POLITECNICO DI TORINO

MASTER'S DEGREE COURSE IN CIVIL ENGINEERING

October 2022

Point-Cloud To Building Information Model workflow
A Case-Study

Supervisor:
Prof. Anna Osello

Candidate:
Ahmad Chesti

Co-supervisor
Prof. Davide Lorenzo Dino Aschieri

Table of Contents

1. **Abstract** 4

2. **Acknowledgement** 5

3. **Introduction** 6

   3.1 **Objective** 7

   3.2 **Fundamental Problem** 7

   3.3 **Description of the Building** 9

4. **BIM (Building Information Modeling)** 12

   4.1 **BIM definition and features** 13

   4.2 **Applications of BIM in the Construction Sector** 15

   4.3 **Advantages and Disadvantages** 17

   4.4 **BIM softwares** 19

   4.5 **Scan-to-BIM** 21

5. **Interoperability concept** 23

6. **Point Cloud in BIM** 24

7. **3D Modelling from Pointcloud** 30

   7.1 **Manual Modelling in Revit** 30

   7.2 **Automatic Modelling** 40

      7.2.1 **Python** 41

      7.2.2 **Plugins** 44

8. **Interoperability Check** 50

9. **Results and Discussion** 55

10. **Conclusion** 57

References 58

Table of Figures

Figure 1: Google Map Location 9
Figure 2: Outer View of the Building 11
Figure 3: Internal view of the building 11
Figure 4: Workflow diagram for Building Information Modelling. [3] 13
Figure 5:BIM model containing geometries and semantic information of elements. 14
Figure 6: Point Cloud in Autodesk ReCap 25
Figure 7: BIM model creation processes in new or existing buildings depending on available, preexisting BIM and LC stages with their related requirements [30] 26
Figure 8: Systematic overview of data capturing and surveying techniques to gather existing buildings' information [30] 27
Figure 9: Segmentation of Truss element 28
Figure 10: Segmentation of Column truss element 29
Figure 11: Segmentation of Beam truss element 29
Figure 12: Six steps of the proposed methodology 30
Figure 13: Importing Pointcloud to Revit 32
Figure 14: Pointcloud to Revit 33
Figure 15: Single Bay Pointcloud 33
Figure 16: Revit levels that specify views 34
Figure 17: Creation of Truss family in Family Editor 35
Figure 18: Creating families from a point cloud using AutoCAD 37
Figure 19: Truss Family 37
Figure 20: Column Family 38
Figure 21: Beam Family 38
Figure 22: View of the Revit 3D model with point cloud\ 39
Figure 23: Final model in Revit 39
Figure 24: Visualisation of elements in python (Open3D) 43
Figure 25: Comparison of Plugins of Revit 44
Figure 26: As-built Structure toolbar 45
Figure 27: Elevation View of pointcloud by As-Built 45
Figure 28: Fitting of the structural element 46
Figure 29: Structural Element Recognition 46
Figure 30: Segment of Model made with As-Built Plugin 47
Figure 31: Problems with As-Built Revit 47
Figure 32: Final Model created by FARO as-Built plugin 48
Figure 33: Top View of Model 48
Figure 34: Elevation View of the model 49
Figure 35: Section view of the model 49
Figure 36: IFC export in Revit 50
Figure 37: Robot structural analysis link in Revit 51
Figure 38: Integration of model in Revit with Robot Structural Analysis 51
Figure 39: Mapping of Unassigned elements in Robot Structural Analysis 52
Figure 40: Model in Robot Structural Analysis Professional 2023 53
Figure 41: Complex column reduced to a single axis 53
Figure 42: Model transferred to SAP 2000 54
Figure 43: Model transferred to ETABS 54

1. Abstract

Building information modelling is now widely utilized in the building sector. Reverse engineering is evolving into a cutting-edge method for analyzing an object's structure, design, and functionality because of advancements in technology. This methodology allowed retrieving lost or nonexistent information on the construction by applying the most up-to-date approaches for obtaining spatial information about the object.

The purpose of this research is to investigate the efficiency and application of conversion of a point cloud from an existing structure to a BIM model and subsequently check interoperability to various FEM softwares using the IFC format.

The primary focus of this research is on reverse engineering using data from three-dimensional scans, techniques for building three-dimensional models, and automation of this process using Python, Revit, and Revit plug-ins. Revit provides an interface for third-party plugins to interact with pointcloud and draw objects in Revit.

In the result of the research, several methods of modelling from the point cloud were identified, from manual to automatic one. This thesis represents the beginning of a path toward automating the creation of structural models using point clouds. This method improves BIM modelling procedures and will be helpful in the future. Building a structural model from a point cloud can be used to renovate or retrofit an existing structure. With this knowledge, the engineer can optimize workflow, improve model accuracy, and save time.

Keywords:
Point cloud, Building information modelling (BIM), Revit, Finite element analysis (FEM), Interoperability, IFC, Revit Plugins, Python,

2. Acknowledgement

First and foremost, I am eternally grateful to my two supervisors, Professor Anna Osello and Professor Davide Lorenzo Dino Aschieri, for their enthusiasm and compassion in leading me through this research. It has been a pleasant and stimulating place to work in thanks to their guidance, support, and advice (both academic and otherwise) throughout the research process, for which I am very thankful. Their sage advice encouraged me to refine my ideas and raised the caliber of my work. Additionally, I want to express my gratitude to Rector Guido Saracco for assuring teaching and assistance through COVID-19. In addition, I would want to use this chance to express my gratitude to those that managed the remote server, virtual classroom, and lockdown browser to ensure flawless online learning.

I am also thankful to all of my friends, coworkers, and the other people I've met over the years who have helped shape the person I am today. I also want to thank my friends for assisting me with the different issues I ran into while working on this project, notably Mueed Qadri.

Lastly, I would like to thank my parents and my younger sister for all their love, support, and encouragement, in teaching me the principles and values that have contributed to my personal and professional life. None of this would have been possible without them.

3. Introduction

It is standard practice for the general contractor to deliver the as-built documentation to the owner or the facility management team at the end of every building or restoration project. The as-built information is provided in paper-based documentation, such as drawings and equipment lists, which are difficult to update and maintain throughout a facility's service life. One of the main issues with the handover process is ensuring that the building information obtained is correct and reflects the conditions as built. Because a building information model (BIM) is a digital representation that collects and transmits building information amongst various stakeholders, it may be utilized as an information repository to store and provide as-built information. BIMs are usually created based on design information in the design or construction phases (called as-designed BIMs). Such as-designed BIMs might not be able to reflect the as-built conditions, as a building does not always get constructed as specified at the design phase exactly. Changes and updates are likely to happen during the construction phase.

Many instruments and exact surveying processes are accessible today, which have gained popularity in recent years due to the quick development of technological equipment and precise surveying methods. As a result, the accuracy of building-related information is appropriate. Of course, one area where this rapid advancement has had a big influence is the use of 3D high-definition laser scanning technology. Important information on the as-built circumstances may also be found in the 3D models produced by laser scanners. These days, laser scanner survey output data can be incorporated into BIM models. Additionally, BIM models created from 3D scanned data are increasingly being used in the AEC (Architecture, Engineering, and Construction) and construction, historical conservation, and facilities management sectors.

As numerous procedures and processes have been automated and digitalized, the usage of BIM in the construction sector has essentially superseded all previously used conventional methods. One of these innovations is 3D laser scanning technology, which has established itself as a dominant force in building BIM geometric models of existing items. This technology is important because it improves three-dimensional building mapping accuracy compared to older techniques that frequently result in mistakes and inaccurate results. [1]

3.1 Objective

The goal of this thesis is to examine the workflow required for the creation of a 3D model. The FCA (Fiat Chrysler Automobile) warehouse at Corso Luigi Settembrini, which is currently a part of the Cittadella Politecnica Project, was chosen as a case study. Another goal is to research the most widely used BIM software and determine whether the 3D model is compatible with these applications.

There are three steps in the modelling process. The first phase entails fieldwork, during which a laser scanner was used to capture the building. The second stage involves using the proper software and scanning data to create a 3D representation of the point cloud. Building modeling with suitable BIM software is the third stage. Using the Autodesk Recap program, a 3D digital representation of the point cloud was produced. The design of the 3D BIM model was then accomplished using the Autodesk Revit program and certain methods to create the model automatically were also explored.

After the model was created, it was exported to various FEM software to visually assess the model's interoperability.

3.2 Fundamental Problem

Even though certain software firms (like Autodesk with Revit) are introducing new tools for exporting point clouds, there is no effective software that facilitates this straight transition from point clouds to fully enhanced BIM models. The complex components make this task very difficult. Additionally, it is crucial to analyze and understand the complete chain from the acquired 3D point clouds to well-structured and semantically filled 3D digital models to construct an effective digital representation of buildings. Such a procedure should consider three essential steps: data collection, segmentation, and enhanced 3D model. This research focuses on applying BIM techniques to existing buildings, also known as "as-built" or "as-is" BIM. The "as-built" BIM method entails transforming measurements of the geometry and appearance of existing buildings into semantically rich representations. This method is based on the first phase of data collecting and surveying, followed by the second phase of the data treatment, which results in the final model that has been semantically enhanced.

Making as-built BIM projects has generally been a manual procedure, which is a significant problem. Depending on the facility's complexity and modelling demands, the project can take many months to complete. Even while modelling individual geometric primitives can be done quickly, the manual procedure takes a long time and may take thousands of primitives to model a whole facility. The as-built Biomodelling process has been streamlined and made more effective with automatic and semi-automated point cloud extraction techniques. By minimizing human interaction during model generation, these approaches enable semi- or fully automated geometry reconstruction of the scanned environment from the point clouds.

Nevertheless, depending on the project's scope, the problem of as-built BIM reconstruction can be very complex regarding available inputs and expected outputs. (Tang et al., 2010) identified and discussed in their studies some technology gaps in automated as-built BIM creation capabilities, revealing areas where research on this problem should be concentrated, for instance, modelling of complex structures and representing non-ideal geometries that occur in existing facilities, handling realistic environments with clutter and occlusion, representing models using volumetric primitives rather than surface representations, and developing quantitative performance measures for tracking the progress of the field. [2]

3.3 Description of the Building

The structure is located in Corso Luigi Settembrini, 178 in the area of Mirafiori Sud. The structure consists of several warehouses, Industrial buildings converted into research, teaching, library, exhibition spaces, covered atriums, and green spaces for the Department of Architecture and Design of the Turin Polytechnic. most of them are not in use and are planned to extend the university campus.

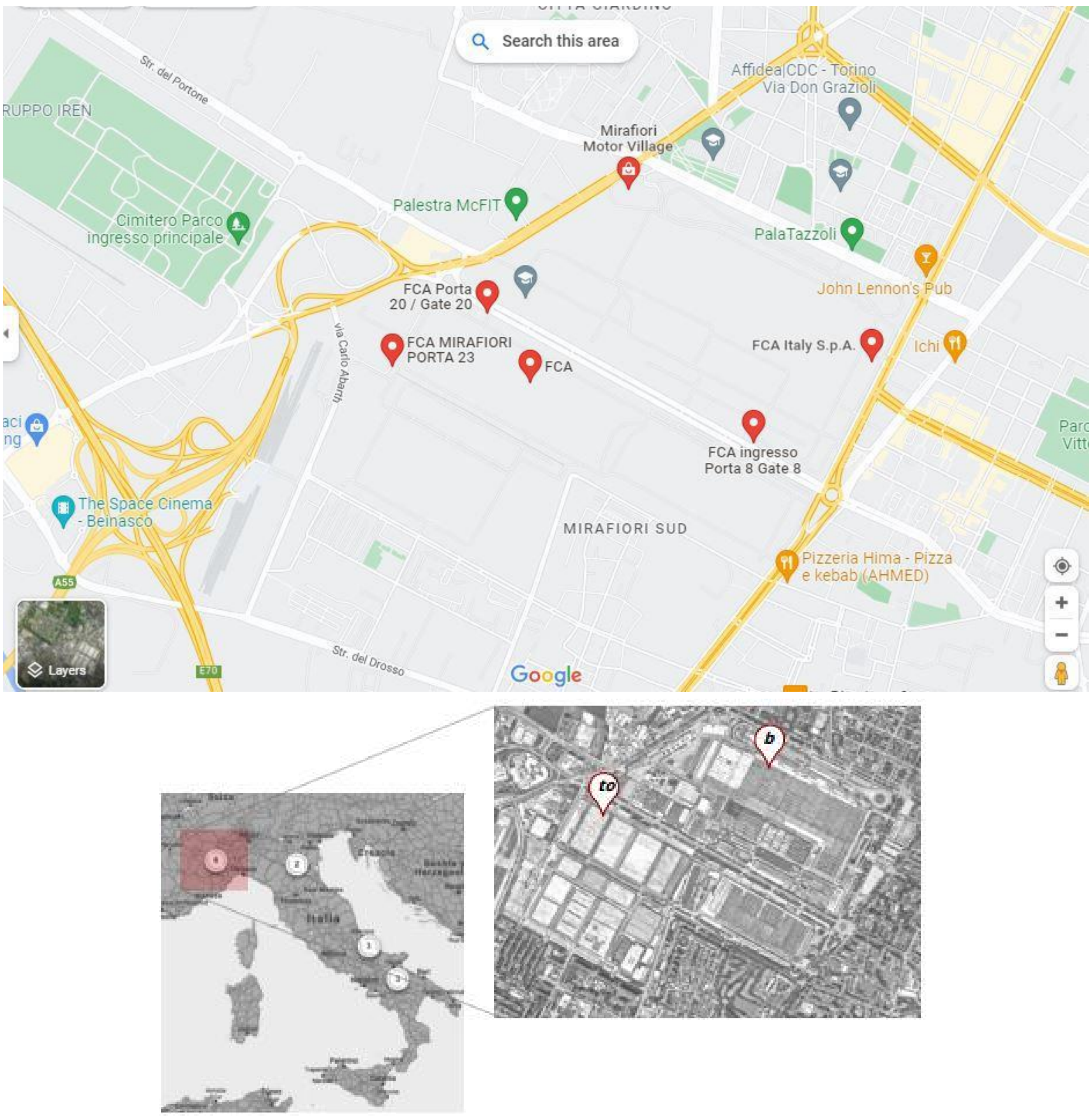

Figure 1: Google Map Location

Fiat Chrysler Automobiles (FCA) Mirafiori, which can be considered the highest model of industrialization established on the big plant that lasted more than a century, is one of the places that best exemplifies the modern Italian identity. In the southern section of Turin, the Fiat Mirafiori industrial district includes the FCA (Fiat Chrysler Automobile) warehouse.

An international automaker, FCA Mirafiori develops, designs, engineers, markets, and produces cars, body parts, control systems, and spare parts all over the world. In addition to Fiat, the company's spare parts and services brand, it also owns several automobile brands, including Abarth, Dodge, Mopar, Fiat Professional, Jeep, Lancia, Alfa Romeo, Chrysler, Ram, SRT, and Maserati.

