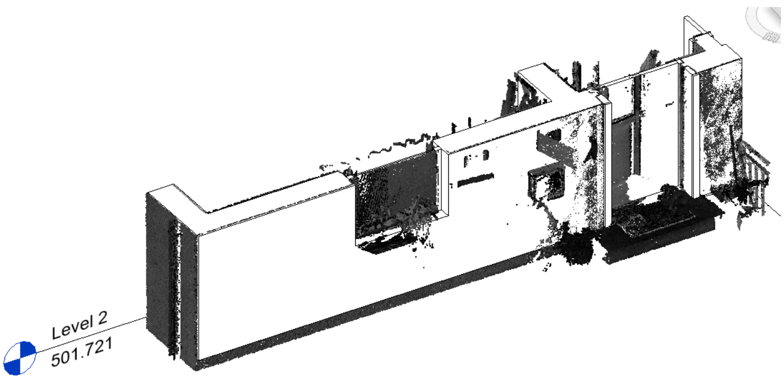


Figure 52 – Using section view to create the door and window

Table 10 – Pros and cons of Creating the door and window in common process

Time: 60minutes

Pros: The tolerant is small and easy for the modeler to edit.
Cons: This process takes many times because it requires creating a new door and window family type and comparing the same door or windows in different views (floor plan views, section plan views, 3D views) to ensure the dimension is true. The modeler has to always work with high concentration.

Semi-automation process: The software will automatically determine the door and window height and width, then create new family types that match the dimensions from the point cloud data. At this step, the structural opening size is correct, but if you want the door to have a higher detail than the modeler, you must manually add it.

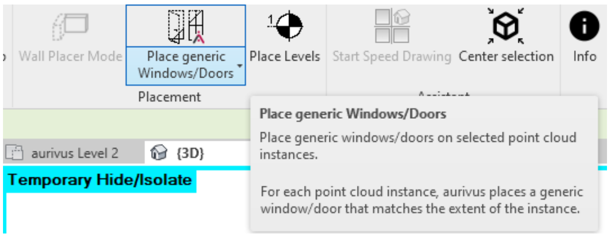
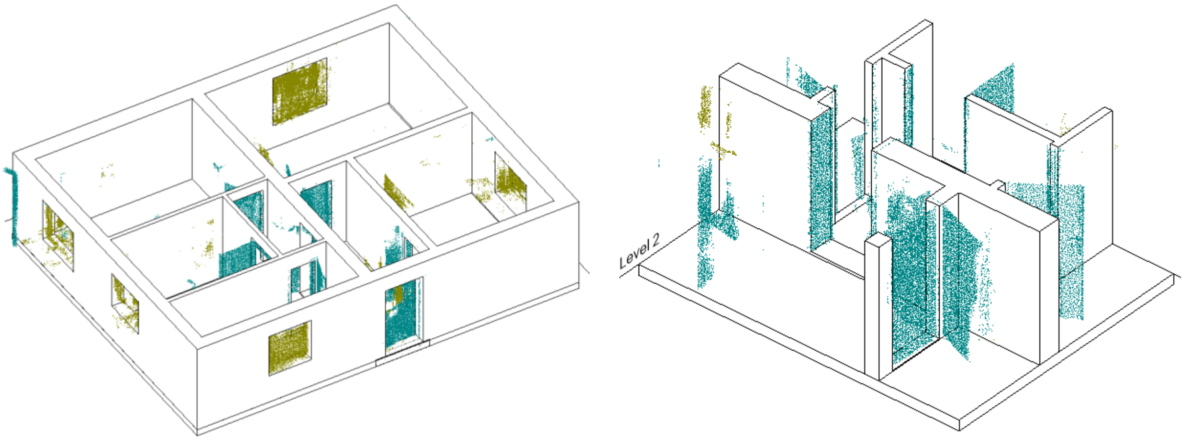


Figure 53 – Automation creates walls and windows by add-in



a) b)

Figure 54 – a)Automation creates walls and windows by Add-in, b) Using scope box to checking it again

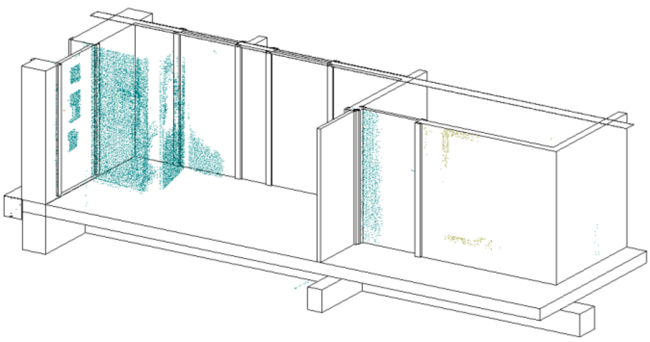


Figure 55 – Automation creates walls and windows by add-in

Table 11 – Pros and cons of Creating the door and window in semi-automation process

Times: 10 minutes
Pros: Quickly and with high accuracy of structural opening size and windows' height.
Cons: The accuracy of the automation process depends on the quality of point cloud data. If the LOD of the door and windows is higher, the modeler should create them manually. After that, compare it with the structural opening size and windows' height from the software's result

4.2.2.6. Step 6: Creating the stair and railing:

This task does not have much difference between the two processes. However, using Aurivus Add-in helped the modeler classify stairs and railings faster.

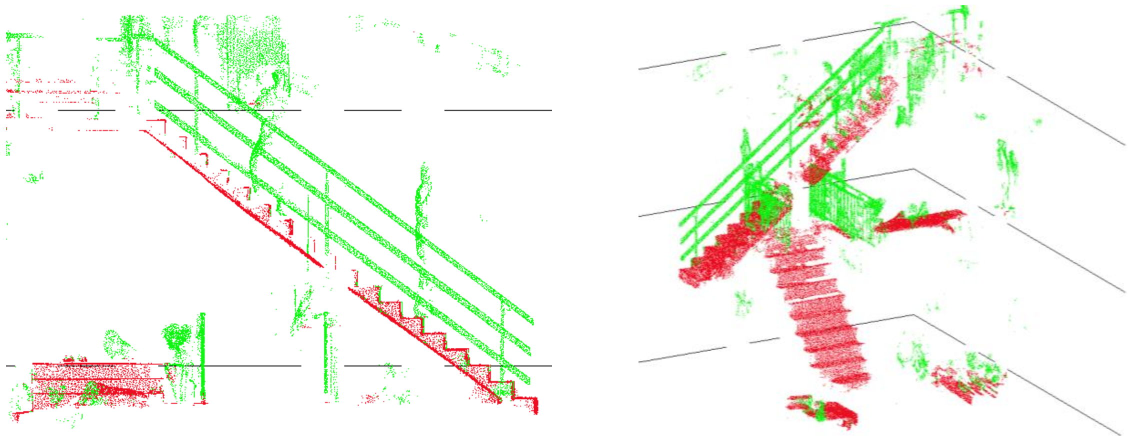


Figure 56 – Isolate only stair and railing by using Aurivus add-in

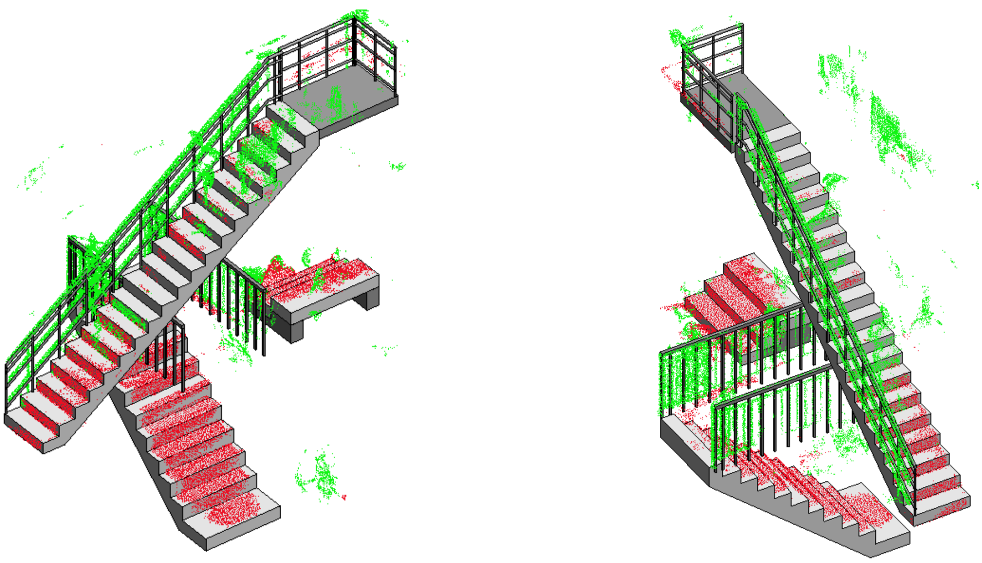


Figure 57 – Stairs and railings were modeled manually based on the isolated object.

4.2.2.7. Step 7: Creating the roof and roof structure

Common process: Usually, in this step, the modeler uses multiple section views on the same plan to determine the size and position of the timbers. Then use an elevation view to adjust their height further, improving accuracy.