Additionally, the Group has more than 40 R&D facilities (more than 20 of which are in Europe), and more than 100 factories, and engages in direct sales in more than 130 nations. It was created through the reorganization of the American group Chrysler Corporation and the Italian firm Fiat SPA, whose tax headquarters are located in the Netherlands.

There are roughly 14 production facilities in Italy, and six of them are in the city of Turin. In addition, the case study concentrated on the Fiat Mirafiori industrial complex, which is the largest plant in the city of Turin. Torino's industrial past, as well as its impressive and social history, are represented by the Fiat Mirafiori facility.

Industrial buildings converted into research, teaching, library, exhibition spaces, covered atriums, and green spaces for the Department of Architecture and Design of the Turin Polytechnic

The place is located in the heart of Turin's industrial area. Here the design and automotive lessons are held. The headquarters is also well equipped with classrooms and laboratories as well as containing a section of the secretariat. There is also a small basketball court and some green areas.

The structures were constructed from 2006-11 and are made of steel prefabricated elements for the Trusses, beams, and columns of which most are complex.

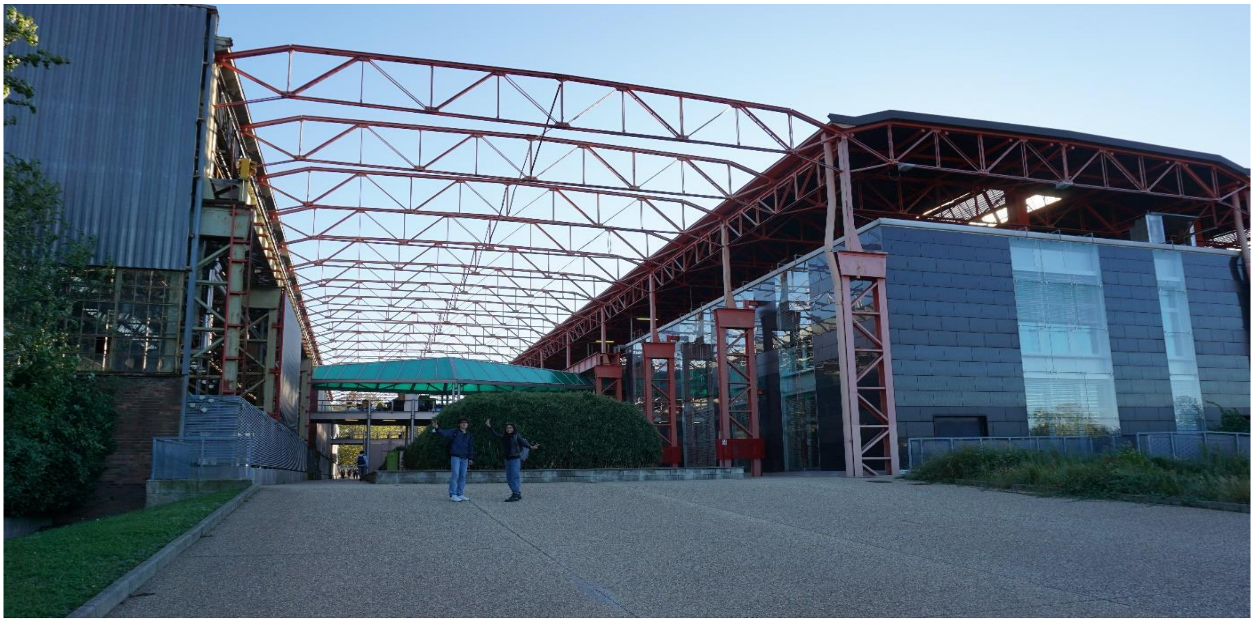

Figure 2: Outer View of the Building

Figure 3: Internal view of the building

4. BIM (Building Information Modeling)

An early, popular definition in the UK jointly proposed by the Royal Institute of British Architects (RIBA), the Construction Project Information Committee (CPIC), and Building SMART is:

"Building Information Modelling is [the] digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition." (Smith, 2011). New digital models for the design and specifications of buildings and constructions have emerged as a result of the last decade's rapid advancements in software design and analysis in the construction industry. The BIM model was also a new and innovative digital model. The Associated General Contractors of America and US construction firms define BIM as "an object-oriented building development tool that utilizes 5-D modelling concepts, information technology, and software interoperability to design, construct, and operate a building project, as well as communicate its details."

Due to this development, BIM software now incorporates 3D models or more dimensions with integrated, smart building components connected to databases. As a consequence, it acts as a reliable basis for choices made at the first, intermediate, and last stages of the building life cycle. It also serves as an interdisciplinary venue for communication and knowledge sharing among all parties involved.

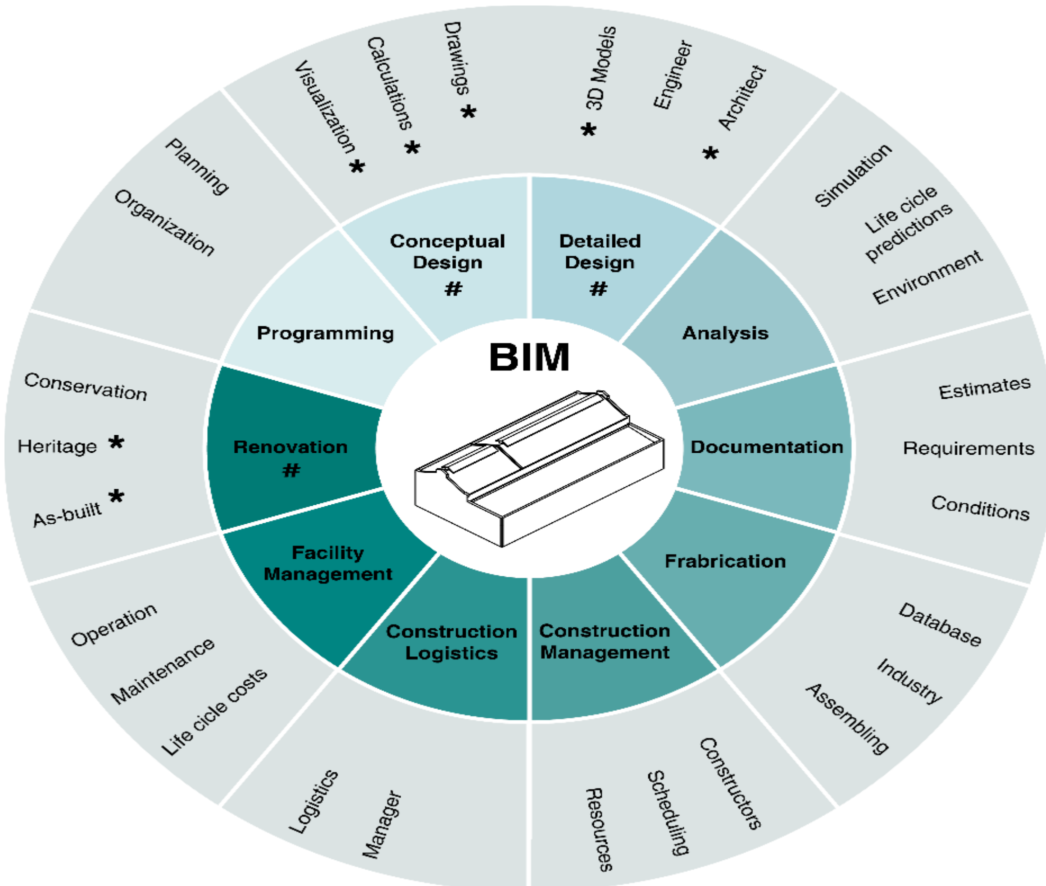

Figure 4: Workflow diagram for Building Information Modelling. [3]

4.1 BIM definition and features

BIM is a comprehensive digital representation of a constructed facility that also includes a lot of information about it. The display of the materials' three-dimensional geometry is accompanied by the presentation of non-physical objects, project schedules, and project structure. Semantic data about each object, including its composition, cost, and technical characteristics, are connected.

Additionally, BIM is a trustworthy database source for a facility's complete life cycle, from the project's inception through destruction, according to the US National Building Information Modeling Standard. But for BIM to be effective, all interested parties must cooperate throughout a facility's life cycle for BIM data to be imported, exported, and updated. [4]

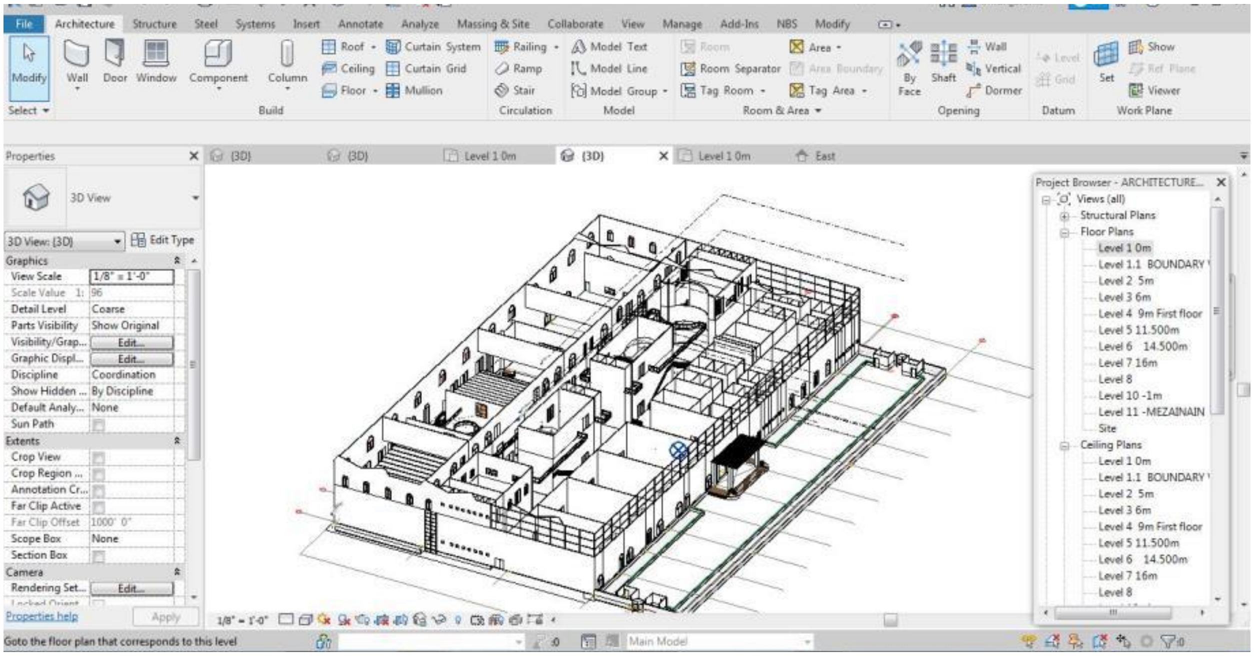

Figure 5:BIM model containing geometries and semantic information of elements.

The idea of BIM is not new. BIM was initially mentioned by Professor Charles Eastman in the late 1970s. Since then, the growth of BIM in the construction sector has provided new definitions and viewpoints on its application. BIM is now seen as a cutting-edge method of boosting efficiency in the AEC industry and an ideal tool for managing building projects throughout their entire cycles. Additionally, BIM has changed the construction industry sector, increasing the cost- and time-effectiveness of building.

The definitions given above make it clear that BIM is a technology that enhances the planning, scheduling, design, and materialization of construction projects. Modelling, construction simulation, assessment, and decision-making are all done using BIM. Finally, throughout the entire lifetime of the project, from the initial design through facility maintenance, BIM promotes and encourages collaboration and coordination amongst the many stakeholders involved.

4.2 Applications of BIM in the Construction Sector

It is well recognized that engineers may advertise their work using the BIM outcome, and researchers can utilize it to convey their ideas. Therefore, a building information model enables all interested stakeholders to view and assess the project's 3D portrayal. BIM includes a useful tool for model analysis and the detection of flaws, omissions, clashes, and dangers, as was previously indicated.
The many levels that makeup BIM are examined below. [5] [6]

3D model: a three-dimensional model that contains measurements for height, length, and breadth

4D model: The 3D model as well as the estimated building schedule

5D model: The building cost estimate in addition to the 4D model

6D model: In addition to the topographic design, the 5D model also includes integrated GIS data.

7D model: BIM model for managing buildings throughout their lifecycles

More precisely, BIM applications at various levels have the following characteristics:

1. 3D model:

- Walkthroughs of models. This is a concern for designers and builders since they can see, anticipate, and resolve issues before they emerge in actual reality.
- Clash detection: This is the computerized detection of imminent issues at the design stage before the start of the construction.
- Project Visualization: This is a crucial marketing tool that enables the potential buyer to see the building as it is being constructed in all of its stages.
- Prefabrication: Either on-site installation or remotely managed circumstances can be used to accomplish this.

2. 4D time:

- Management and planning of construction. BIM tools are utilized for the planning of the construction as well as the monitoring of safety and health applications on the job site.
- Visualization of the schedule. This program assists researchers in making choices based on reliable, precise, and current information.

3. 5D cost:

- Quantitative take-off. The constructor or manufacturer may clarify precise and current information about cost estimation, such as materials, quantities, size, and regions, using the BIM model. The project-wide automated updating of all changes boosts efficiency in the building industry.
- • Cost estimate in real-time. Every piece of the BIM model now includes cost-related data, which makes the model more accurate when estimating the entire cost of the project's materials and their worth.

4. 6D Sustainability:

- The improvement of power consumption management is a result of the use of 6D BIM technology. Information from 6D BIM is included in facility management, resulting in improved business outcomes. The information in question may contain product details, the manufacturer and contacts of each component, the date of installation, warranty information, photographs, etc. This technology produces a better sustainability plan that adheres to the initial energy-saving objectives with the aid of analytical tools.

5. 7D Facility Management1:

• It relates to maintaining a technological project throughout its life cycle by connecting all "smart" objects or systems to all the information that interests them. The BIM model in this instance is continuously updated during the building phases and allows the designer the chance to produce the "As-Built" construction model that will be provided to the manufacturer. The "As-Built" BIM model, which acts as a database for the administration and operation of a project, is updated with all the pertinent information of all objects.

• Data collection. Updated and recorded data on the building's operation and functions are sent through sensors. With the use of this data, the BIM may predict energy usage and take action to save operating costs.

The potential applications of BIM for facilities management were emphasized in a subsequent study from Banecerik-Gerber [6]. According to the study, the following situations call for the usage of BIM:

(1) locating and identifying building components, (2) facilitating real-time data access, (3) visualization and marketing, (4) checking maintainability, (5) creating and updating digital assets, (6) space management, (7) study of planning and intended use of construction, (9) controlling and monitoring energy consumption (9) emergency protocols and contingency plans and (10) personnel training and development.

4.3 Advantages and Disadvantages

Advantages:

The advantages of BIM over other techniques mostly stem from the project participants' and factors' capacity to contribute to the model's creation, input, and deductions or information from it.

Thus, when all participants collaborate in a single digital model, the substantial benefits it brings become apparent and apparent. As a result, several functionalities can be improved throughout the materialization process. That is, starting with the model's control of compliance with construction rules, followed by the design, cost

projections, work scheduling, facilities management, and finally decommissioning or demolition.
More precisely, BIM has the following benefits over other approaches:

- Development of collaboration. Compared to drawings, collaboration with models is simpler. Collaboration between disciplines is possible, and project progress may be shared.
- The construction component's schedules are revised often. This enhances quantitative computations, which in turn lowers expenses.
- By combining the use of several various techniques, the drawing may be used to create greener structures with more sustainable solutions. The AEC sector has viewed BIM as a significant potential, and many businesses are implementing green BIM techniques.
- The growth of digital databases enables cross-disciplinary cooperation, coordination, in-depth analysis, and efficient data interchange.
- The potential for database updates and alterations. In this approach, each project component alteration is automatically absorbed and conforms to all other project components.
- Several design ideas may be shown since a 3D depiction of the design enhances knowledge of the building and its areas.
- Greater productivity as a result of the simplicity of information acquisition.

Disadvantages:

- Since the majority of BIM software does not produce reliable cost estimates, the data must be moved to other programs. IFC files must be utilized in this situation to transmit the data, which causes part of the data to be lost.
- A BIM program is highly expensive; thus, it is only a meaningful investment if it is utilized to its fullest extent.
- There aren't many BIM technology professionals around. As a result, more money may need to be spent on education and training.
- Powerful computers are required to register and process the point cloud due to the enormous amount of data that must be handled.
- To assure that the final model will be comprehensive, dependable, and free of gaps, it is required to scan the item from several angles. Hidden geometry that is not visible to the scanner cannot be measured.

4.4 BIM softwares

Few studies were conducted to present the BIM software (an already widely used and well-liked product), and as a result, few comparative references have been made to its characteristics. BIM technology is used by many professionals, including architects, structural engineers, mechanical and electrical engineers, and even interior designers.

The study concentrated mostly on websites that deal with commercial software that lists some of its characteristics and assists users in choosing the best option.

Consequently, some of the most used BIM applications include:

- **Autodesk BIM 360:** BIM 360 is an Autodesk cloud-based solution that allows project teams to effectively work in a collaborative environment. In the AEC industry, it connects all project stakeholders to execute projects from conceptual design through construction and ultimately project turnover. [6]

- **Autodesk Revit.** Revit is a commercial building information modelling (BIM) software by the company Autodesk. It's generally used by architects, structural engineers, mechanical, electrical, and plumbing (MEP) engineers, designers, and contractors. Autodesk Revit allows users to create, edit, and review 3D models in exceptional detail. It is a 4D building information modelling program. The most commonly used file formats, such as DWG, DGN, and IFC, are Revit compatible. Therefore, even when some of the coworkers choose other platforms but utilize the same formats, the support for these formats enables them to collaborate. [7]

- **Autodesk ReCap**: For the use of point clouds in BIM technology, ReCap software is an essential component. It may use many index scan files to build a point cloud projection file (RCP) (RCS). converting the scanned file data to a point cloud format with Autodesk ReCap so that it may be viewed and manipulated in other programs. Autodesk ReCap can aggregate scanned files and clean, categorize, spatially sort, compress, measure, and show them. It also handles large-scale data sets. AutoCAD and other Autodesk tools, including Autodesk Revit and Inventor, may utilize the generated high-speed format. By choosing the import scan file option in Autodesk ReCap, you may start a new project.

- **Archicad.** Archicad is a software tool for architects working in the architecture-engineering-construction (AEC) industry for designing buildings from the conceptual phase all through to the construction phase. It is a BIM software developed by GRAPHISOFT, enabling architects to work in a BIM environment. Archicad works on two platforms: macOS and Windows with no significant differences between them. Its features include parametric custom profiles, façade design, workflow improvements, and quicker and more fluid 2D navigation. Archicad can import and export files in the DWG, DXF, IFC, and BCF formats. Additionally, various paid and free add-on programs, such as Trimble SketchUp, Google Earth, etc., provide the platform with additional capability. [8]

- **Trimble Connect.** Trimble Connect is a collaboration tool offering up-to-the-minute, construction-ready project information: View, review and reference Tekla models, drawings, and other data you need for a successful construction project. Among other 3D file formats, IFC, DWG, DGN, and RVT (Revit 2019 and before) are supported. Some of its capabilities include commenting on to-do lists, filtering model objects, managing permissions and alerts, and 3D markup. [9]

4.5 Scan-to-BIM

An important benefit for the AEC industry, including existing building interventions, is the incorporation of photogrammetry and laser scanning into the BIM workflow. They are efficient ways to capture the initial condition, keep a current record of the construction site, identify potential construction errors, evaluate changes over time, and produce as-built documentation. This is significantly more important for structures that already exist because it's possible that not all site-specific factors can be known. It is typical for new information to surface throughout an intervention in an existing building. Additionally, it can require updating the project's documentation and changing the initial design, with everything that entails. This is quickly achieved and controlled in a BIM environment. [11]

On objects of great complexity or with a range of scales, photogrammetry and laser scanning are effective survey techniques [12] [13]. Both are regarded as tools for collecting large amounts of data. The benefit of photogrammetry and 3D laser scanning is that they can eliminate the tedious tasks involved in conventional survey operations, freeing up more time for other crucial steps like building modelling or building analysis. [14] Both methods represent the captured geometry of the complete building and are produced as the final point cloud file.

When utilizing typical equipment to do architectural surveys is difficult or impossible, or when laser scanning is not recommended because of the scale of the site or the presence of inaccessible areas such as high rooftops, the photogrammetric method can be helpful. It is essential to make sure that all geometry is recorded by images with appropriate information overlap and to avoid significant jumps between shots for the photogrammetric survey to be carried out correctly. It is also crucial to have suitable weather and uniform lighting. To sum up, further notes and measurements must be made on the spot to properly scale and orient the model. [15]

On the surfaces of objects and locations, laser scanners record the geometry and, in certain cases, the texture of the surface. [16] The phrase "laser scanner" refers to a wide range of devices with various principles and functions that are designed for various situations, goals, and levels of accuracy and precision. The entire environment must be visible or clean enough to scan, there must be enough scan

points within the equipment's range, and there must be proper connections between all of the building's rooms, floors, outdoor, and indoor environments. Occlusions and inaccessible areas must also be taken into account. All of these measures are essential to ensuring that the program can recognize corresponding features and correctly align each scan when the raw files are processed.
There are very few decent illustrations of a thorough approach to creating a 3D model using photogrammetry and laser scanning. Some authors concentrated on developing parametric and nonparametric families to fill up existing element libraries, [17] while others investigated the possibility of wall generation [18] [19].
Others worked on modelling specific building parts using manual and automated trials. [20] [21] [22] It is possible to comprehend how the issue has been studied with particular activities to optimize certain elements of the process through these examples and other complimentary ones found in the literature.
However, few good examples demonstrate broader modelling issues. For instance, it is essential to construct a clear and practical approach that explores the points that must be taken into account and to be ready to reduce errors in the survey, processing, data manipulation, and creating modelling phases. This research seeks to close this gap and demonstrate, using a case study, how to digitally reconstruct the building while balancing the level of accuracy with the needs necessary to use the model in a BIM environment.

The scan-to-BIM conversion procedure is still entirely manual at the moment, and many people agree that it takes time, is laborious, is subjective, and requires expertise. [23] [24]

Even with training, the outcome produced by one modeller may differ greatly from that produced by another person, according to Xiong et al. [25] Thus, there is a lot of research being done on the automation of the scan-to-BIM process. Point clouds can be utilized as a visual aid (often in a top view) or sections can be generated to manually model a building from them. The manual modelling process introduces various problems since it relies on 2D images or is limited to particular areas. Semi-automatic tools were created to prevent potential mistakes. Realworks (Trimble), CloudCompare (EDF R&D), and 3D Reshaper (Technodigit), among other point cloud processing software, offer tools for immediately generating geometric primitives or meshes from 3D data.

Unfortunately, such modelling does not provide objects that can be incorporated directly into BIM tools like Tekla Structures, ArchiCAD, or Revit (all from Autodesk) (Trimble). There must be a conversion process, which frequently requires multiple pieces of software. Additionally, this conversion may result in issues with data interoperability. As a result, plugins for BIM software, such as Scan-to-BIM, ImaginIT, PointSense, FARO, or semi-automatic software, such as EdgeWise, and Trimble, were created especially for the scan-to-BIM process. In such software, structural components are transformed from user-provided data to point clouds. [26]

5. Interoperability concept

The demand for full integration between the application fields grows as Building Information Modelling methods become more widespread. Due to their abundance, it is hard to locate a single piece of software or a single operator who is capable of managing all the details of the building. It is therefore vital to have some tools that permit data sharing between operators and software.

"Software interoperability is seamless data exchange at the software level among diverse applications, each of which may have its internal data structure. Interoperability is achieved by mapping parts of each participating application's internal data structure to a universal model and vice versa." (NIBS, 2008) [27]

It is possible to bring two key internal elements to this concept by analyzing the most well-known meaning of the terms. Since multiple pieces of software that operate in various ways must somehow communicate with one another, interoperability might result in standardization because of the conversion from a model with an internal data structure to a universal one that needs to be customized for different environments.

As a result, the quality of the information that needs to be transmitted goes beyond simple graphic data because the components of a BIM are actual objects made up of qualities more than just geometry, such as materials, quantities, costs, and temporal, energy, and structural ones. For this reason, the topic of data sharing was extensively researched by researchers, associations, software companies, industries, etc., leading to the development of a suitable ad-hoc technology that adapts to the needs of BIM applications. [28]

6. Point Cloud in BIM

Many older buildings and facilities have trouble gathering information, which can be problematic for building managers. The majority of the time, the lost document contains records regarding buildings, machines, pipelines, electrical equipment, and previous renovations. To aid in building and facility management, the point cloud survey enables you to start over, detail everything, and create a BIM-style schematic of an existing structure.

Fundamentally, the point cloud maintains the connection between BIM and other types of computer models and the real world. Point clouds may successfully convert 3D physical space into digital format and inform/expand your current digital model, going beyond merely maintaining the guide or theoretical representation.

A crucial link for the use of point clouds in BIM technology is the Autodesk ReCap program. It may use many index scan files to build a point cloud projection file (RCP) (RCS). converting the scanned file data to a point cloud format with Autodesk ReCap so that it may be viewed and manipulated in other programs. Autodesk ReCap can aggregate scanned files and clean, categorize, spatially sort, compress, measure, and display them. It also handles large-scale data sets. AutoCAD and other Autodesk products, including Autodesk Revit and Autodesk Inventor software, may utilize the generated high-speed format. By choosing the scan file to import, we may start a new project in Autodesk ReCap. Various well-liked scan data formats, such as Faro, Leica, Lidar, etc., are supported. After choosing which scan file to import, change the input options that have an impact on the point cloud's size and appearance. At this point, the imported file will be shown on the projection screen while being operated with a variety of tools.

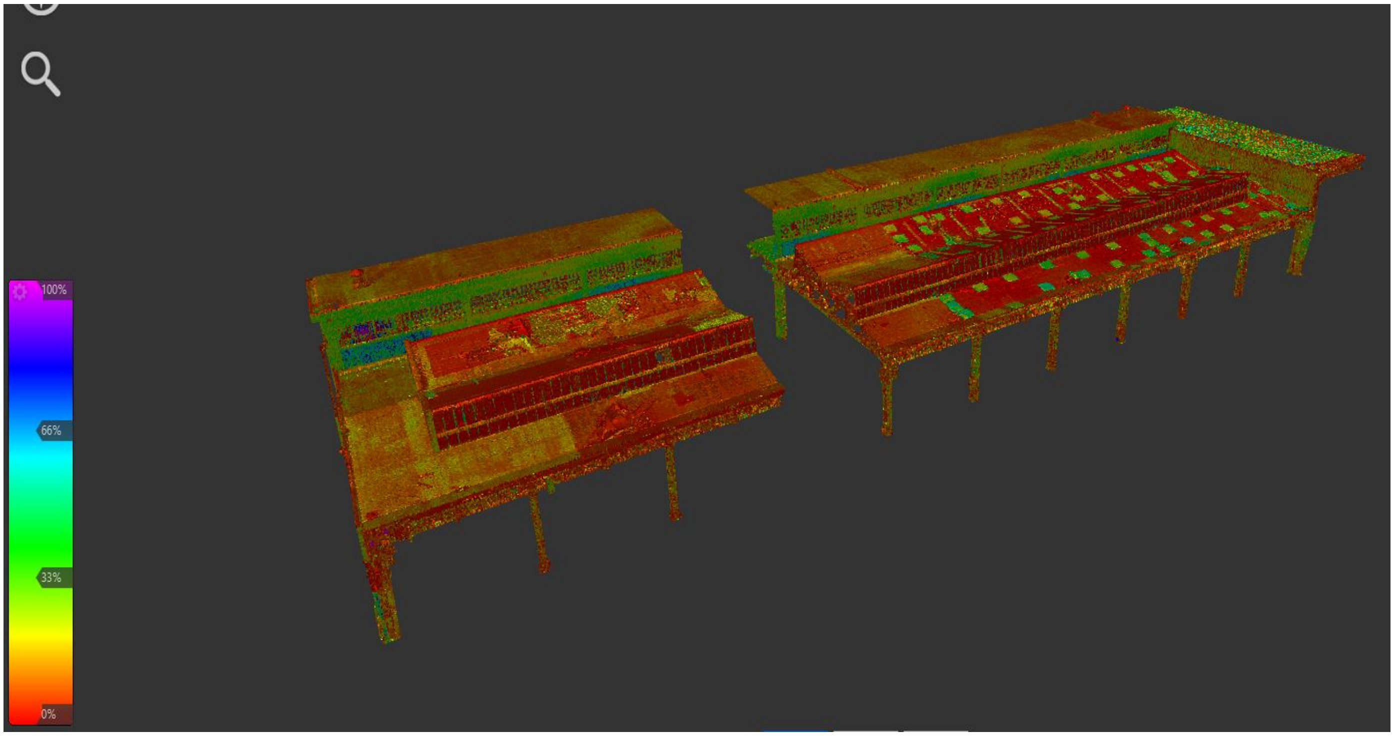

Figure 6: Point Cloud in Autodesk ReCap

The Pointcloud as you can see is not complete. A part of the point cloud is missing which could be a result of some error in postprocessing of the scans obtained or this part of the building was not scanned due to some obstructions. Still, the missing part was modelled with the location of the elements taken as the average of the other bays. Since it is a symmetric building, the elements fitted nicely on the point cloud.