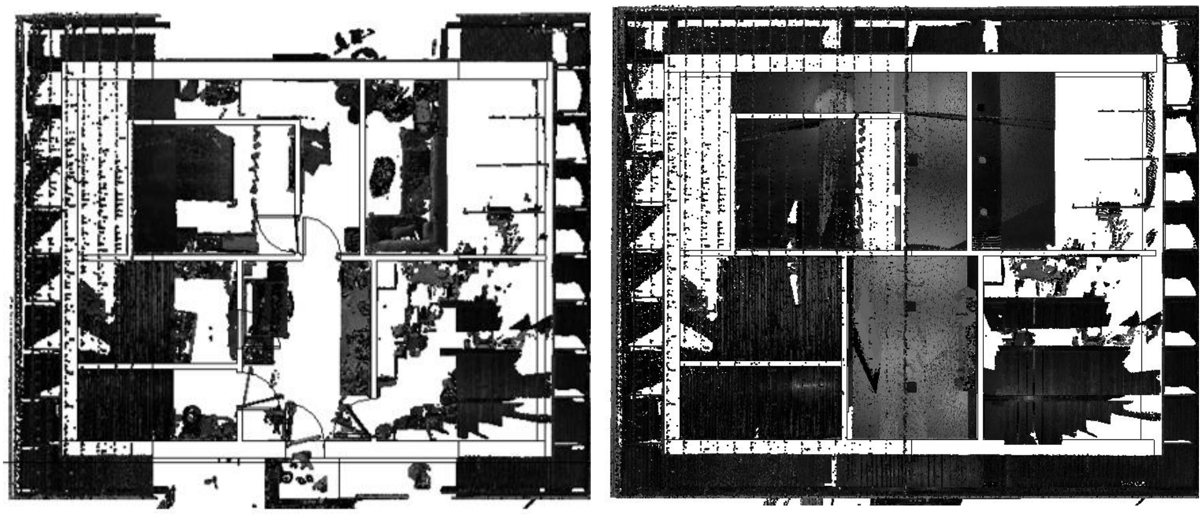


Figure 58 – Create some floor plans in different elevations to compare

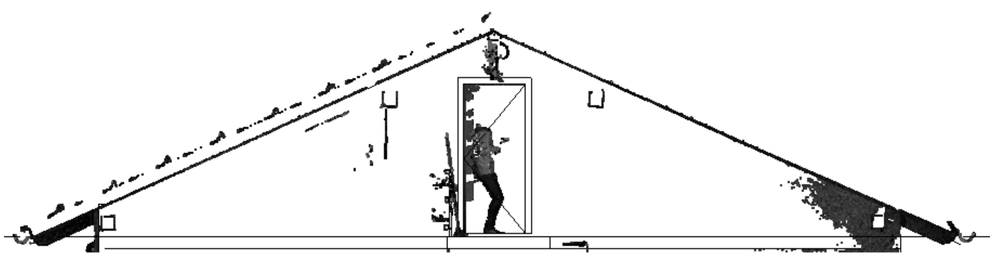


Figure 59 – Using this section plan to estimate the size and elevation of timber

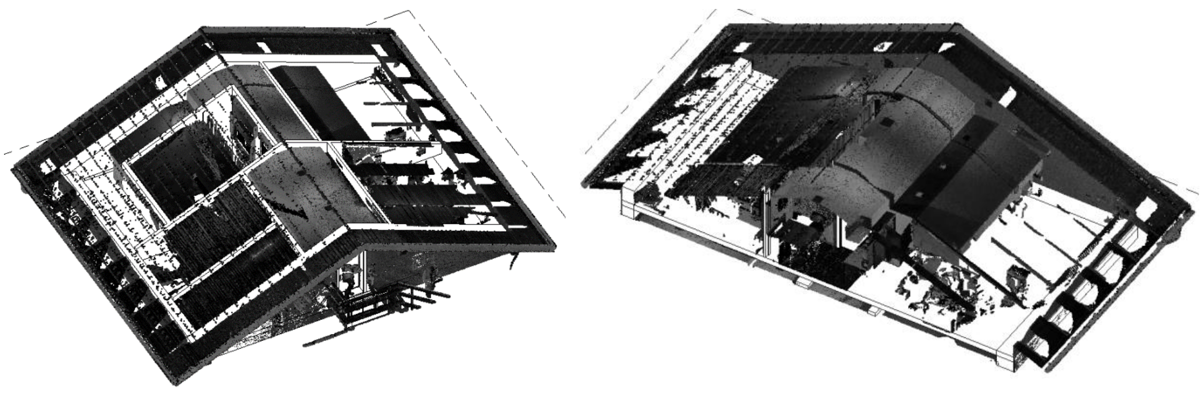


Figure 60 – Comparing the timber created with the point cloud data in different views

As can be seen from the 61 figure, the scope box has been used many times to compare the position of newly created timbers with the point cloud data. Although this method is time-consuming, it is highly accurate.

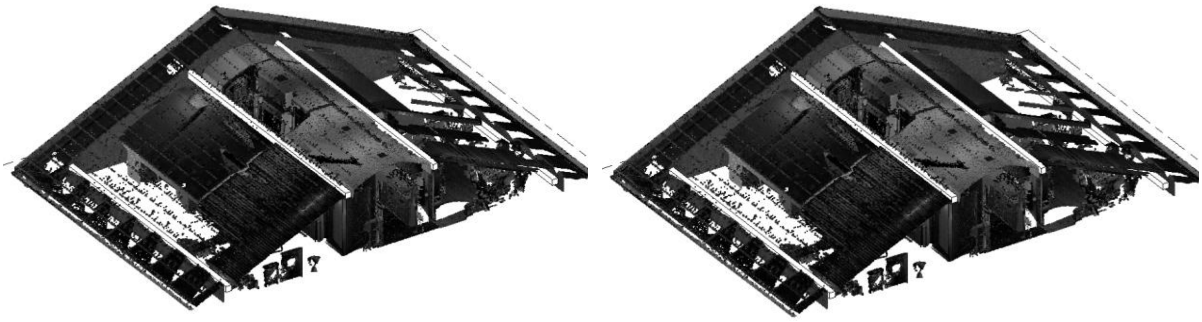


Figure 61 – Comparing the new timber created with the point cloud data by using the scope box

In figure 612as can be seen, the data point cloud in some timbers is damaged or missing due to the scan process. And it also does not have the information needed to create a timber model.

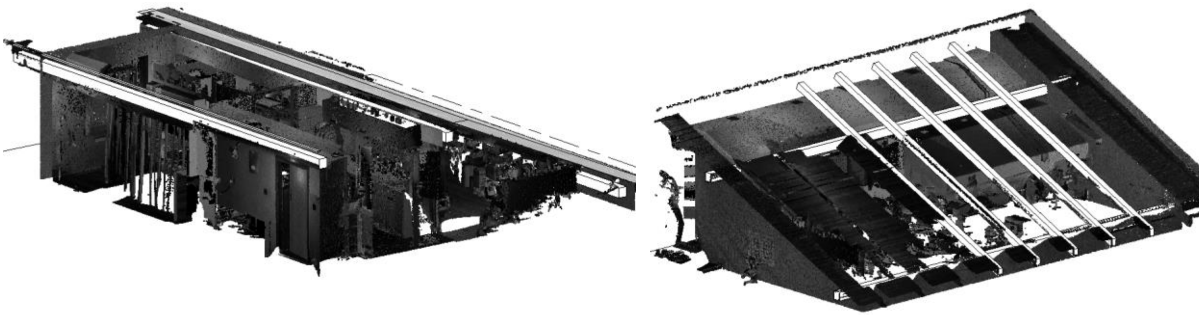


Figure 62 – Comparing the new timber created with the point cloud data by using the scope box

Based on the newly created timber and section view, roof slope and thickness can be determined, then based on the floor plan to find roof boundary.

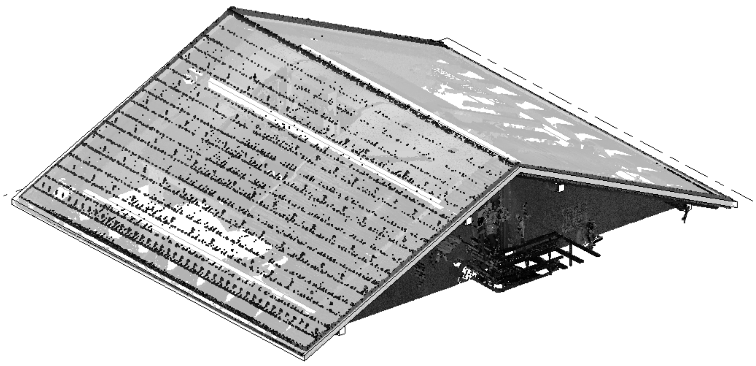


Figure 63 – Based on the location of the timber placed roof

Table 12 – Pros and cons of creating roof and roof structure in common process

Time: 150 minutes
Pros: No

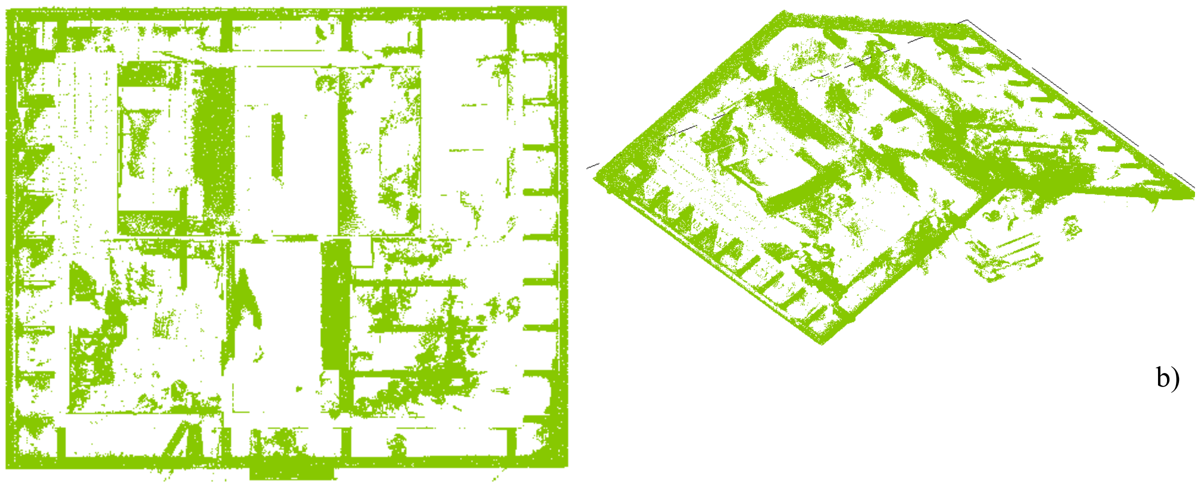
Cons: This process takes many times because it requires creating many section views to compare the same object in different views. On the other hand, with the missing point cloud of some objects, the modeler only can predict its size based on their experience. The timber, wall, and roof colour is mostly similar in every part of this file. It is the most severe problem when classifying the object manually by eyes.

Semi-automation process: Using the software, the roof and the roof structure were graded by colour orange and green, respectively. This way, the modeler will still have to create the roof manually, but there is no need to compare multiple section views, thus saving more time.

b)

a)

Figure 64 – The roof was classified with different views: a)Floor plan view, b) Elevation view



b)

a)

Figure 65 – The timber structure was classified with different views: a)Floor plan view, b) 3D view

In this step, use the speed drawing tool. After selecting a specific timber element, it will be automatically displayed in different views, including 3D, section, and elevation views. This saves the modeler time by not having to create the views manually. Moreover, only timber element is displayed on all views, preventing confusion with other objects.