Importing point clouds into Revit requires specific file formats, such as rcp or rcs formats. The file rcp format are project files grouped with multiple rcs scan files. A rcp file and perhaps more rcs files are produced as a consequence of indexing the original format file. Use AUTODESK RECAP to combine a portion of the point cloud since the point cloud contains geographic coordinates, and AUTODESK RECAP will be able to identify the geographic coordinates of each point. AUTODESK REVIT will not be able to combine the scanned point clouds into a single model. Autodesk Recap also has different display modes. In some point clouds without RGB, different display modes can better distinguish objects, such as the direction of the slab, etc.

Pointcloud Modelling

A point cloud is a collection of points that may be used to represent the surface of a real-world item in three dimensions after it has been 3D scanned. The point model can also be derived from a digital model that has previously been created but has no physical analogue. Although XYZ coordinates, which may be easily recorded in a file, are typically used to represent cloud locations, certain formats have a somewhat different representation.

Rapid visualization of a real-world item is made possible by point clouds. In addition, they serve as the foundation for reverse engineering of real-world objects and are successfully used for measurement and control of objects, 3D printing, visual visualization of remote locations or large extended objects, image recognition, automated analysis, reconstruction, and operation, and the creation of mathematical and three-dimensional models. [29]

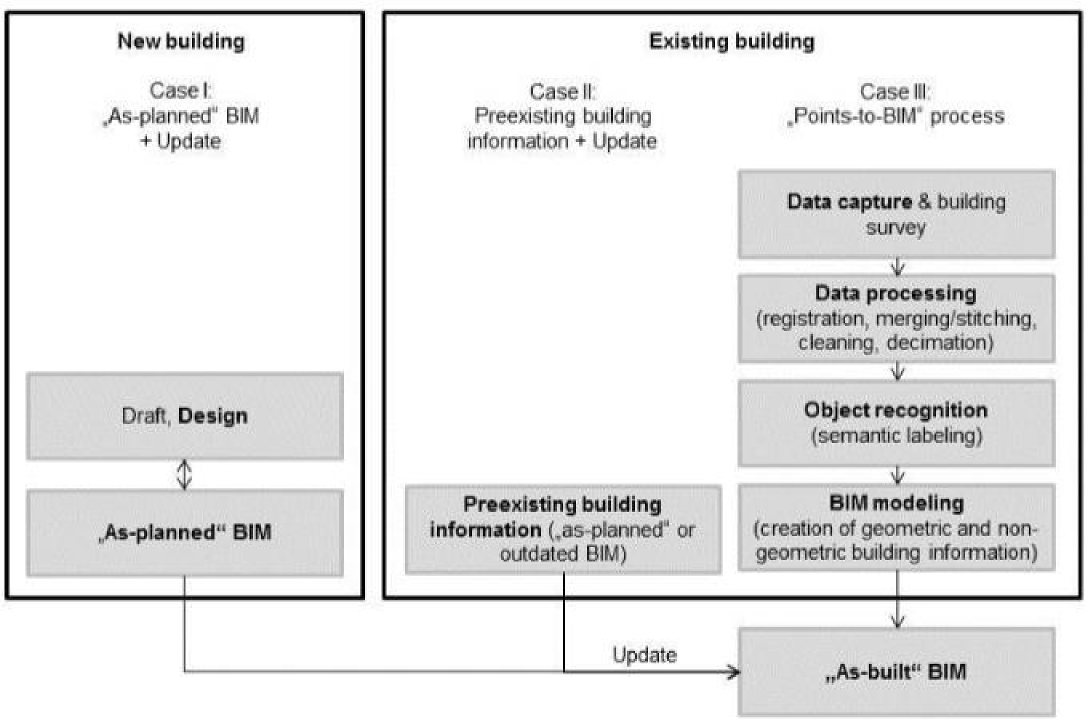

Figure 7: BIM model creation processes in new or existing buildings depending on available, preexisting BIM and LC stages with their related requirements [30]

Point cloud Registration:

Measurements can only be made using typical static scanning of the environment that is visible from the scan point (i.e. Line of sight). Occlusions, therefore, happen when environmental items obscure the scanner's field of vision. To reduce them, several arrangements are utilized to provide the necessary amount of coverage. Registration is done to enable these several scans to be positioned correctly about one another. [29]

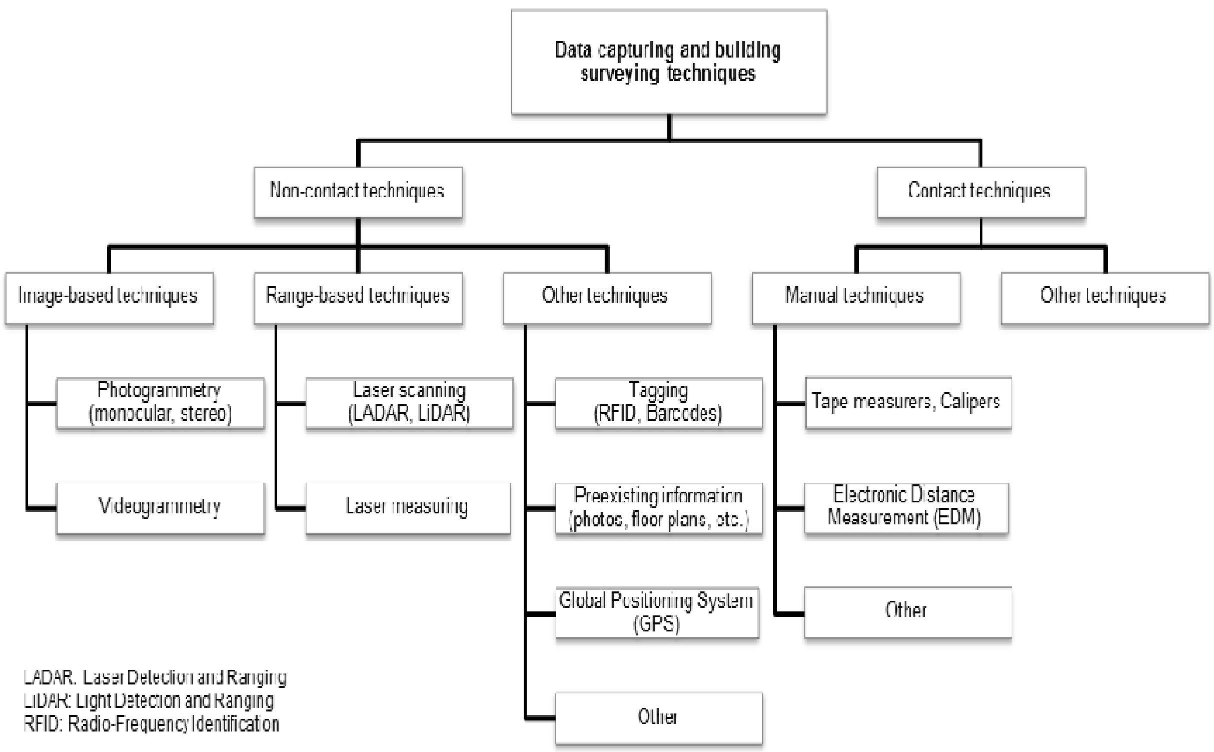

Figure 8: Systematic overview of data capturing and surveying techniques to gather existing buildings' information [30]

The iterative closest point (ICP) method, which has taken the lead, is typically used in a data-driven (cloud-to-cloud) manner of registering point data. It performs a six-degrees of freedom iterative translation and rotation from a free dataset to a fixed one until the transformation converges within the specified tolerance. This type of registration has the benefit of being completely automated due to its targetless nature. However, for the process to converge accurately and fast, the scans must be placed reasonably. The starting conditions can be enhanced by the user adding matching tie points to enhance the registration by lowering ambiguity in the matching phase. This is accomplished either by taking the outcomes of registration by targets or by providing at least three points of commonality between pairs of scans. The ICP can then be conducted as a fine or local registration step after that. [29]

Segmentation:

To create families of elements that could be then used repeatedly, the point cloud was sliced using Autodesk ReCap and its various tools. The segmented file could then be sent to AutoCAD to be exported to the family creator in Autodesk Revit, which made modelling much easier.

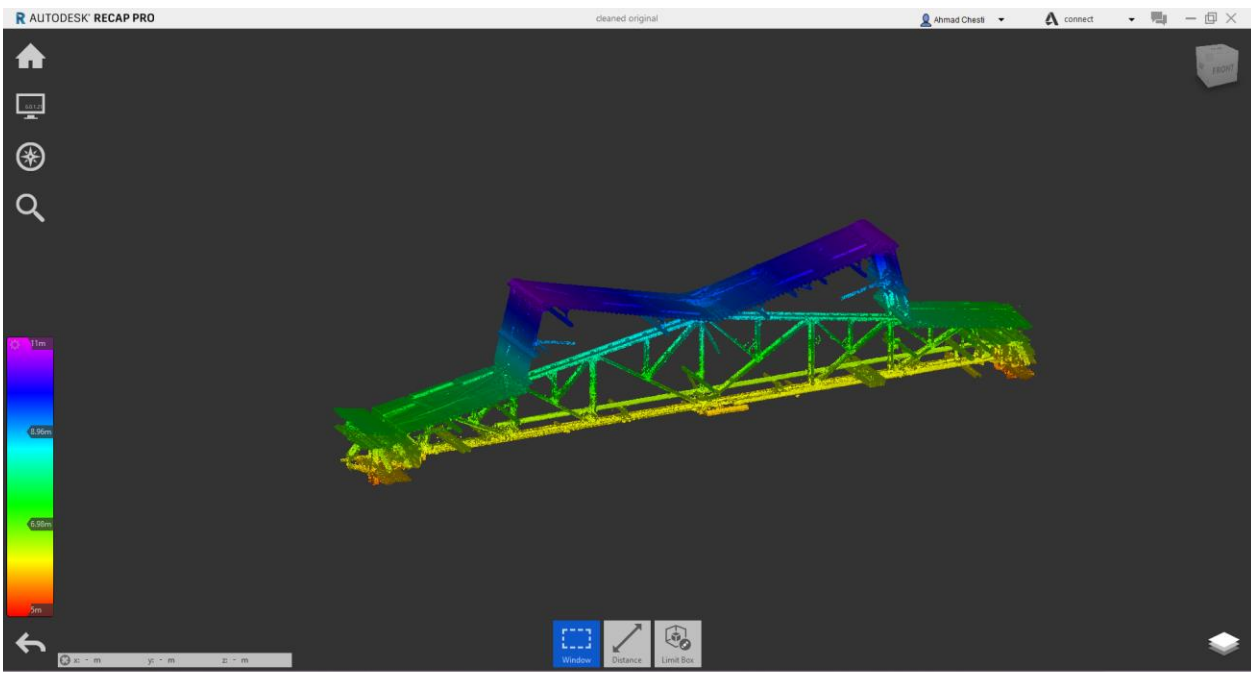

Figure 9: Segmentation of Truss element

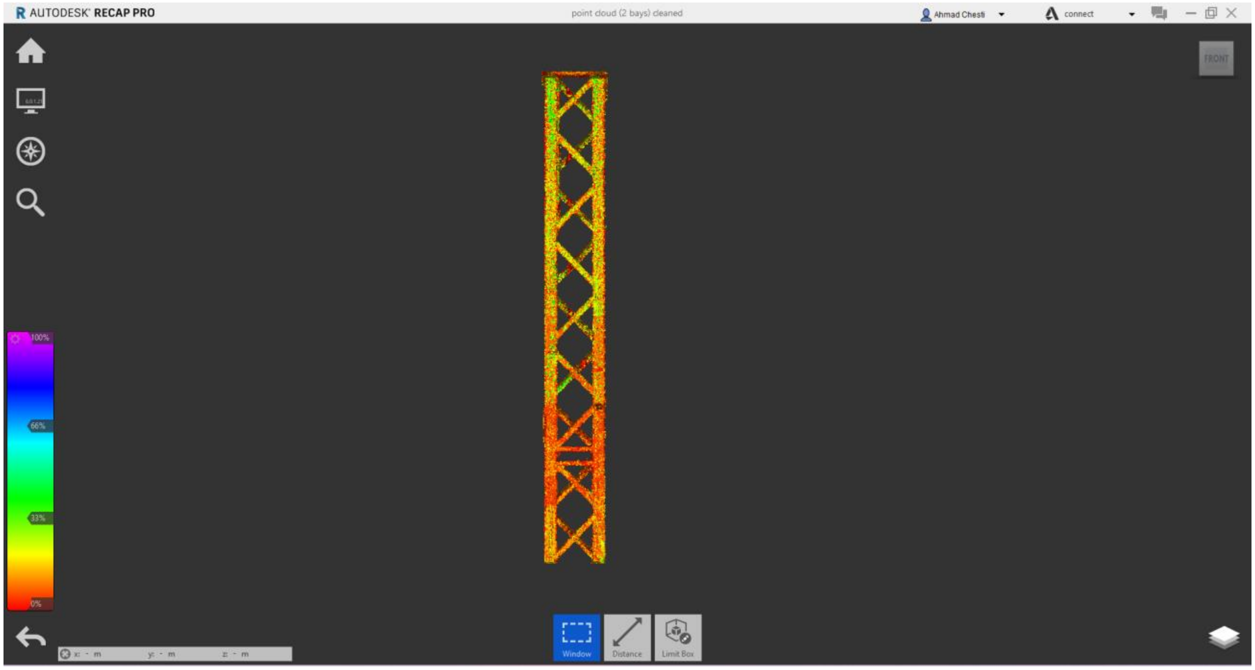

Figure 10: Segmentation of Column truss element

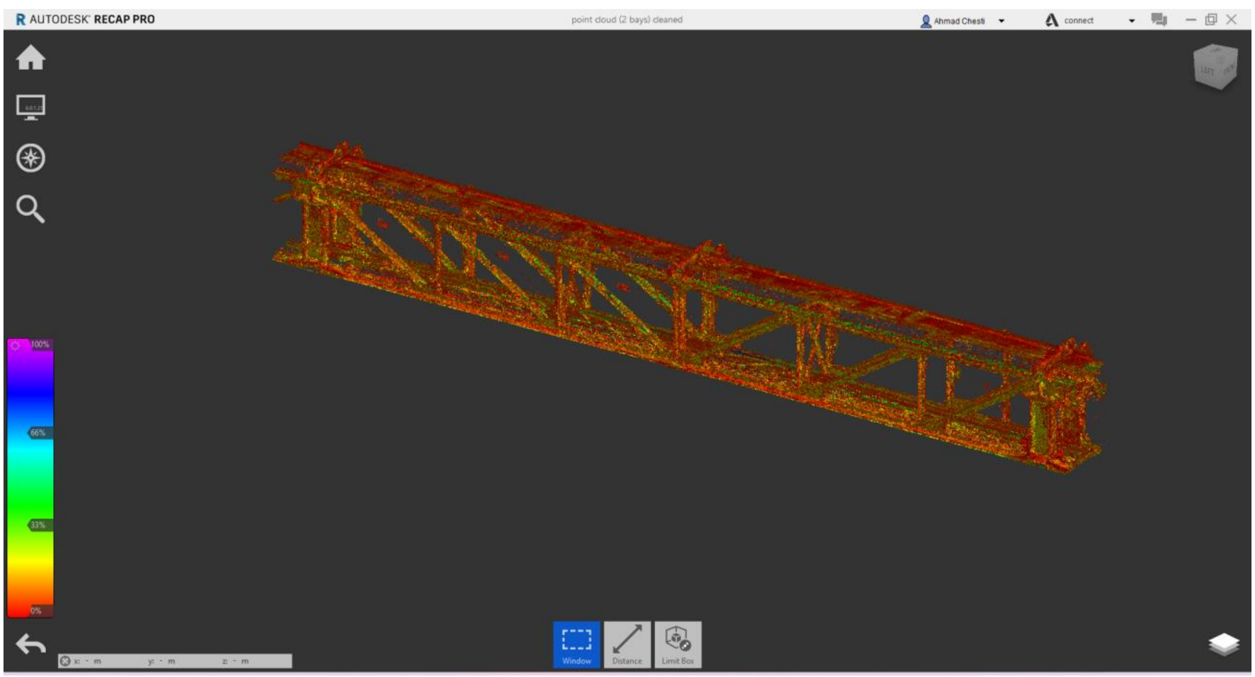

Figure 11: Segmentation of Beam truss element

7. 3D Modelling from Pointcloud

The many modelling strategies utilized for the project are presented in this chapter. The 3D model's final destination is not only the project's goal; it also has a scientific aspiration. The establishment of a comprehensive and efficient process that can be modified and reused in the future is crucial.

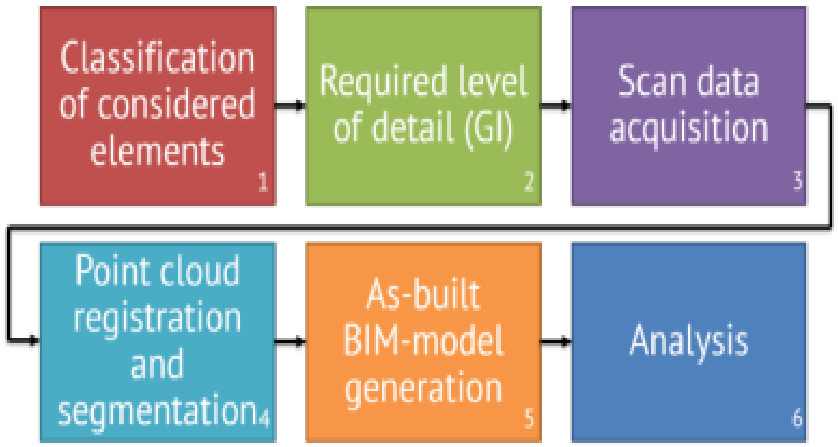

Figure 12: Six steps of the proposed methodology

7.1 Manual Modelling in Revit

Manual modelling is now the most practical method for using point cloud design. The overall design process is slowed down by this method's limitations. Understanding how manual and automatic modelling functions will help you compare their output and achieve this. Only solid-state models are created using Revit. There is no built-in functionality in this program for handling and manipulating the point cloud.

While ensuring that the data structure and formats adhere to IFC (Industry Foundation Classes) standards, the application Autodesk Revit is utilized to communicate the process to a broader audience. For building design at Autodesk, Revit is the main parametric modelling tool. It consists of tools for creating structures in a 3D environment that are inextricably linked to 2D views and data views for non-spatial variables, such as cost.

Autodesk has taken the lead in promoting IFC as the impartial product model enabling the building lifecycle. To encourage software interoperability in the AEC/FM sectors and advance an information-centric strategy and information reuse, Autodesk founded the Industry Alliance for Interoperability (IAI) consortium in 1994. Over the course of the previous 25 years, this endeavour has evolved into The Building Smart Institution, a non-profit organization with industry leadership that creates and updates the IFC as a neutral and open BIM specification.

The IFC4 scheme certification for Autodesk Revit is still in progress. Autodesk Revit has maintained continual certification with the official standard and its revisions. According to a recent study that assessed its collaboration capabilities and contrasted its performance as a full IFC-complier, Revit performs the best in terms of standard compatibility, data loss, and misrepresentation across the data creation processes. The decision to use Revit for this paper's demonstrations is further justified by:
(i) its efficiency in importing and managing point clouds (through RCS and RCP Autodesk native formats); (ii) the availability of a user-friendly three-dimensional virtual building modelling interface; and (iii) a potent family editor tool, where standard Revit elements have corresponding IFC containers and require no user-actions. In any non-proprietary software whose data structure and format comply with the open Official Standard of IFC model specifications: ISO 16739-1:2018, our demonstrated flow can be repeated without the loss of object information or geometric misrepresentation.

Before beginning the actual modelling, a few things must be done. The first step is to obtain a point's coordinates from the point cloud and enter those coordinates into Revit to set the survey point. In this instance, a point on the ground was picked. The project base point, which establishes the origin of the coordinate project system (0, 0, 0), and the survey point, which identifies a real-world location close to the model, are the two coordinate systems used by Revit. Once the survey point was established, it was moved to the origin and the same spot as the project base point (without altering its coordinates). Using this procedure ensured that the model was close to the internal origin and avoided some potential issues. Additionally, this guarantees that the ground level of the building will be

automatically located at level 0 within Revit when the point cloud is inserted, eliminating the need for manual movement or position changes.
Inserting the point cloud into Revit is the next step. To guarantee that the point cloud is positioned at the same coordinates that were specified when georeferencing, it must be done using the ‘shared coordinates’ option. The point cloud must then be fixed within the project to prevent accidental rotation or movement. Even if the point cloud needs to be unloaded and then reloaded within the same project, these operations are necessary to guarantee that it is always positioned in the same location. This positioning procedure enables us to segment the files in large projects so that we only load what is necessary at the time. The multiple components of a partitioned point cloud will always be loaded in the proper position thanks to the guarantee provided by the same reference.

The following are the characteristics of Point cloud in Revit:

- usually exhibits model object behaviour.
- shown in a variety of modelling techniques (for example, in 3D, on plans, and in sections)
- divided into plans, sections, and 3D view boundaries, making it simple to separate cloud segments.
- Select, move, rotate, copy, remove, show symmetrically, and other operations are available.
- It depicts a point cloud object that can be snapped to using direct point snaps or assumed plane snaps.

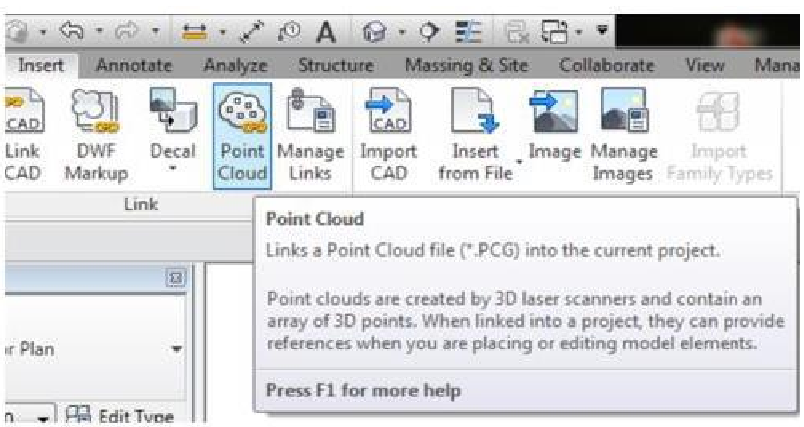

Figure 13: Importing Pointcloud to Revit

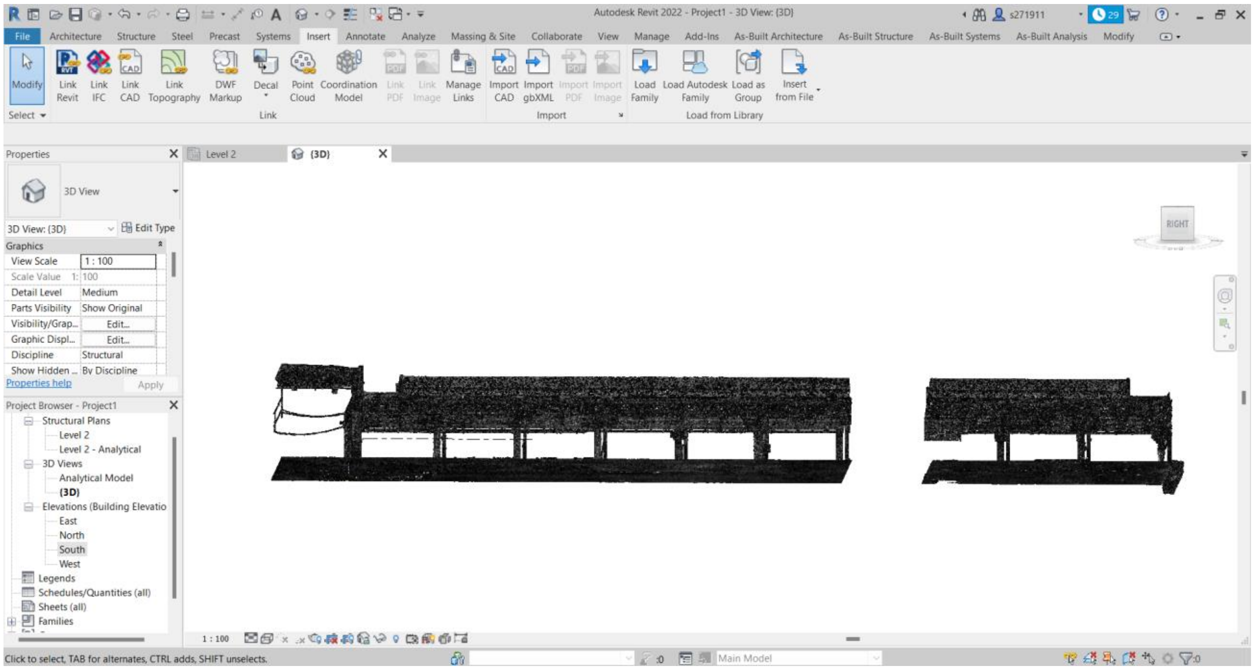

Figure 14: Pointcloud to Revit

The point cloud was divided into bays (1 set of column, truss, and beam elements).

Each bay was inserted in Revit and modelled one by one. Due to the similarity between many elements in consecutive bays, the process of copying the element made the modelling of the whole building easier.

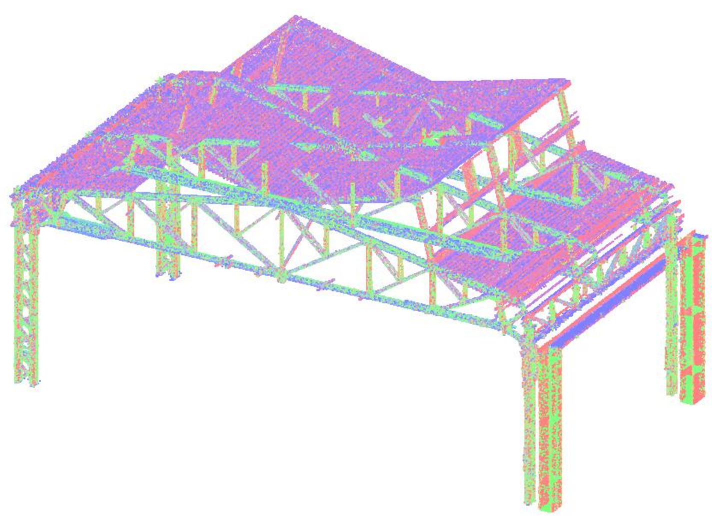

Figure 15: Single Bay Pointcloud

The modelling processes may be started by reorienting the building inside the workspace and performing a visual examination to identify and generate the levels once the point cloud has been added and fixed within Revit. It is required to determine and design the structures levels. These levels are essential because they aid in the proper placement of the building elements. These levels can serve as geometric start and termination locations for modelling restrictions. Because they are distinguishable as voids in the point cloud, floor-to-ceiling structures like walls and columns may be modelled using the 2D floorplans that levels provide. It is crucial to adopt a practical mindset to prevent the creation of extra levels that would complicate the workflow. In our situation, levels for columns, beams, and various truss (roof) points were created.

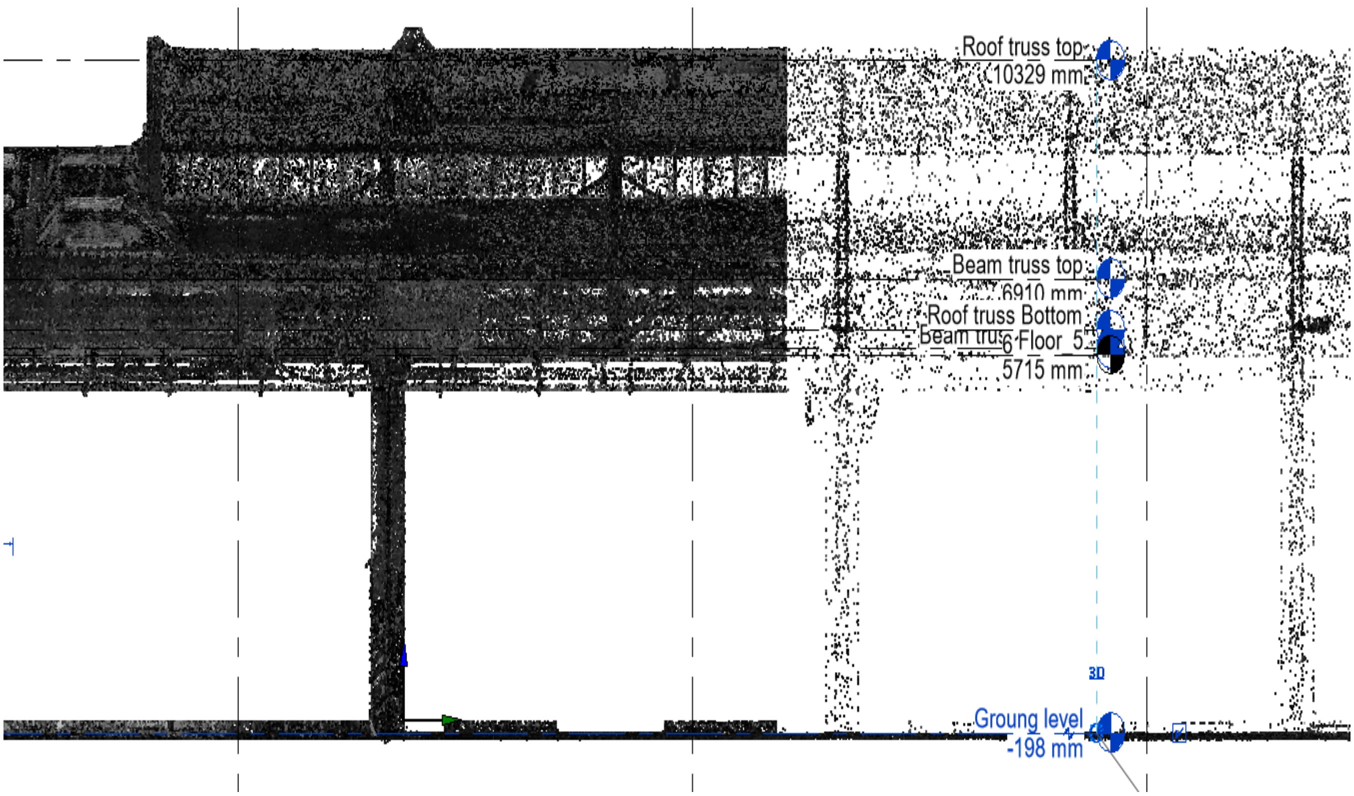

Figure 16: Revit levels that specify views

It is simpler to create a model using point cloud data thanks to the snap feature. The Revit "Line", "Grid," "Rotate," and "Move" tools, for example, can be linked directly to points in the point cloud or implicit flat surfaces that are dynamically defined in the point cloud.