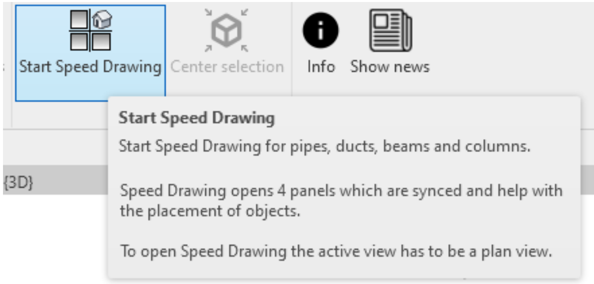


Figure 66 – Using tool speed drawing

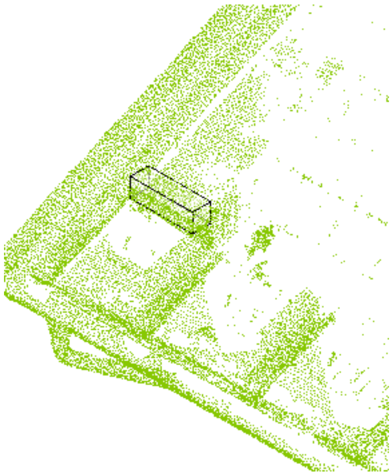


Figure 67 – The timber element selected will be present in different views (3D views)

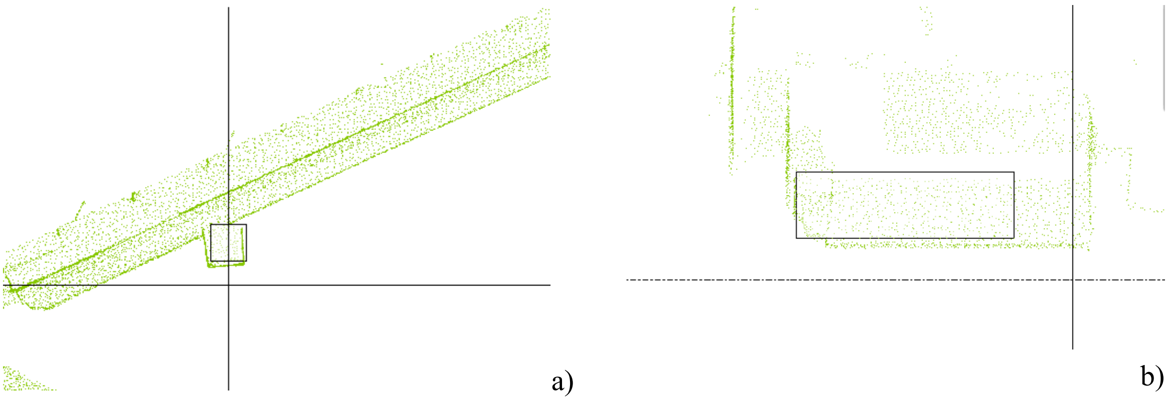


Figure 68 – The timber structure selected with different views: a)Elevation view, b) Floor plan view

From the 69 figure, it can be seen that the timber elements are rendered indistinctly due to the poor quality of the point cloud data. However, the modeler can still finish drawing them, which is impossible to do manually.

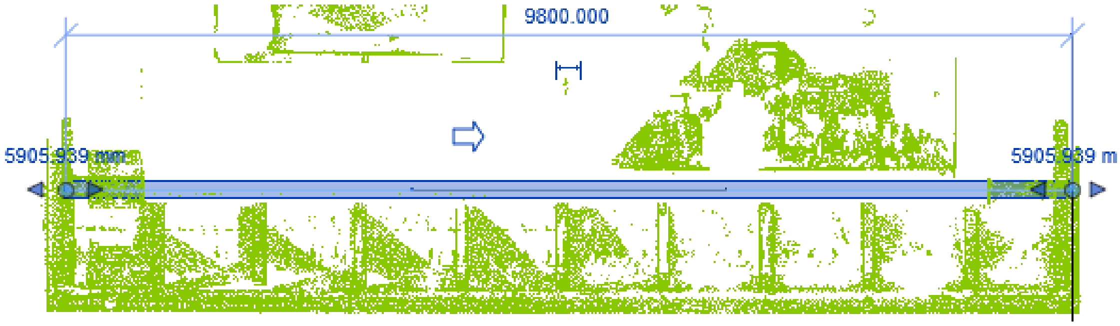


Figure 69 – The selected timber element in the floor plan view

From the figure 70, it is easy to check that the timber elements are all placed at the correct elevation and have the correct cross-section. This can only be done manually with experienced modelers.

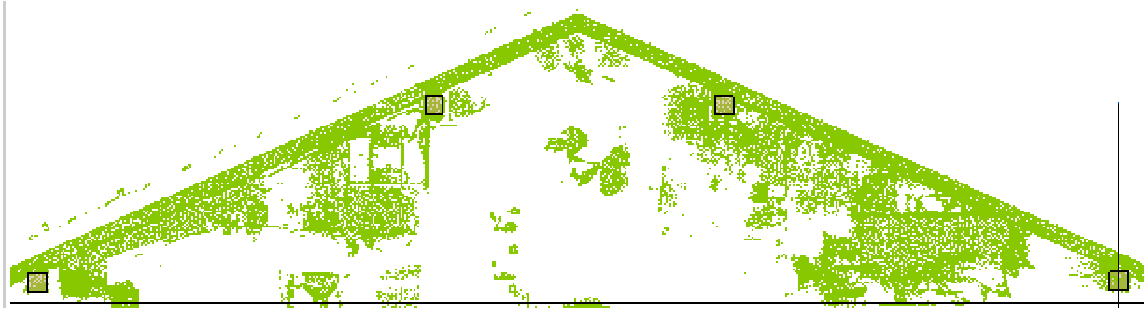


Figure 70 – Elevention view of these new timber elements

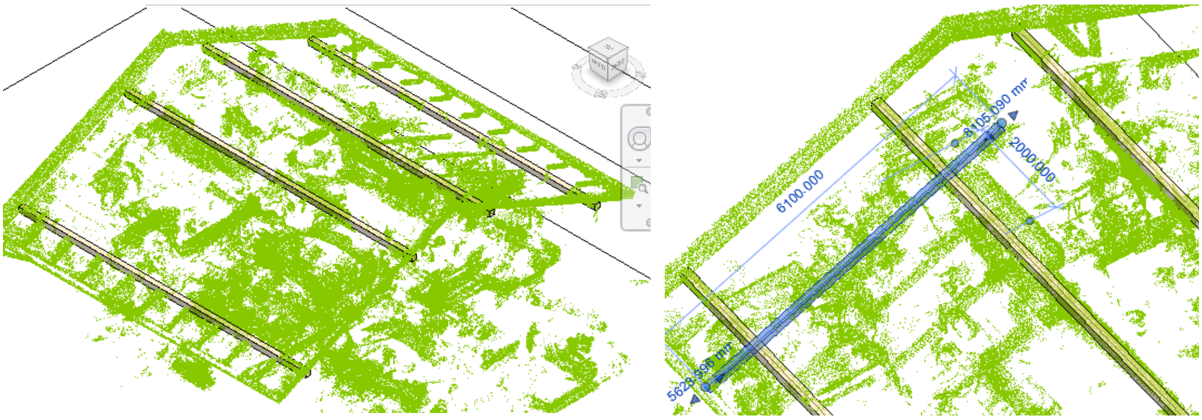
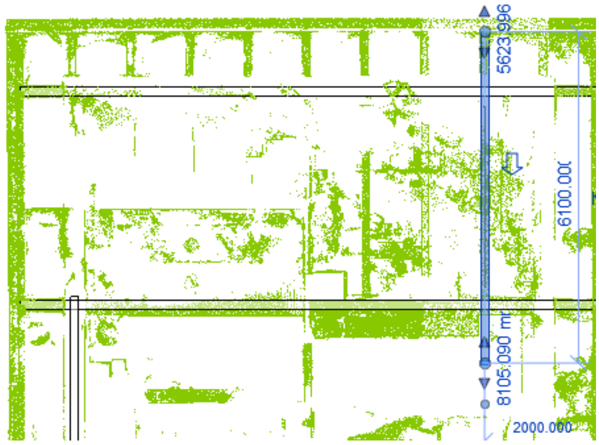


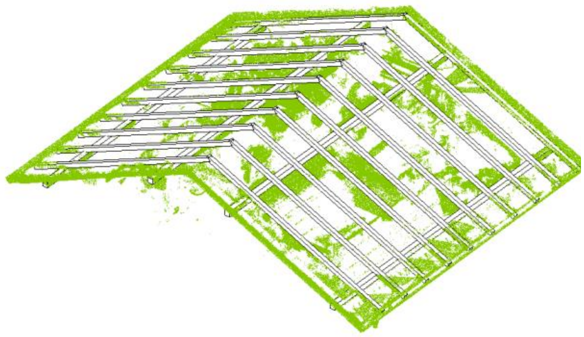
Figure 71 – Different 3D views of these new timber elements

Figure 72 below shows that although the point cloud data has many problems, such as noise or unclear, based on the suggested reference views, the modeler can still draw all the timber in the roof position.

Once you have determined the location of the timber roofs and finished drawing them, the final step is to draw the roof, which will be easier.



a)



b)

Figure 72 – a) A timber finished drawing in the floor plan. b)The roof timber was drawn complete.

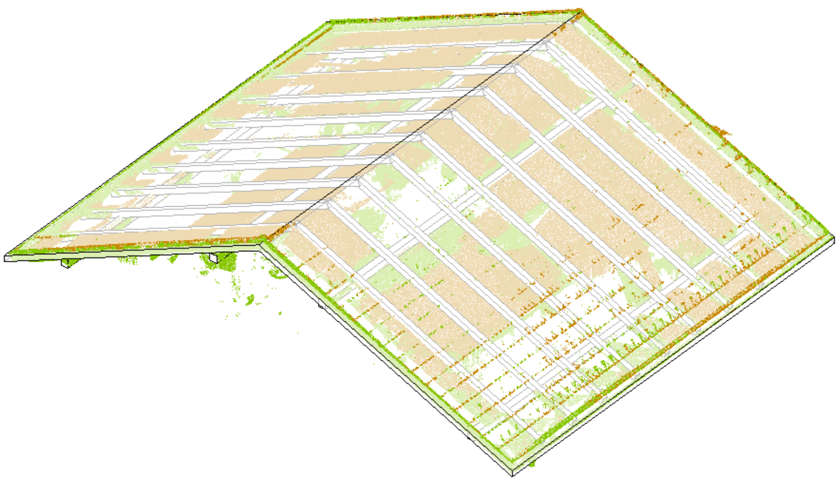


Figure 73 – The roof was drawn complete

Table 13 – Pros and cons of creating roof and roof structure in automation process

Time: 15 minutes
Pros: Quickly and with high accuracy
Cons: Sometimes the reference data is missing because it is unclear in the point cloud file

4.2.2.8. Interoperability testing in IFC

The tool IFC open viewer was used to test the interoperability of the new BIM model. As can be seen, every property set of each element is visible. For example, in the 74 figure below, the roof has been hidden to check timber, and timber has been fully displayed, with no missing or misleading dimensions.