Family Creation

Having a large family library speeds up and simplifies modelling within a BIM workflow. Since these families are typically parametric elements, productivity can be increased by customizing them to a project's requirements. But because there aren't enough libraries available that can handle BIM projects, it's necessary to model these families in their entirety.

With the help of the family editor in Autodesk Revit, we can create modelled families either internally within the project or externally. In either scenario, the element can be assigned to the appropriate category to ensure that it functions as a family created specifically for this project within the project. All of the columns, beams, and trusses in our case were modelled in the family editor. The insertion of point cloud files in conventional formats is not supported by the Revit Family Editor. So, to insert them into the family editor, it is necessary to separate the points referring to the objects to be modelled and export them in .dxf format.

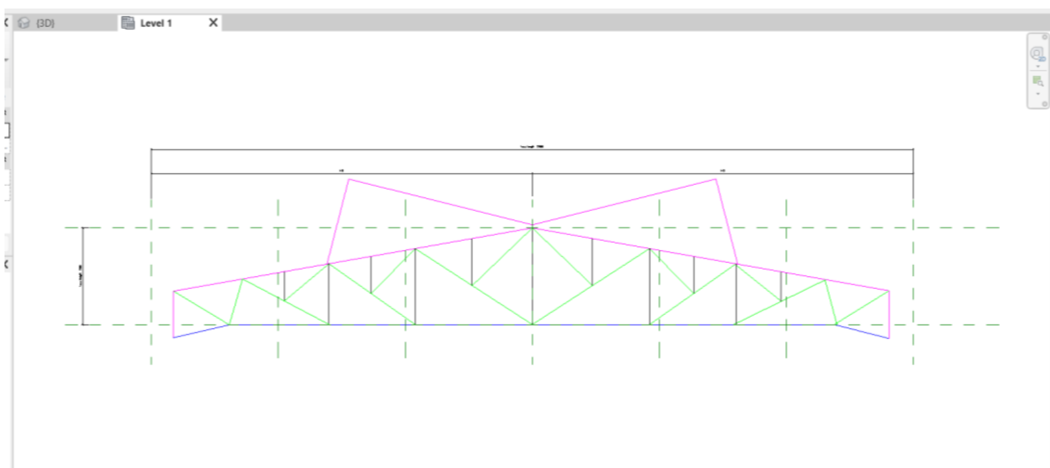

Figure 17: Creation of Truss family in Family Editor

The modelling of custom families can frequently be as difficult as the modelling of an entire building due to their complexity, time requirements, and highly parameterized elements. To decide how modelling will be done and to cut out pointless work, it is essential to understand for what purpose the family will be destined. In our project, the appropriate families were found, and it was determined which of their internal dimensions would require parameterization. This reduces modelling time by using the same truss family, for instance, in multiple scenarios.

We learned from some cases that not every problem has a universal solution. To create an ideal model, it is frequently necessary to break down the geometry to be modelled and use a variety of methods and tools. To ensure that the chosen decisions and methods are deliberate ones, it is important to take into account the non-uniformity of geometry and imperfection that exist in reality. To ensure that the model matches the building geometrically and aesthetically and satisfies the requirements, careful modelling must be done with attention to the building's details.

The modelling strategy used a macro-to-micro reconstruction of the building's geometry, giving priority to structural components like columns, beams, and roofs before creating supplementary components and other details. This practical and well-structured approach helps to concentrate decision-making and problem-solving efforts because there will only be one aspect of the building that will be the focus of attention. The model was developed to prevent clashes and disagreements between the construction elements.
Since only one person was responsible for modelling, conflicts could be avoided because they were completely under their control. The interaction of the columns, beams, and other components was meticulously done to ensure a perfect intersection and to accurately replicate the original building. However, there were times when there were conflicts, like between the trusses and the columns. This happened because it was impossible to distinguish these points, which reduced the accuracy of the survey of the building's congested points.

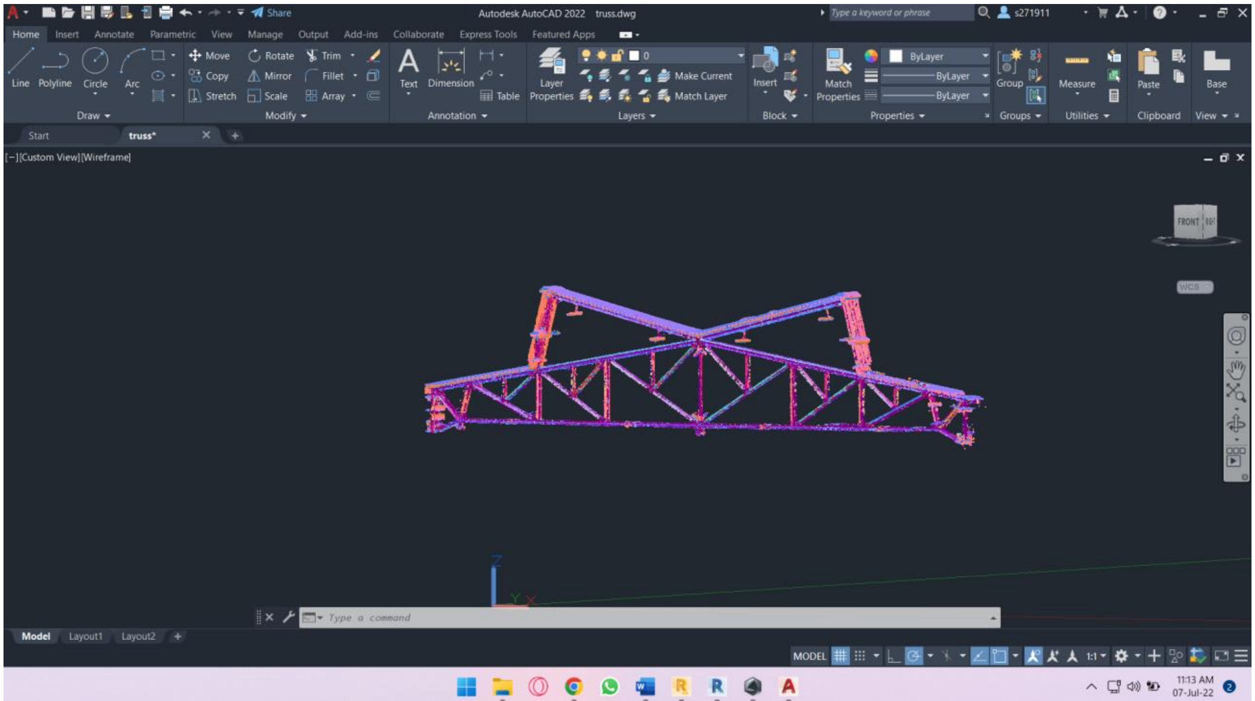

Figure 18: Creating families from a point cloud using AutoCAD

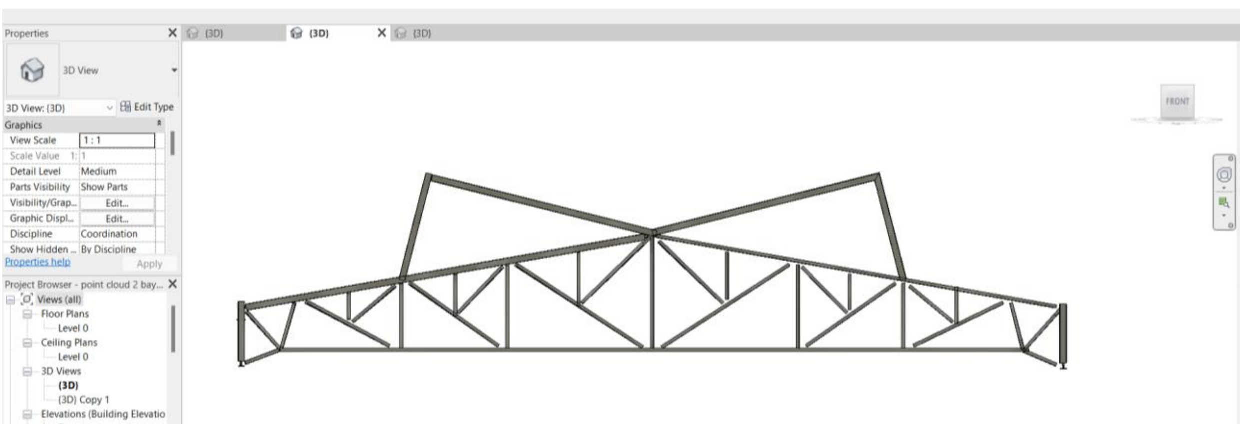

Figure 19: Truss Family

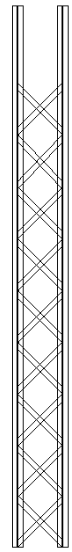

Figure 20: Column Family

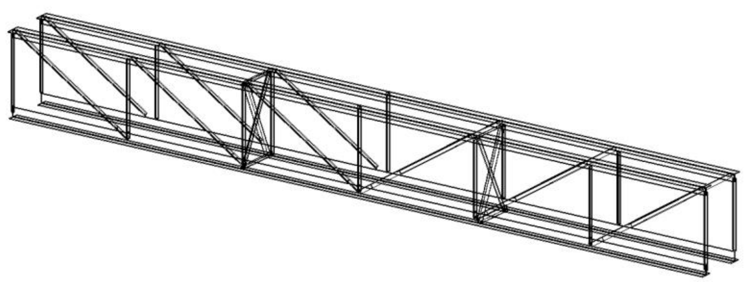

Figure 21: Beam Family

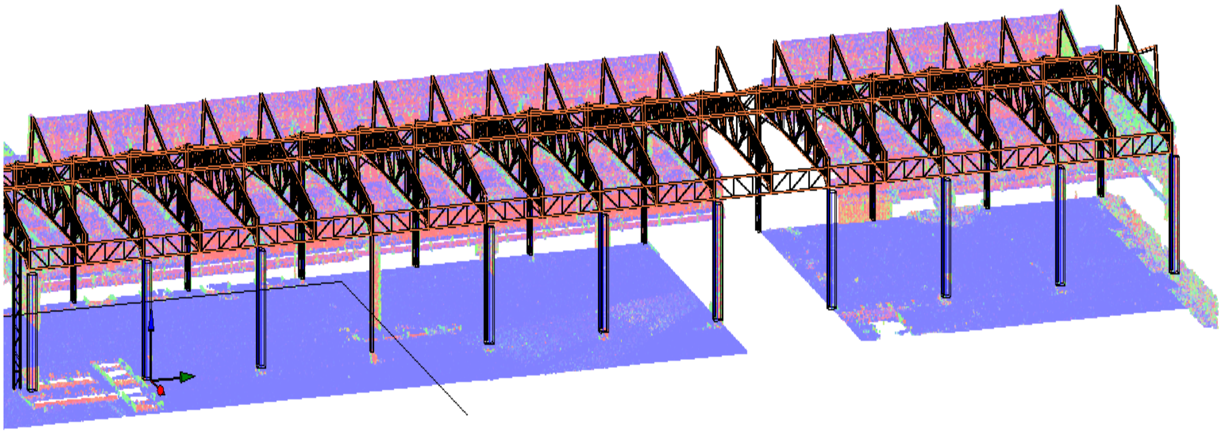

Figure 22: View of the Revit 3D model with point cloud

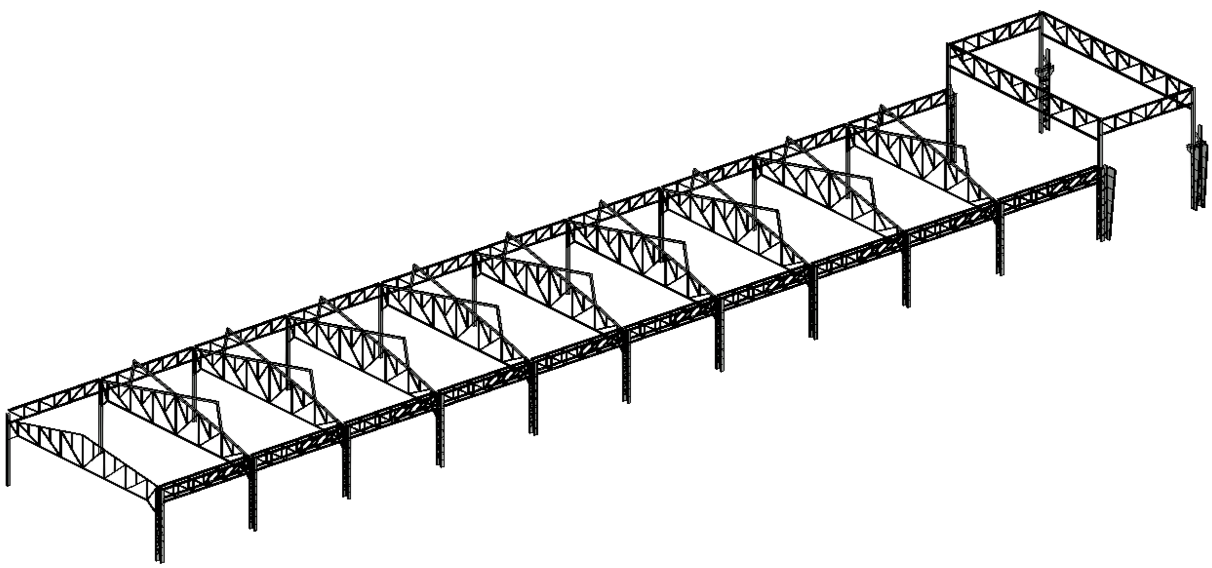

Figure 23: Final model in Revit

7.2 Automatic Modelling

This thesis examined techniques for automating the modelling process, essentially doing away with the manual method. Reverse engineering is currently in the most urgent need of this task. These automated solutions are extremely uncommon, not widely used, and have constrained functionality.