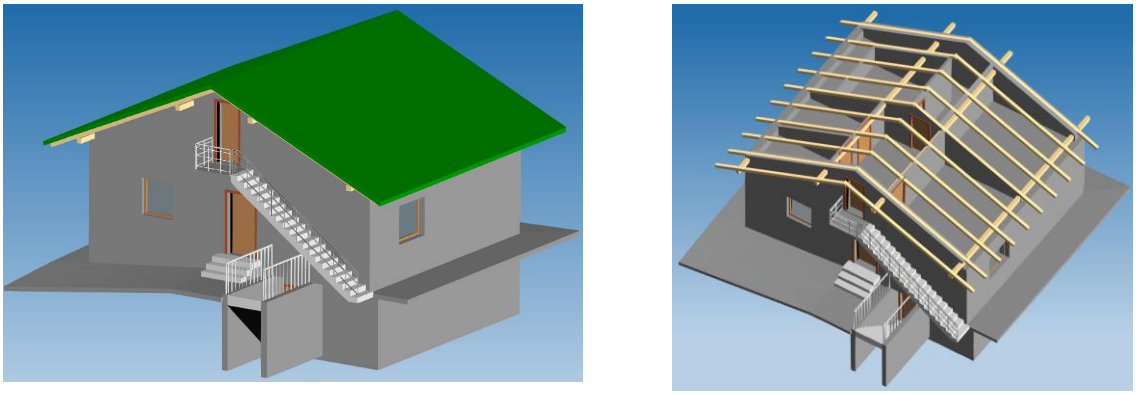
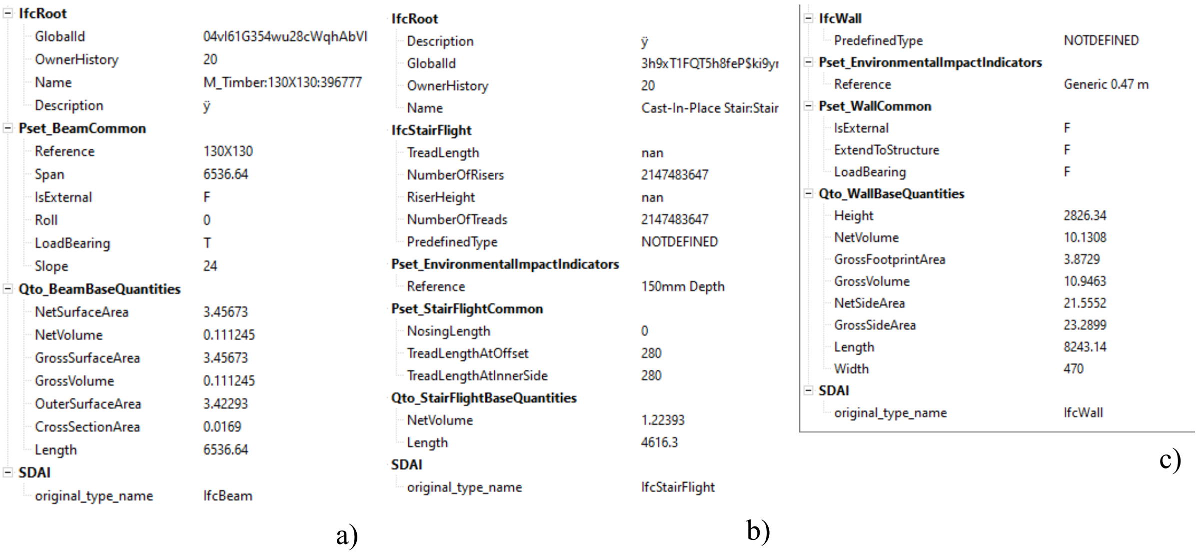


Figure 74 – Every element visible in the browser and no object is missing

For example, in figure 75 below, to check the information of the property set of each element type, you can see that the property list of each object has been fully displayed.



IfcRoot	
GlobalId	04vl61G354wu28cWqhAbVI
OwnerHistory	20
Name	M_Timber:130X130:396777
Description	ÿ
Pset_BeamCommon	
Reference	130X130
Span	6536.64
IsExternal	F
Roll	0
LoadBearing	T
Slope	24
Qto_BeamBaseQuantities	
NetSurfaceArea	3.45673
NetVolume	0.111245
GrossSurfaceArea	3.45673
GrossVolume	0.111245
OuterSurfaceArea	3.42293
CrossSectionArea	0.0169
Length	6536.64
SDAI	
original_type_name	IfcBeam

a)

IfcRoot	
Description	ÿ
GlobalId	3h9xT1FQT5h8feP$ki9yı
OwnerHistory	20
Name	Cast-In-Place Stair:Stair
IfcStairFlight	
TreadLength	nan
NumberOfRisers	2147483647
RiserHeight	nan
NumberOfTreads	2147483647
PredefinedType	NOTDEFINED
Pset_EnvironmentalImpactIndicators	
Reference	150mm Depth
Pset_StairFlightCommon	
NosingLength	0
TreadLengthAtOffset	280
TreadLengthAtInnerSide	280
Qto_StairFlightBaseQuantities	
NetVolume	1.22393
Length	4616.3
SDAI	
original_type_name	IfcStairFlight

b)

IfcWall	
PredefinedType	NOTDEFINED
Pset_EnvironmentalImpactIndicators	
Reference	Generic 0.47 m
Pset_WallCommon	
IsExternal	F
ExtendToStructure	F
LoadBearing	F
Qto_WallBaseQuantities	
Height	2826.34
NetVolume	10.1308
GrossFootprintArea	3.8729
GrossVolume	10.9463
NetSideArea	21.5552
GrossSideArea	23.2899
Length	8243.14
Width	470
SDAI	
original_type_name	IfcWall

c)

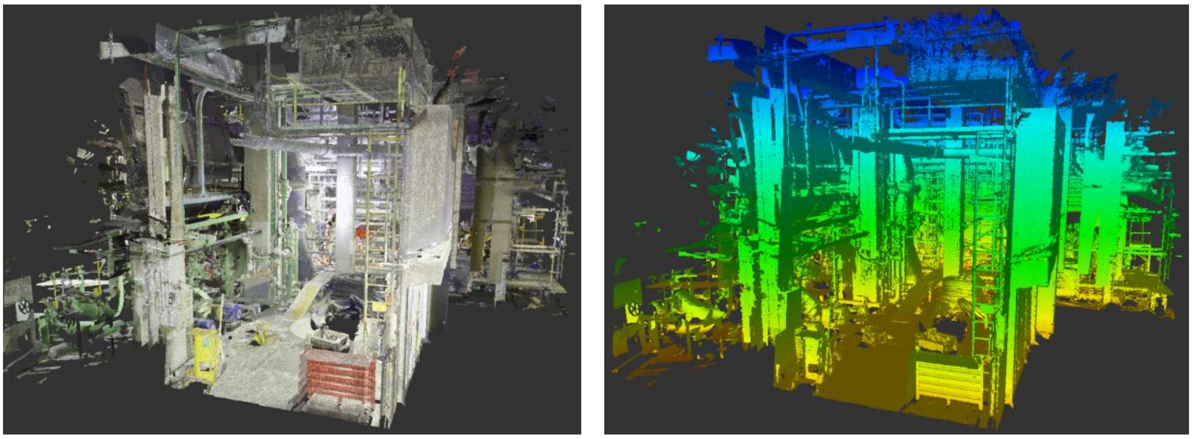
Figure 75 – The property set of 3 different elements: a) Timber, b) Stair, c) Wall

4.3. Case study 2

4.3.1. Introduction

The second case study was provided by Elea IC company. It is a point cloud data of the MEP system in a part of the industrial project. The entire data has many construction materials, including steel scaffolds, stairs, concrete walls, and MEP equipment. The scanner device is a terrestrial laser scanner Leica RTC360, the same as the previous case study. However, the quality of the point is not good because some objects are missing or unclear, which can be seen in these figures below. Thus, using this data to create the as-built BIM model is very challenging for BIM modelers.

The main goal of this case study is to create the as-built BIM model for a small scope in the whole MEP system that is provided. Based on the result of this process, figure out the pros and cons when applying a semi-automation tool to generate the Revit BIM model from the point cloud of MEP systems. LOD requirement. The LOD requirement for this as-built BIM model is around 150- 200. At this level, each pipe's diameter, elevation and slope have an approximate size in reality.



a) b)

Figure 76 – The current situation of the point cloud data with two different color modes: a) Normal option b) Elevation option

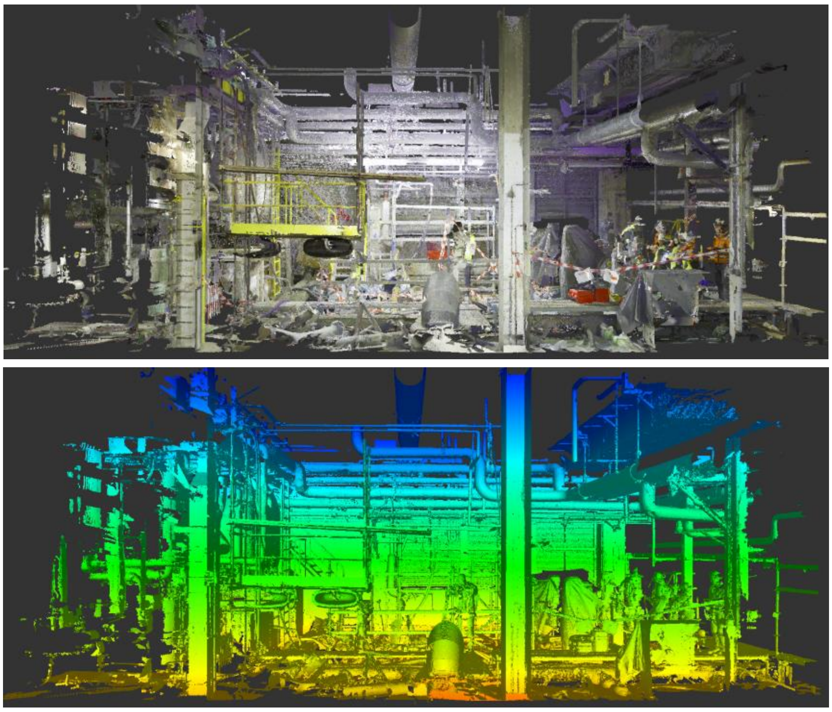


Figure 77 – The current situation of the point cloud data with two different color modes: a) Normal option b) Elevation option

It can be seen in this elevation view even though 2 different color modes are used, the normal option and the elevation option, to enhance the ability to classify objects. But because, at this point cloud data, there are too many different objects, including walls, scaffolding and water pipes, it is difficult to classify by eye.

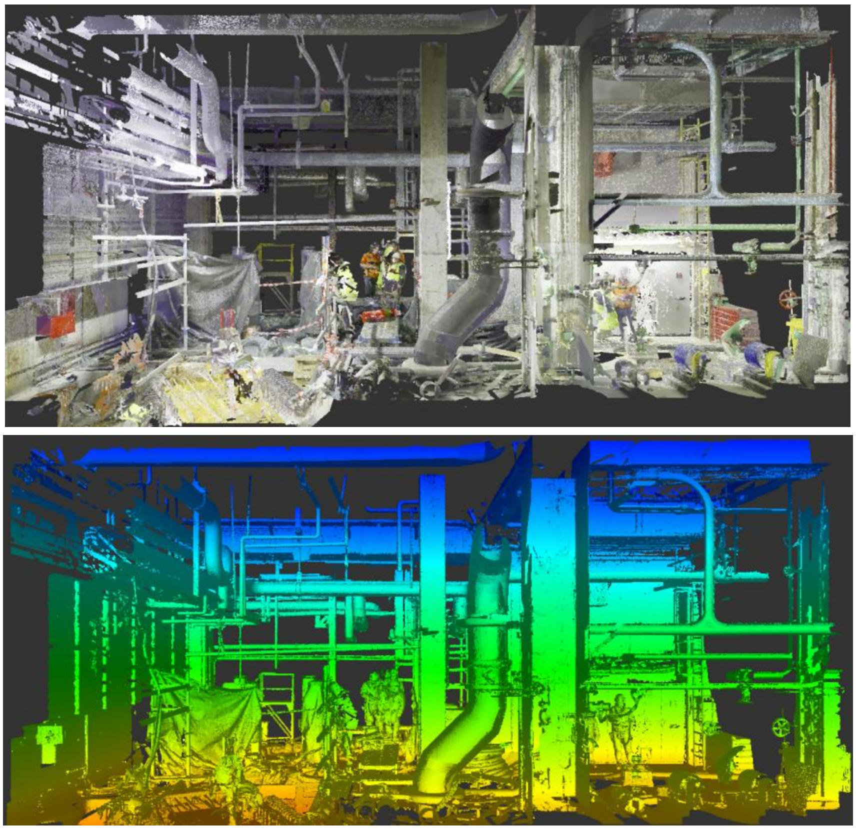


Figure 78 – The current situation of the point cloud data with two different color modes: a) Normal option b) Elevation option

4.3.2. The approach workflow

The diagram below presents the typical workflow of the Revit modeler when generating a MEP model with point cloud reference. The reason to use two different workflows for MEP and Architecture is that the process and steps to create a BIM model for each object are different. The MEP model has fewer types of objects, but each object is more complex in the drawing process. The manual steps and the semi-automation are delivered parallel for an easier comparison basis. Times are considered dependant on the experience of the user. Indicatives values were provided, considering the author’s experience, for comparison purposes.

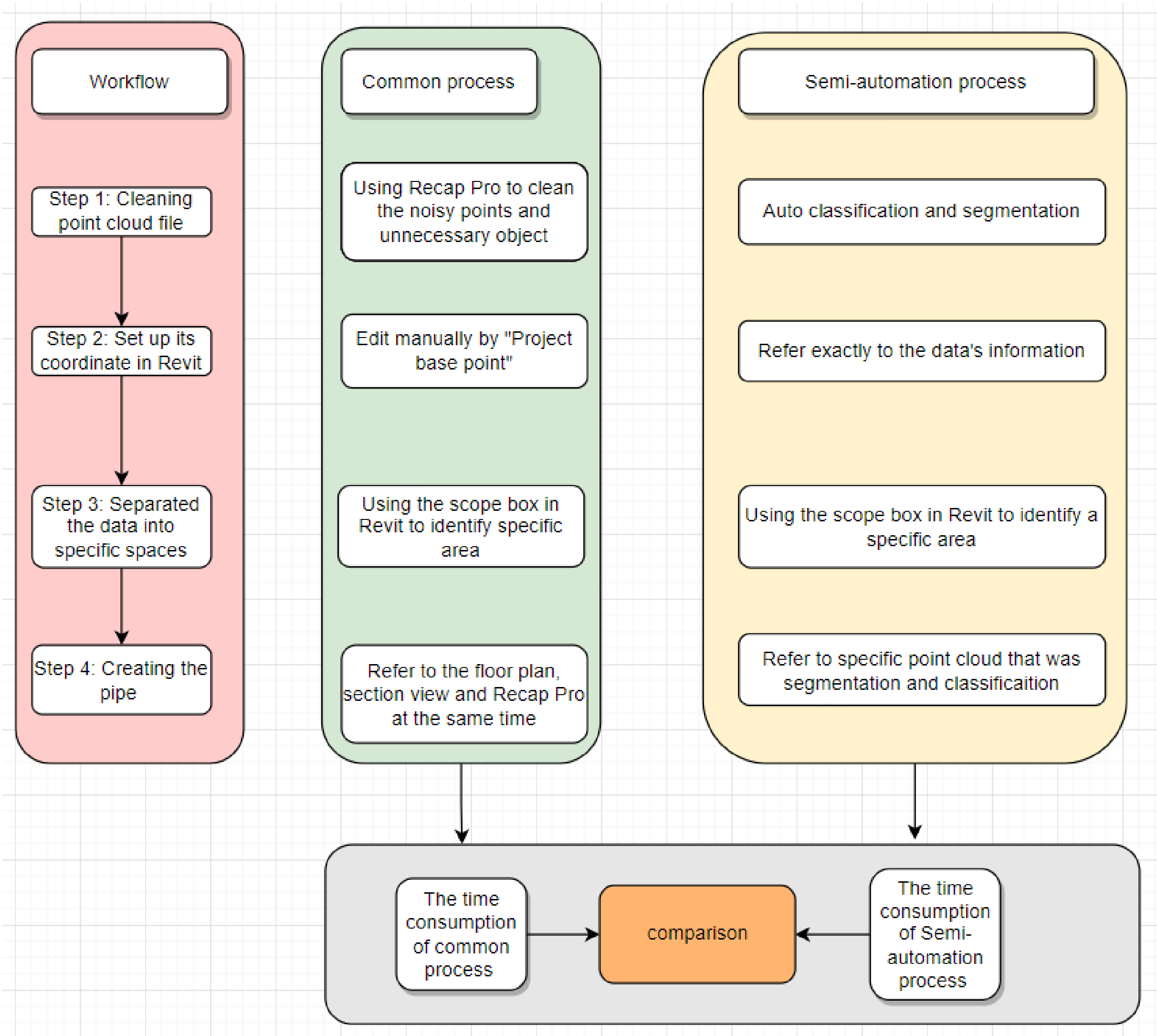


Figure 79 – The approach workflow of case study 2

4.3.2.1. Step 1: Cleaning the point cloud file:

Common process: In this step, when manually doing the same as in case study 1, the modeler will use Recap Pro to select and delete unnecessary objects. As can be seen, there are many very small pipe segments and many noise areas interspersed with those pipes. Removing these noise regions manually requires a lot of time.

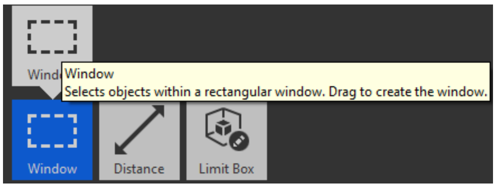


Figure 80 – Cleaning manually by using Recap

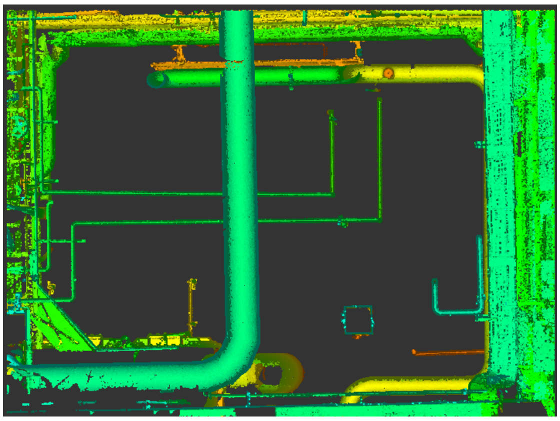


Figure 81 – Cleaning manually by using Recap

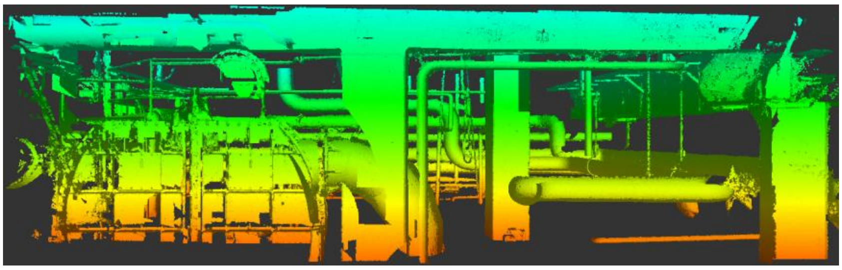


Figure 82 – Cleaning manually by using Recap

Table 14 – Pros and cons of cleaning the point cloud file structure in common process

Time: 60 minutes or can be more.
Pros: No
Cons: Takes a lot of time, and sometimes it is impossible. For example, the picture shows the pipes in different diameter sizes mixing with structural columns, structural beams and some MEP equipment. It is tough if the modeler removes them by hand or classification by eyes.

Semi-automation process: In this step, similar to case study 1, the software automatically classifies objects by colour. Here pipe segment is purple, and the pipe fitting is blue. Then it also automatically hides unnecessary objects, such as walls and structural columns.

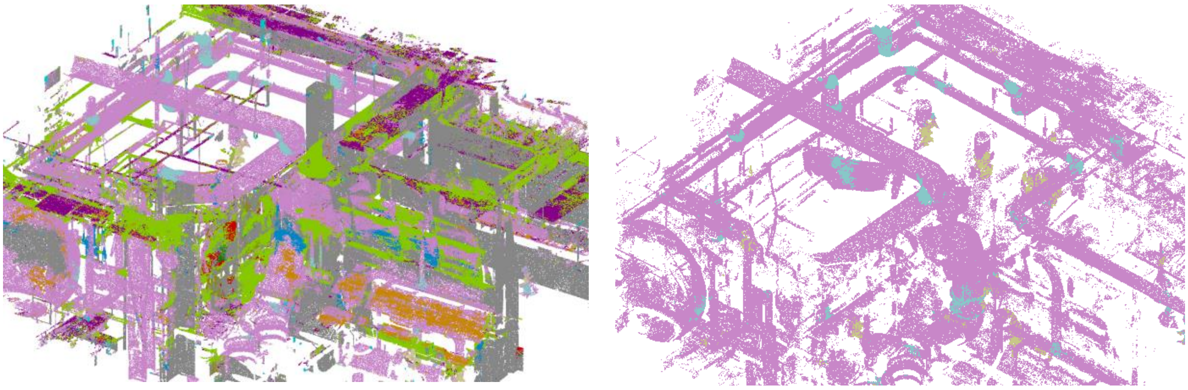


Figure 83 – Auto classification by Aurivus add-in

In this figure 83, the pipe segments and pipe fitting can be seen more clearly. To do this manually is difficult and takes a lot of time.