Complex construction components must be accurately modelled and timely examined. This objective is driving researchers to look for automated BIM data generation solutions. The number of publications on BIM automation has increased by about 400% over the past five years (229 papers from 2014 to 2019 and 57 papers from 2009 to 2013 were found on SCOPUS using the keywords BIM and Automation). However, there is a disconnect between researchers and industry practitioners, particularly regarding the standards governing the adoption of BIM in the construction sector. These primarily have an impact on how automation is implemented or integrated into actual non-modular contexts. The main obstacles to standardized automated solutions in BIM modelling continue to be complex forms and numerous morphological and typological variables. However, there is a good chance that improvements in processing power and a new understanding of graphics and computer vision will result in dependable standards in the near future.

Why is manual labor so bad? The issue has been resolved formally, so everything is well. A person might, however, fail to detect a very slight deviation when working with a huge object, even though it is beyond tolerance. Timing is the second issue. The third argument relates to the human element: deviations inevitably occur, and the employee will individually decide whether they adhere to the standards or not. They will also decide what to do with them. There is always a chance of making a mistake.

7.2.1 Python

Data visualization of the point cloud was the initial phase in the Python modelling process. The most effective way to convey and comprehend trends, outliers, and patterns in data is to create a graphical representation of the information using visual elements. Additionally, it is necessary for using 3D point cloud datasets that depict real-world shapes. However, point clouds are typically excessively dense when gathered via a laser scanner or 3D reconstruction methods like photogrammetry. Many times, the datasets will have many more points than 10 million, rendering them unusable for traditional visualization frameworks like Matplotlib. [31]

To accomplish the tasks of visualization and meshing, Open 3d was used. Open3D is an open-source library that supports the rapid development of software that deals with 3D data. The Open3D front end exposes a set of carefully selected data structures and algorithms in both C++ and Python. Open3D was developed from a clean slate with a small and carefully considered set of dependencies. It can be set up on different platforms and compiled from sources with minimal effort. Open3D has been used in several published research projects and is actively deployed in the cloud. [32]

Visualization using Open3d was done by setting up a virtual environment using "miniconda". This was done to test various versions of the packages easily by creating virtual environments. After that open3d (version 0.8.0.0) was installed along with the dependencies.

Before proceeding with the visualization, the point cloud was in X, Y, Z, and RGB format. It has to be changed into X, Y, Z, Red, Blue, and Green fields to be used in the script. The point cloud variable has a structure thanks to the LasPy library, and we can use simple methods to obtain, for instance, the X, Y, Z, Red, Blue, and Green fields. The following script was used to transform the data into the required format of the script given below.

```
from fileinput import filename
import re
file_name = "columnpts.pts"
f = open(file_name, "r")
data = f.read()
data = data.split('\n')
newdata = []
color = []
```

```
for index, item in enumerate(data):
    if index != 0 and index != len(data)-1 :
        rgb = re.findall(r'\d+$', item)[0]
        rgb = f' {rgb} {rgb} {rgb}'
        item = re.sub(r'\d+$', '', item)
        item = item.rstrip()
        item = item + rgb
    newdata.append(item)

f = open(file_name, "w")
f.write('\n'.join(newdata))
```

Next, we exported the .pts file format of the pointcloud from Autodesk ReCap which was then loaded into the script.
We first load the .pts file into a variable named pointcloud.

Our pointcloud has more points than the script can handle, so we can either segment it and/or minimize the number of points by down sampling our dataset.

To read and display pointcloud in python, the following script in Open3D was used.

```
import numpy as np
import open3d as o3d

pcd = o3d.io.read_point_cloud("columnpts.pts")
# o3d.visualization.draw_geometries([pcd])

downpcd = pcd.voxel_down_sample(voxel_size=0.0005)
# o3d.visualization.draw_geometries([downpcd])
downpcd.estimate_normals(search_param=o3d.geometry.KDTreeSearchParamHybrid(
        radius=0.05, max_nn=100))
o3d.visualization.draw_geometries([downpcd])
```

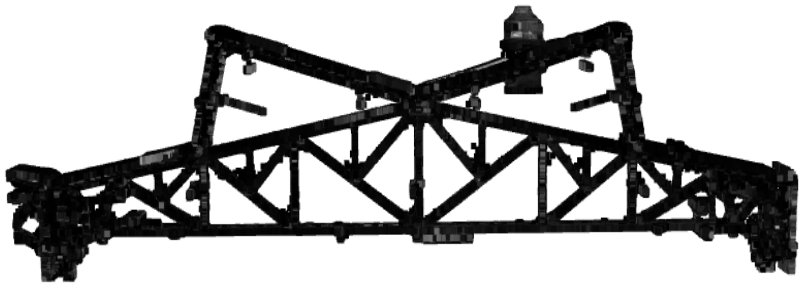

Figure 24: Visualisation of elements in python (Open3D)

The next step was creating a mesh from the point cloud with Python.
This process failed due to the absence of a parameter from the pointcloud called normals.
The Difference of Normals (DoN) provides a computationally efficient, multi-scale approach to processing large unorganized 3D point clouds. The idea is very simple in concept, and yet surprisingly effective in the segmentation of scenes with a wide variation of scale. For each point p in a pointcloud P, two-unit point normals $\hat{\mathbf{n}}(\mathbf{p}, r_l), \hat{\mathbf{n}}(\mathbf{p}, r_s)$ are estimated with different radii, $r_l > r_s$. The normalized (vector) difference of these point normals defines the operator.

The biggest problem with using Python for modelling is the inability to transfer the created mesh into a file format that can be used in any BIM software. The format that Python uses is a proprietary file format which means that it relies on specific software to read the data and it cannot be read without that software. There is no process to convert this into say a rvt format. Also, the research combining the field of laser scanning and python to recreate models is mostly done on topography and museum artefacts. There isn't any available source for using this technology for structural elements.

7.2.2 Plugins

There are numerous plugins available today that allow for the visualization, management, and elaboration of point clouds. There are numerous plugins for viewing and editing, including Undet, Pointfuse, Edgewise, DiRoots, and Pointcab. These plug-ins aid in pointcloud visualization and the manual modelling that follows. By choosing two to three points on the plane where these elements are present in the point cloud, some of these have the ability to automatically extract elements like walls, surfaces, and pipes. However, structural components like columns, beams, frames, bracings and trusses cannot be extracted by these plugins.

Table 2-1 – A comparison of prominent commercial automated geometry creation software. Leica software summary from referenced datasheet, Arithmetica, ImaginIT and ClearEdge 3D from software usage.

	Leica Cloudworx for Revit (Leica Geosystems, 2014)	**ImaginIT Scan-to-BIM**	**ClearEdge 3D Edgewise Building**	**Arithmetrica Pointfuse**
Automation (user input)	Semi-Automated pipe fitting only	Semi-Automated walls and pipes	Automated walls	Automated surfaces
Requires Revit?	Yes (but CAD versions exist)	Yes	Yes	No
Object-based parametric geometry produced?	Yes For pipes but really only acts as point cloud viewer for Cyclone data as a guide for modelling.	Yes As uses Revit family elements for fitted geometry.	Yes As elements detected in Edgewise are generated into Revit geometry in an RVT file export step.	No Produces 3D polygons/ surfaces that can be used as a guide for further modelling.

Figure 25: Comparison of Plugins of Revit

FARO

Additionally, the FARO As-Built Revit plugin was used. It is a creative and potent tool that converts pointcloud data completely and effectively into parametric BIM models. As-Built offers robust, sector-specific functionality for straightforward, accurate, seamless, and effective evaluation. It ensures that any reality-based data, like that from a laser scanner, will be processed in the simplest way possible. By drastically reducing the time for model extraction and minimizing the amount of construction rework, As-Built offers an easy-to-use, seamlessly integrated, and quick path to an as-built BIM model. Numerous 3D construction tools are available in the FARO As-Built for Autodesk Revit plug-in. Without using the Autodesk Revit work planes, we can use the application to create 3D model lines and construction points using real 3D point snaps in the point cloud. By interacting with model planes, they produce precise intersection lines, intersection points, and fitted work planes that are then directly generated in the point clouds.

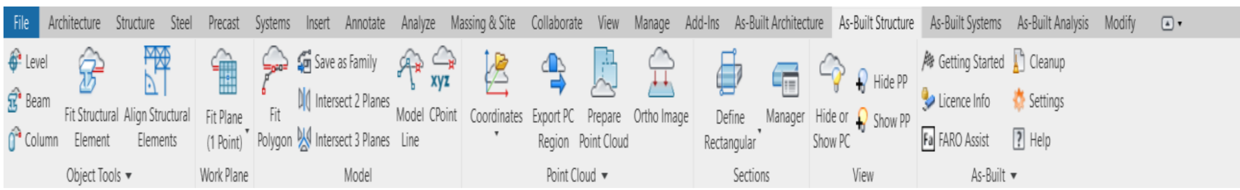

Figure 26: As-built Structure toolbar

It is a semi-automatic modelling tool; thus, some input is required for it to work. For instance, to generate a floor view, you only need to choose a single point, and it will automatically determine the horizontal plane by studying the planes of the pointcloud.

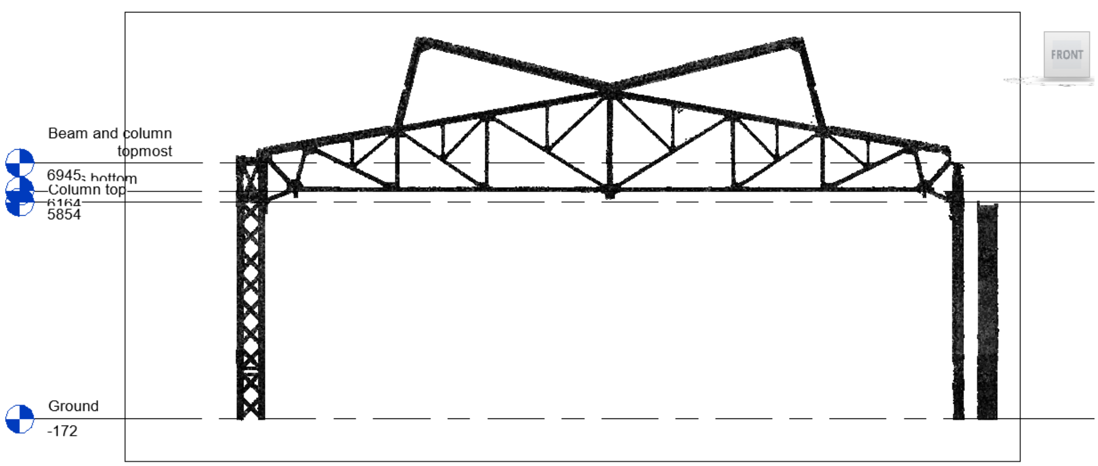

Figure 27: Elevation View of pointcloud by As-Built

Each component is made individually and separately, which means no families are created. The point cloud can be used to fit beams, columns, and framing. To automatically fit the element on the pointcloud, the plugin only needs two points on the necessary plane of the element.