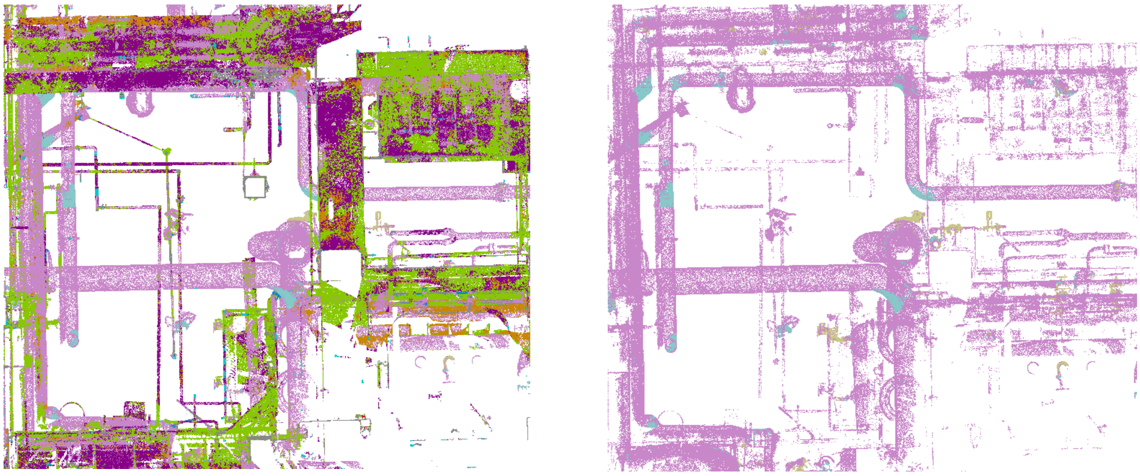


Figure 84 – Auto classification by Aurivus add-in

Table 15 – Pros and cons of cleaning the point cloud file structure in semi-automation process

Time: 15mins
Pros: Saving time and very easy to use this add-in
Cons: Some pipes can be missing or unclear. The result of the classification process depends on the quality of point cloud data.

4.3.2.2. Step 2: Setup its coordinate in Revit:

The comment is similar to case study 1. This step does not have differences between both processes. However, by using the Aurivus add-in, the modeler can get the information of the point cloud file directly throw Revit.

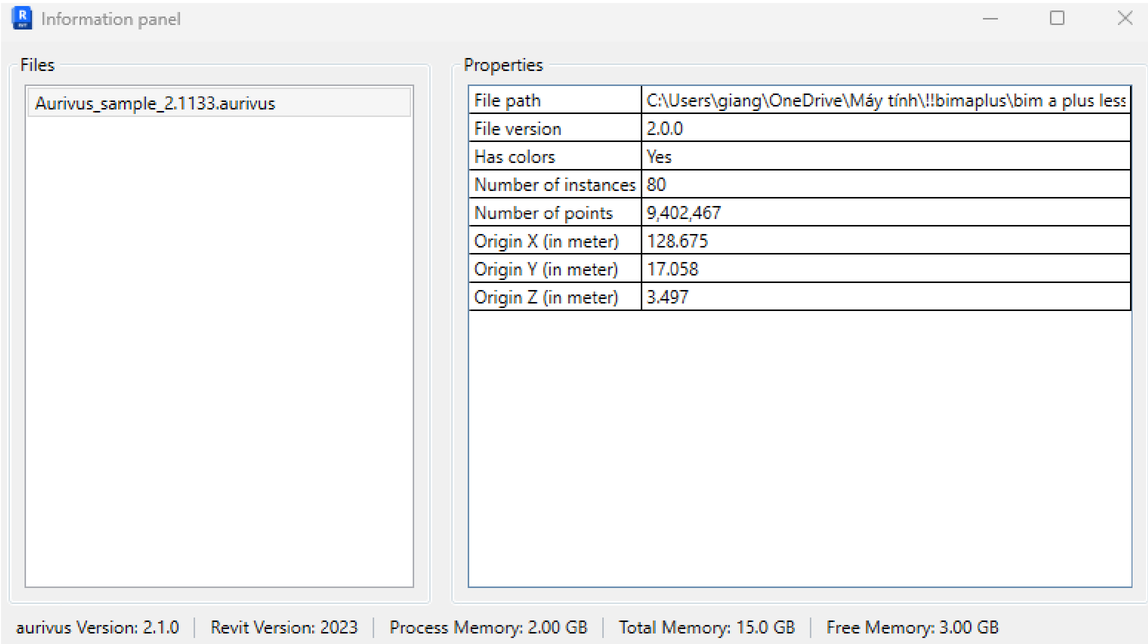


Figure 85 – The information of the point cloud file

4.3.2.3. Separated the data into specific spaces:

In this step, the function scope box in Revit was used to ensure the specific scope is identical in both file

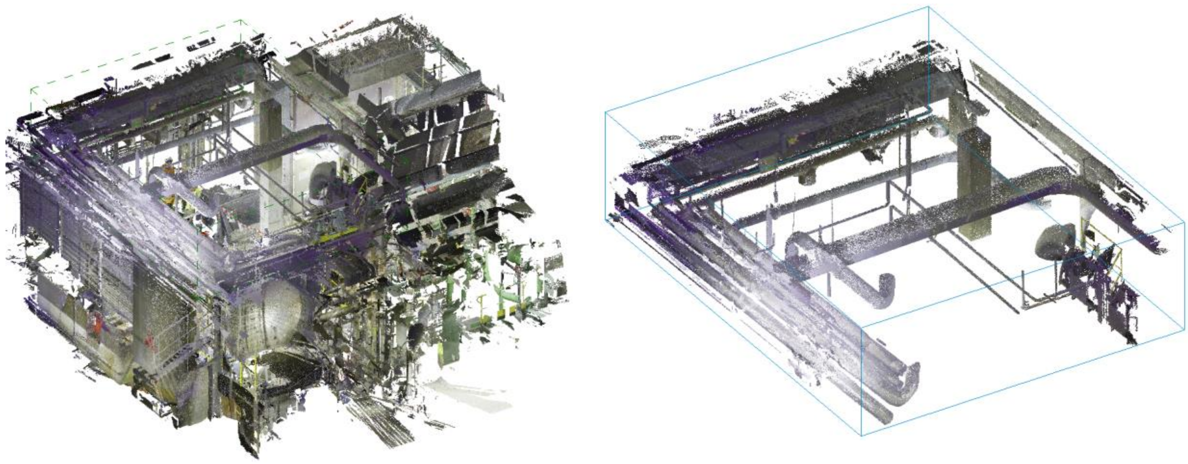


Figure 86 – Using the scope box to identify the same area in both file

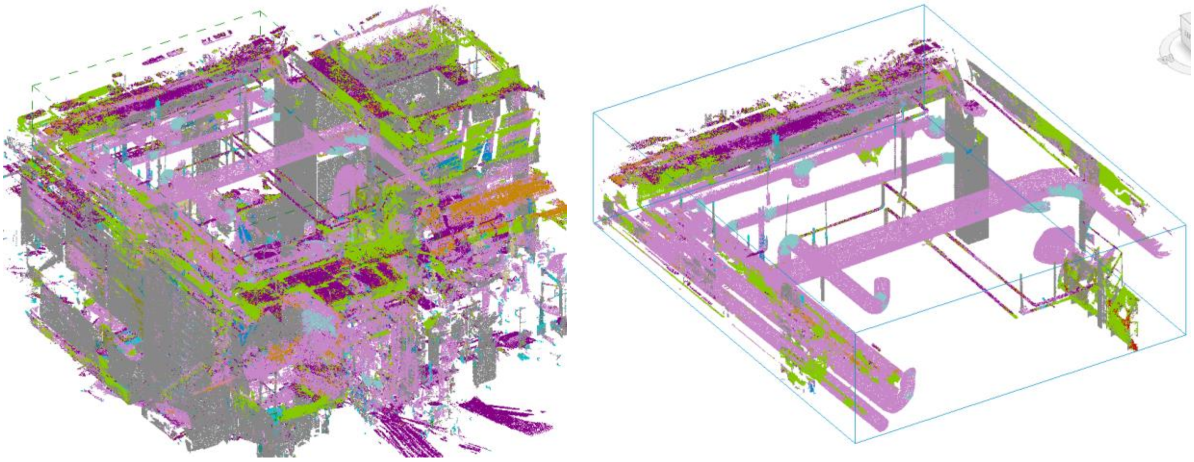


Figure 87 – Using the scope box to identify the same area in both file

4.3.2.4. Creating BIM model for the pipes

Common process: This step requires the modeler to have much experience when creating manually with Revit. First, identify each pipe segment, then, for each pipe segment, create planes and cross-sections to determine its size and slope. The data point cloud quality is as precise as possible for modeling pipes and MEP objects.

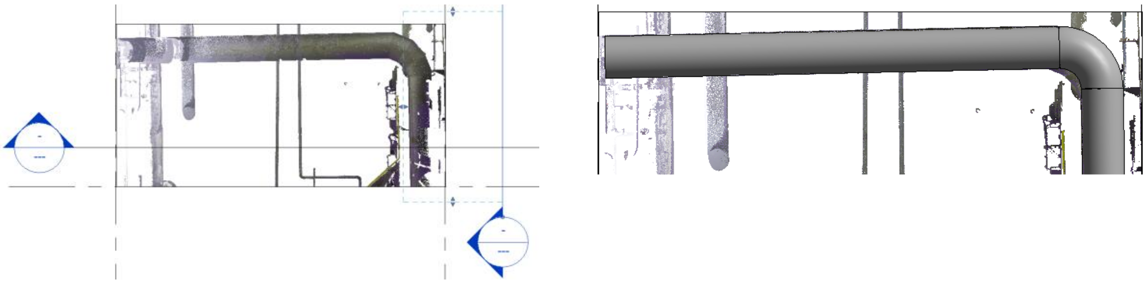


Figure 88 – Comparing the single pipe in the floor plan view

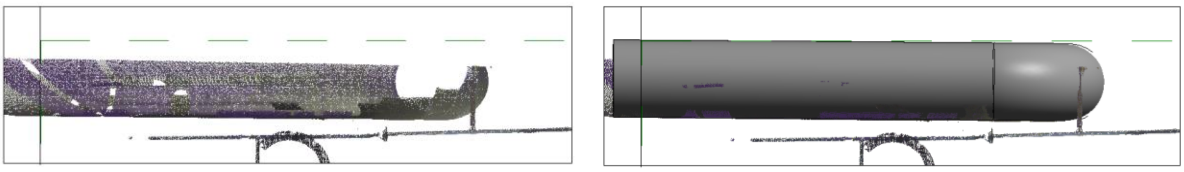


Figure 89 – Comparing the single pipe in the section view

As seen in the figure below, creating a pipe segment must go through at least 3 steps. One locates on the floor plan, 2 add section views to them to determine the diameter, 3 check again in other section views.

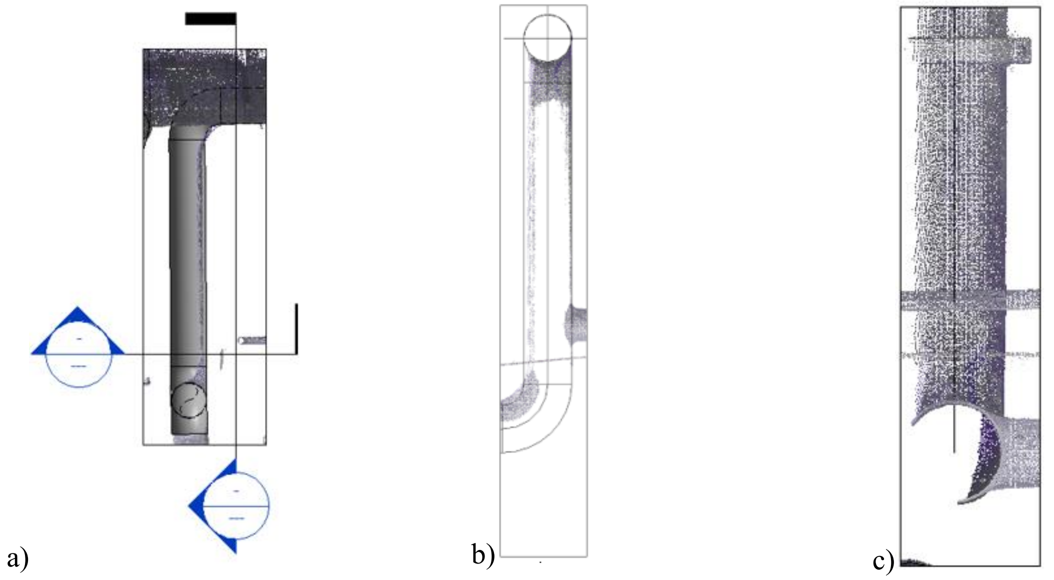


Figure 90 – One pipe segment in three different views: a) Floor plan, b) Section view, c) Section view

Table 16 – Pros and cons of creating BIM model for the pipes in common process

Time: 15 minutes per segment of the pipe
Pros: No
Cons: Take a lot of time, and only possible if the data of this pipe is present in the file scan.

Semi-automation process: Based on the purple pipes, the software has automatically classified in this step, and the modeler will draw faster and not waste time creating more section views.

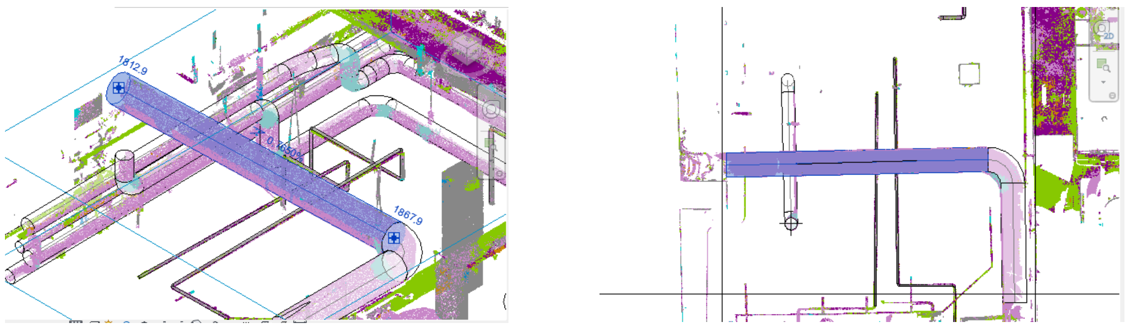


Figure 91 – Creating pipe by using Aurivus add-in

In the figure below, the diameter of the tube is determined based on the section view automatically generated by the software. Then the length and slope of the pipe segment will be adjusted manually based on the floor plan view.

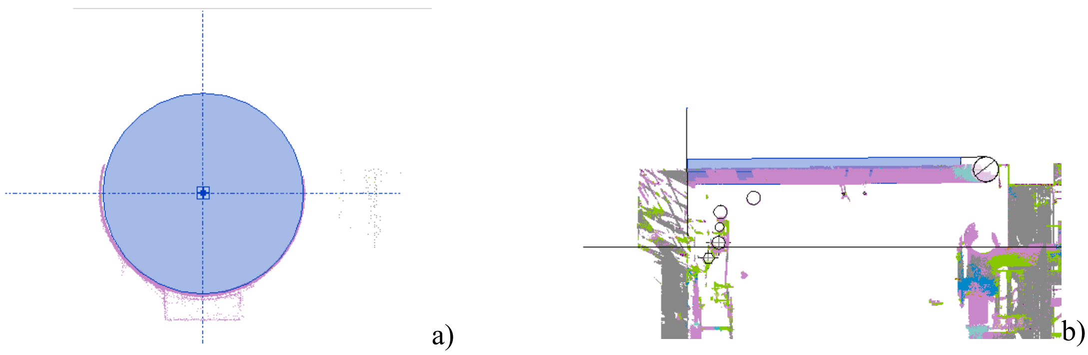


Figure 92 – A single pipe segment with two different view a) Section view b) Floor plan view

Check the pipe created with the scope box and 3D view. It can be seen that the pipe segment is created with high precision and does not have to be reworked.

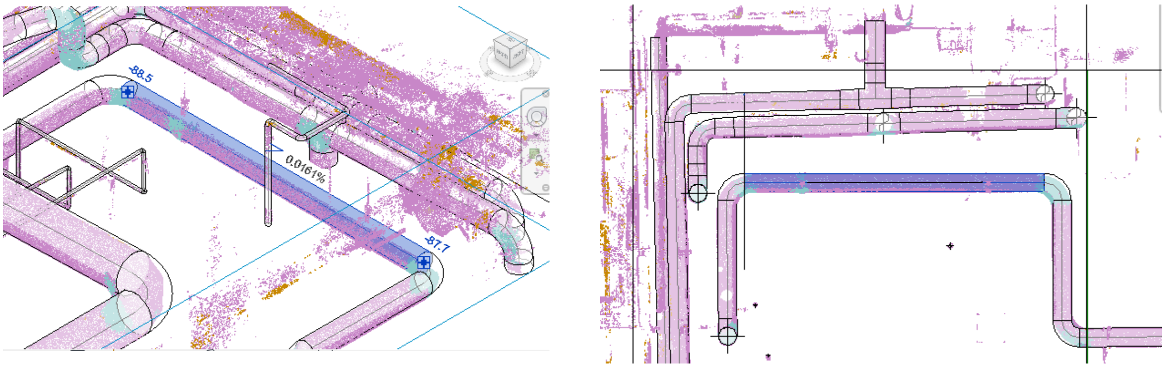


Figure 93 – The piped created in 3D view

In the figure below, it can be seen that although the quality of the data point cloud in this section is bad and has a lot of noise, based on the section views given to the modeler, it can be completed easily.

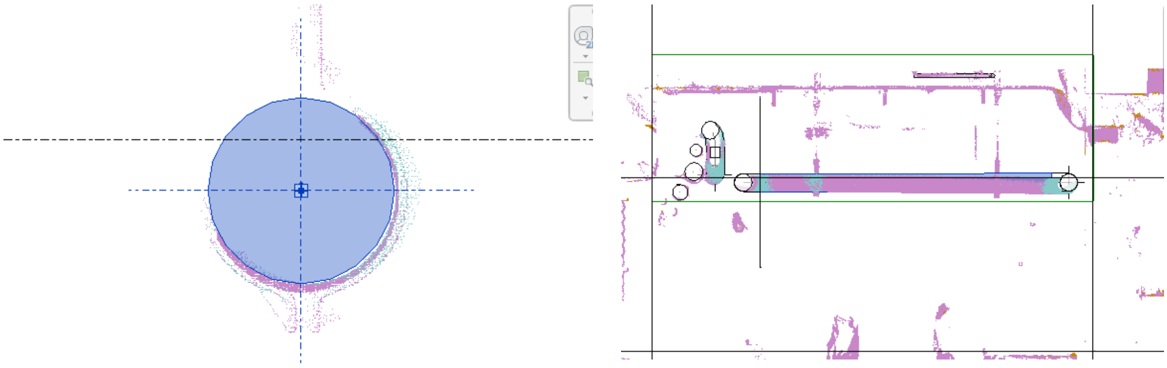


Figure 94 – A single pipe segment with two different section views

The entire pipe displayed in the scope box has been completed quickly and with few errors. The wrong pipe segment is located in an area of noise and missing data.

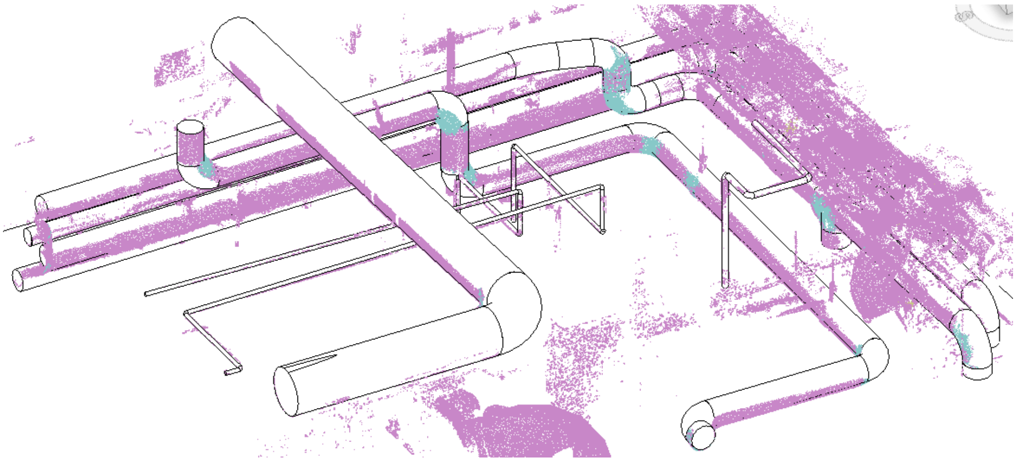


Figure 95 – Creating pipe by using Aurivus add-in

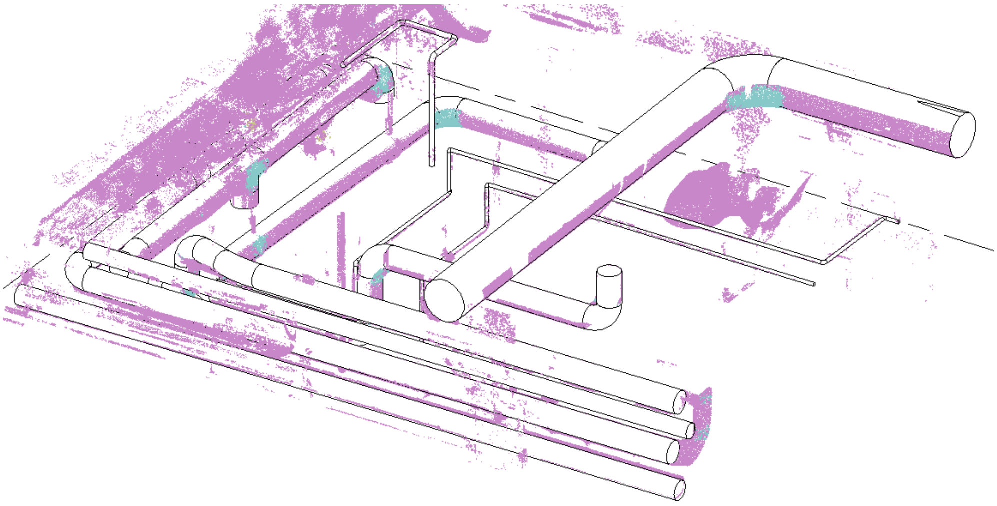


Figure 96 – Creating pipe by using Aurivus add-in

Table 17 – Pros and cons of creating BIM model for the pipes in semi-automation process

Time: 1-5 minutes per segment of the pipe
Pros: The pipe was created with high accuracy in a short time
Cons: No

Interoperability testing in IFC

The tool IFC open viewer was used to test the interoperability of the new BIM model. As can be seen, every property set of each element is visible. For example, in figure 97 below, every pipe and fitting has been fully displayed, with no missing or misleading dimensions.

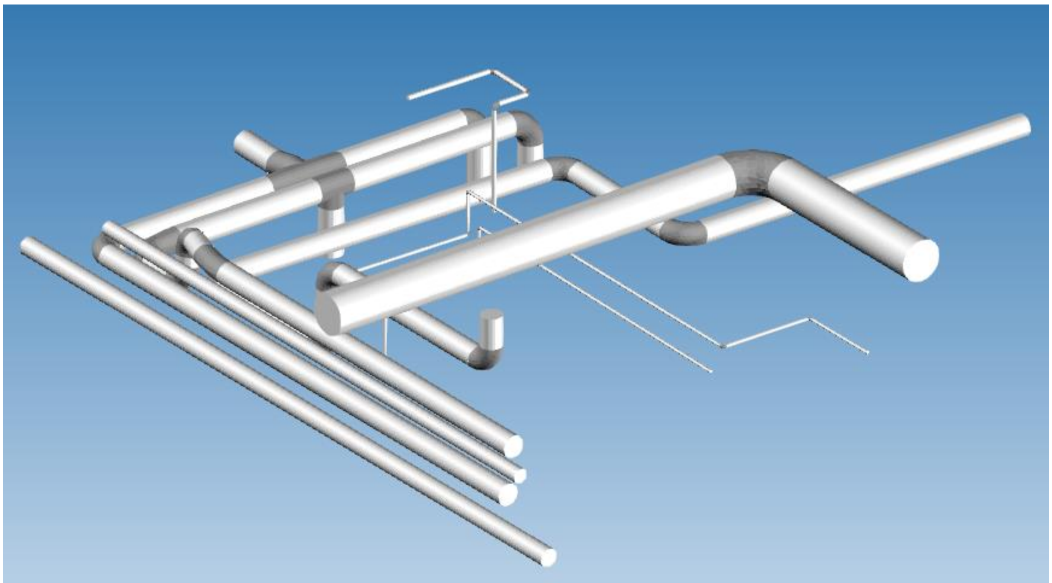


Figure 97 – Every pipe visible in the browser and no pipe is missing

In figure 98 below, to check the information of the property set of each element type, you can see that the property list of each object has been fully displayed.

IfcPipeSegment	
PredefinedType	NOTDEFINED
IfcProduct	
ObjectPlacement	129
Representation	143
ReferencedBy	
IfcRoot	
GlobalId	27g9IE1$n6ew_JvDsH0L
OwnerHistory	20
Name	Pipe Types:Chilled Wate
Description	ÿ
Pset_EnvironmentalImpactIndicators	
Reference	Chilled Water
Pset_PipeSegmentOccurrence	
InvertElevation	5986.76
Qto_PipeSegmentBaseQuantities	
GrossCrossSectionArea	0.291852
OuterSurfaceArea	12.6157
NetCrossSectionArea	0.291852
Length	6587.43
SDAI	
original_type_name	IfcPipeSegment

a)

IfcObjectDefinition	
HasAssignments	13880
HasAssociations	13848
Nests	
IsNestedBy	13761
HasContext	
Decomposes	
IfcPipeFitting	
PredefinedType	NOTDEFINED
IfcProduct	
ObjectPlacement	4899
Representation	4896
ReferencedBy	
IfcRoot	
GlobalId	3oRAwKIRH1IANAZLaw
OwnerHistory	20
Name	M_Elbow - Welded - Ge
Description	ÿ
Pset_EnvironmentalImpactIndicators	
Reference	Standard
SDAI	
original_type_name	IfcPipeFitting

b)

Figure 98 – The Property set of a) Pipe segment b) Pipe fiting

4.4. General evaluation

As can be seen from the table, reaching the LOD of around 150 using semi-automation process can save saving time from 20% to 50% depending on each element. However, it still has some disadvantages. Such as the quality of BIM model depending on the quality of point cloud data, In terms of the complicated element, this tool will not work with high accuracy. The final BIM model can continue working on updating the detail and transfer to other software over IFC format.

Table 18 – Time consumption evaluation

Object type	**LOD**	**Time consumption (minute)**	
		by manual process	by semi-automation process
Floor (base on level)	150	40	3
Wall	200	180	15
Door and window	150	60	10
Stair and railing	100	45	45
Roof and timber structure	150	150	15
Pipe segment	150	15	5
		Total: 490	Total: 93

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5. CONCLUSION

The semi-automation solution for generating BIM model from point cloud data has been figured out, and the application succeed in this research. As a result, better decision making and enhanced project outcomes have been enabled.

In addition, the research has highlighted the significance of considering various factors that can affect data integrity in the Scan to BIM process. These include the selection of appropriate scanning devices and stations, the identification and management of special objects such as structure apertures and mirrors, and the specification of the desired Level of Detail (LOD) for the BIM model. It is possible to ensure the dependability and usability of the generated BIM models by addressing these factors and implementing efficient data acquisition and processing strategies.

Automated algorithms, machine learning techniques, and artificial intelligence have demonstrated great promise in extracting and interpreting information from point cloud data, thereby facilitating more rapid and accurate BIM model generation. To maintain data veracity and dependability, it is essential to evaluate the pros and cons of semi-automation, including the need for human intervention and verification.

5.1. Main outcome

The significant advantage of semi-automation in terms of time savings. The overall modelling process becomes more efficient and streamlined by automating certain processes within the Scan to BIM workflow, such as feature extraction and data interpretation. This advantage is particularly relevant in both the architectural and MEP (mechanical, electrical, and plumbing) aspects, where time-intensive tasks can be automated, freeing up valuable resources for more critical design and analysis activities.

The research framework developed in this thesis demonstrates its effectiveness in the context of comparing the common process and the semi-automation process, which determine by two case studies architectural and MEP practices. Integrating semi-automation solutions into the BIM workflow improves the accuracy and completeness of the generated BIM models.

The advantage of this research extends beyond individual projects and can be applied on a larger scale within companies and the industry as a whole. By adopting semi-automation solutions, organizations can achieve greater productivity and accuracy in BIM modelling, leading to improved project outcomes and client satisfaction. The ability to automate repetitive and time-consuming tasks allows professionals to focus on more complex and value-added activities, increasing overall project efficiency and reducing costs.

This is also reflected in the ease of use of the BIM tool integrated with the project. Any architect or engineer can get used to them immediately without going through a lengthy training process. For companies with many employees, this dramatically reduces training costs. And help improve work productivity immediately after applying, unlike regular improvement projects where the training time to use new technology is very long, becoming a financial burden.

5.2. Future research direction

Intelligent Feature Extraction: Increasing the capabilities of semi-automation tools in order to intelligently extract infrastructure-specific features, such as roads, railways, utilities, and structural elements. This requires the development of algorithms capable of accurately recognizing and modelling these components from point cloud data, thereby reducing manual effort and increasing productivity.

Advanced application in historical building: Developing advanced algorithms to recognize and model intricate architectural details, decorative elements, and historical materials.

AR and VR Integration: Integrating AR and VR technologies into the Scan to BIM process for historical projects. This facilitates documentation, research, and public engagement by enabling virtual excursions, immersive experiences, and improved visualization of historical structures.

5.3. Summary

This thesis has provided significant insight into the application of Scan to BIM and the semi-automatic generation of BIM models from point cloud data. It also contributes to the ongoing development and advancement of Scan to BIM methodologies by laying the foundation for enhancing the efficiency, accuracy, and efficacy of creating as-built BIM models. Taking advantage of the potential of 3D laser scanning and automation technologies, the construction industry can improve data-driven decision-making, project outcomes, and productivity in the digital era of building information management.

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LIST OF ACRONYMS AND ABBREVIATIONS

They are to be listed transparently, logically separated, in column (tabular) form. Acronyms / abbreviations / translations that are not in the public domain should be indicated. Acronyms / abbreviations / translations in the list are to be listed in alphabetical order. Acronyms and abbreviations are to be indicated in the List of Acronyms and Abbreviations.

BIM	Building Information Modelling
AEC	Architecture, Engineering, and Construction
LOD	Level of detail/ Level of Information Need