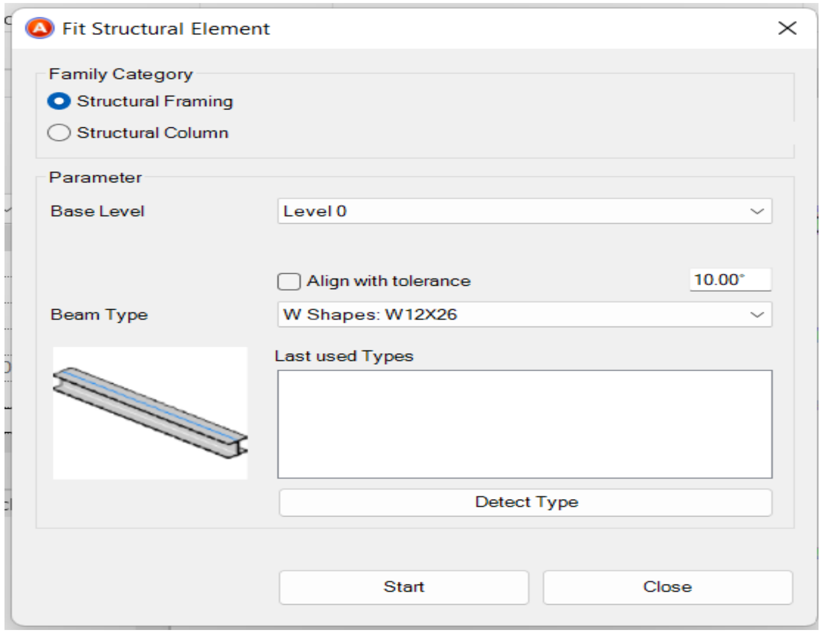

Figure 28: Fitting of the structural element

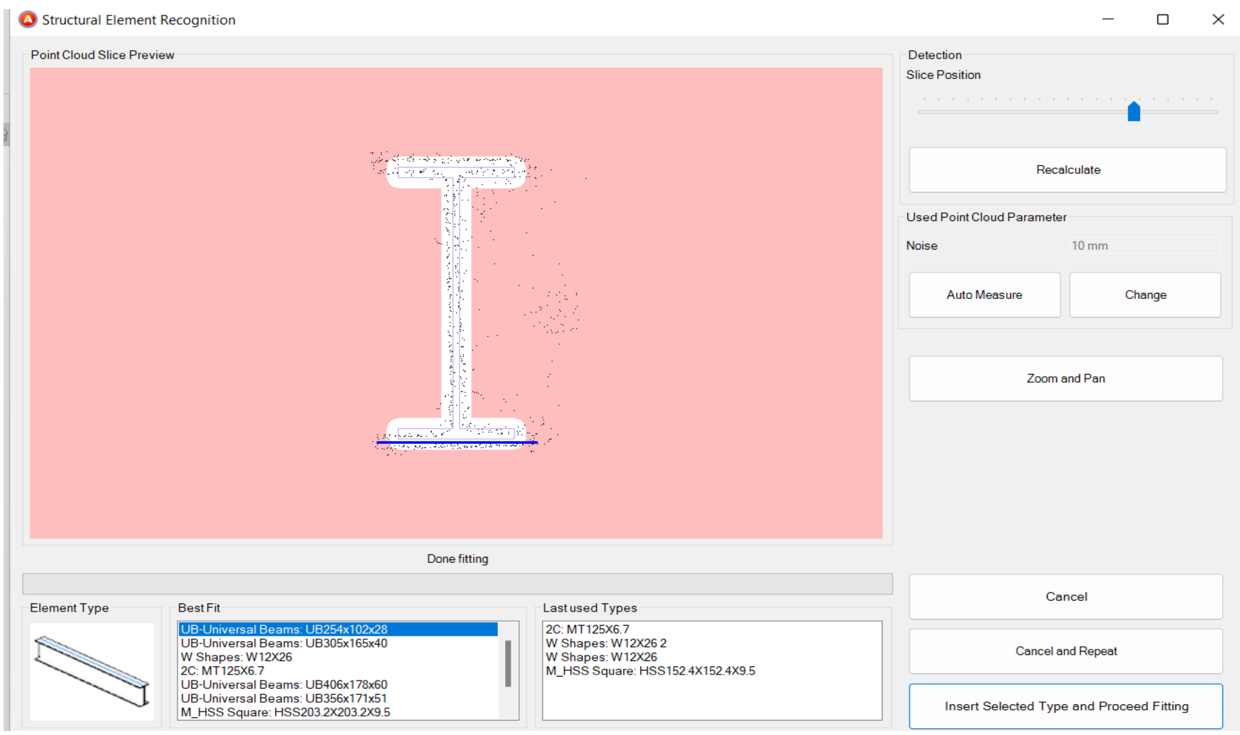

Figure 29: Structural Element Recognition

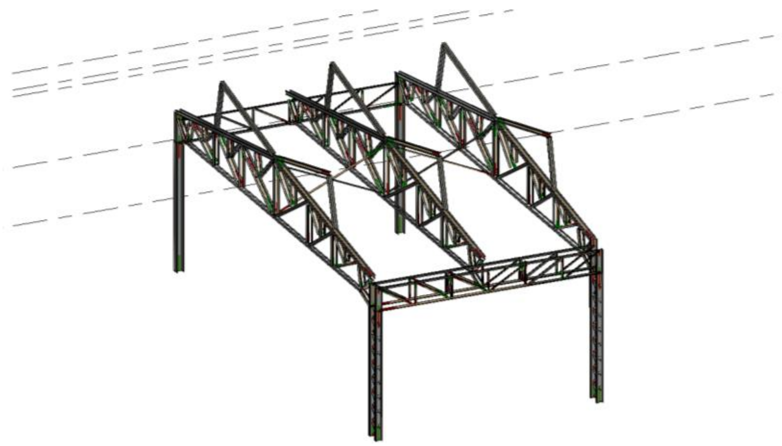

Figure 30: Segment of Model made with As-Built Plugin

One of the shortcomings of this plugin is its poor automatic element detection, and more research is required. The structural element recognition panel frequently incorrectly identifies them because of irregularities in the pointcloud. The elements are frequently detected at a rotation, and we then have to manually position the elements in the right places, which can be difficult in a complex environment. Knowing the type of element makes the process much faster and easier than manual modelling. As-Built modelling was completed in less than five hours because I was already familiar with all the components from manually building the model earlier.

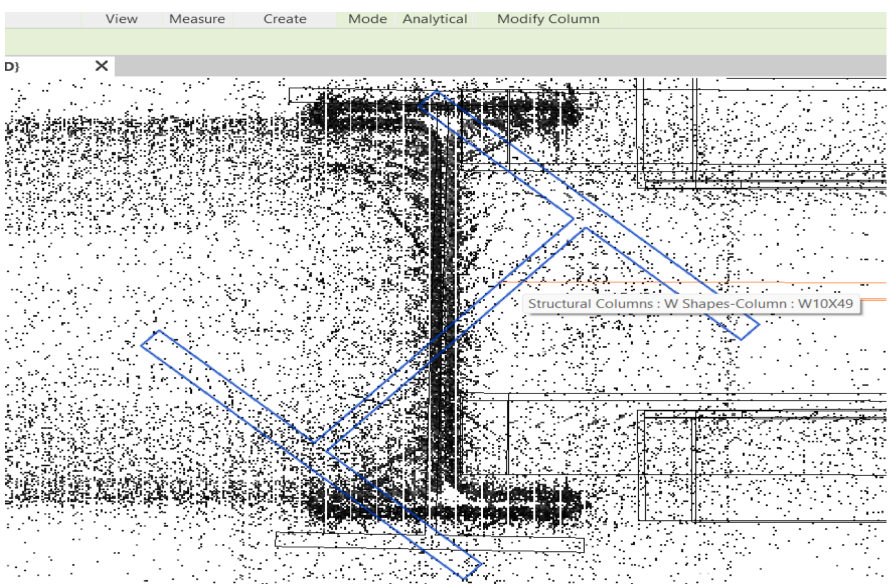

Figure 31: Problems with As-Built Revit

The connection of elements that are detected, which is not always possible after this automatic detection, is another drawback. When the analytical model is transferred into a FEM program, these gaps become apparent. As a result, it necessitates more modelling tasks in the FEM software.

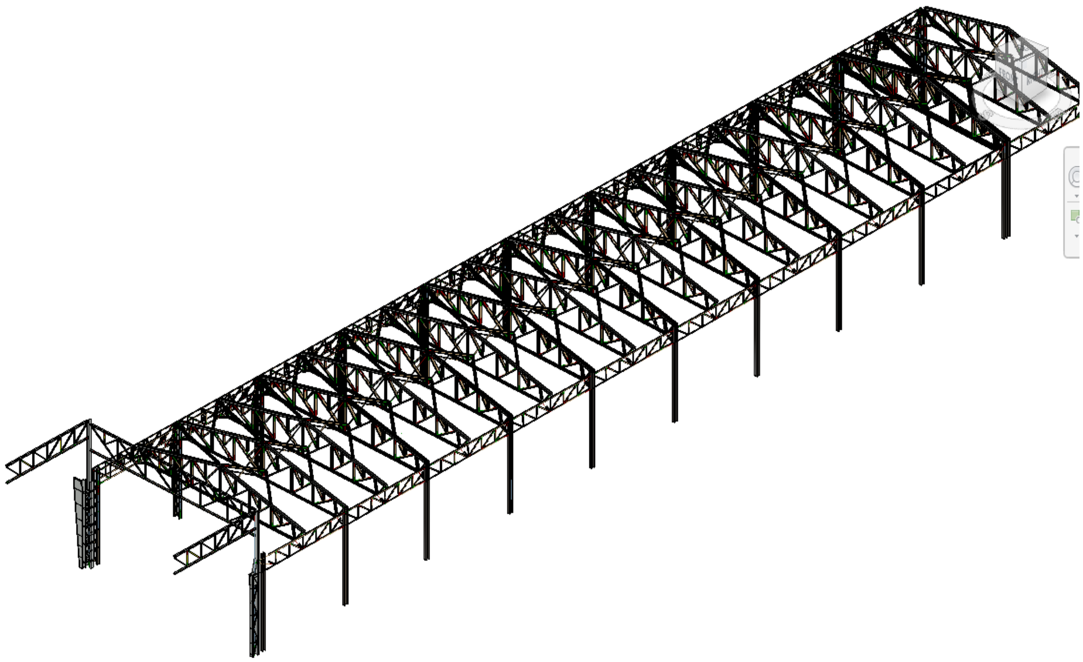

Figure 32: Final Model created by FARO as-Built plugin

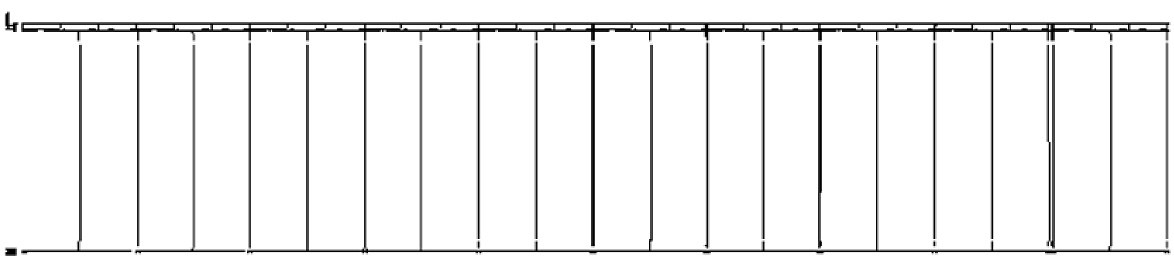

Figure 33: Top View of Model

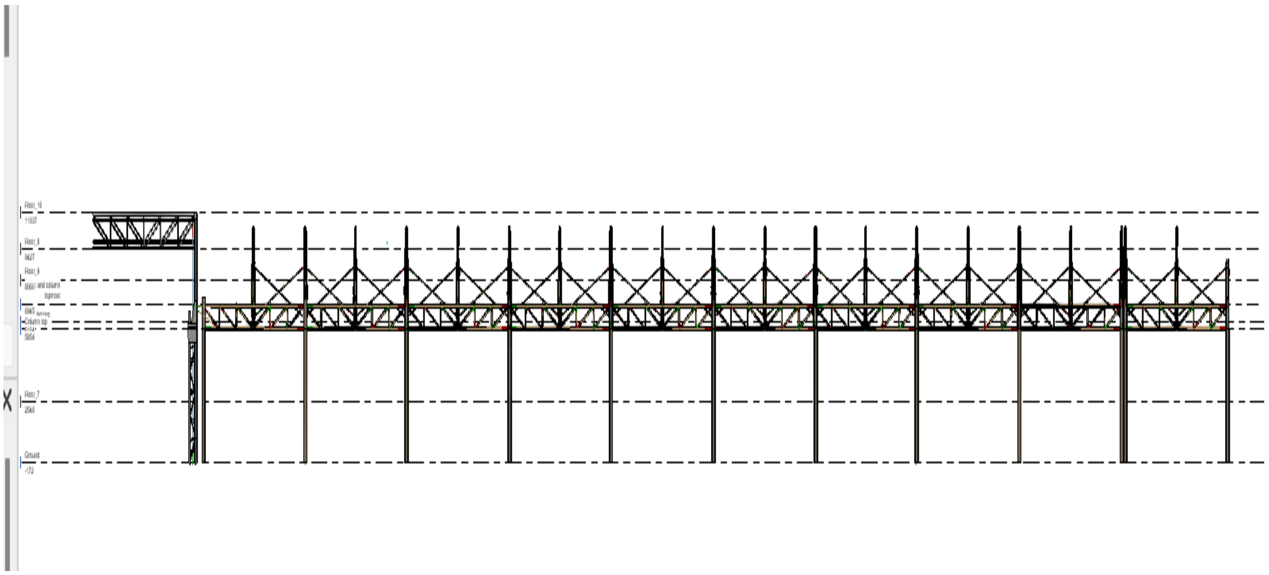

Figure 34: Elevation View of the model

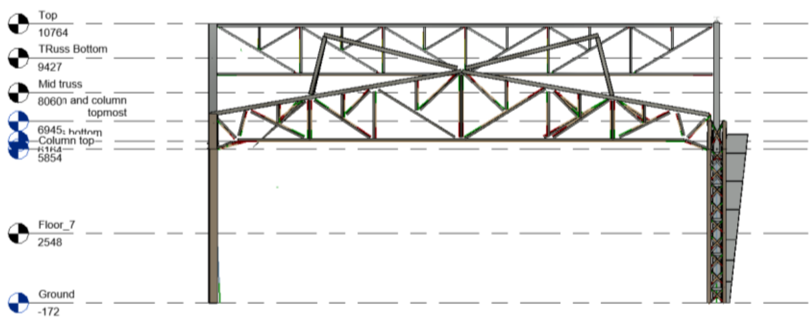

Figure 35: Section view of the model

8. Interoperability Check

The finished BIM model was then sent to various FEM programs to be tested for interoperability. To be used in programs like SAP 2000 and ETABS Ultimate 20, which are not a part of the Autodesk family and have no direct connection to Revit, the model was exported in an IFC format. There is a direct integration between the Revit and Robot softwares for the interoperability test with Autodesk Robot Structural Analysis Professional 2023, and it is also possible to use the smxx and IFC formats. The transfer of data was much better in the same family of software AutoCAD Robot Structural Analysis than SAP 2000 and ETABS ultimate 20 which belong to CSI, Computers and Structures, Inc. as can be seen from the below figures.
There were many missing elements and connections between the elements.

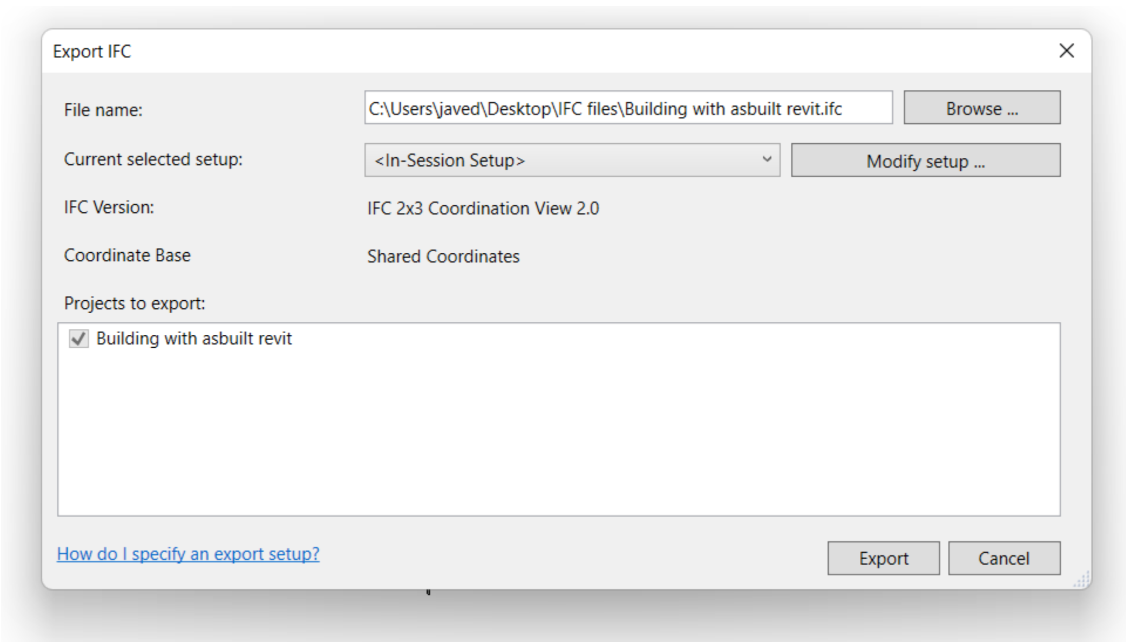

Figure 36: IFC export in Revit

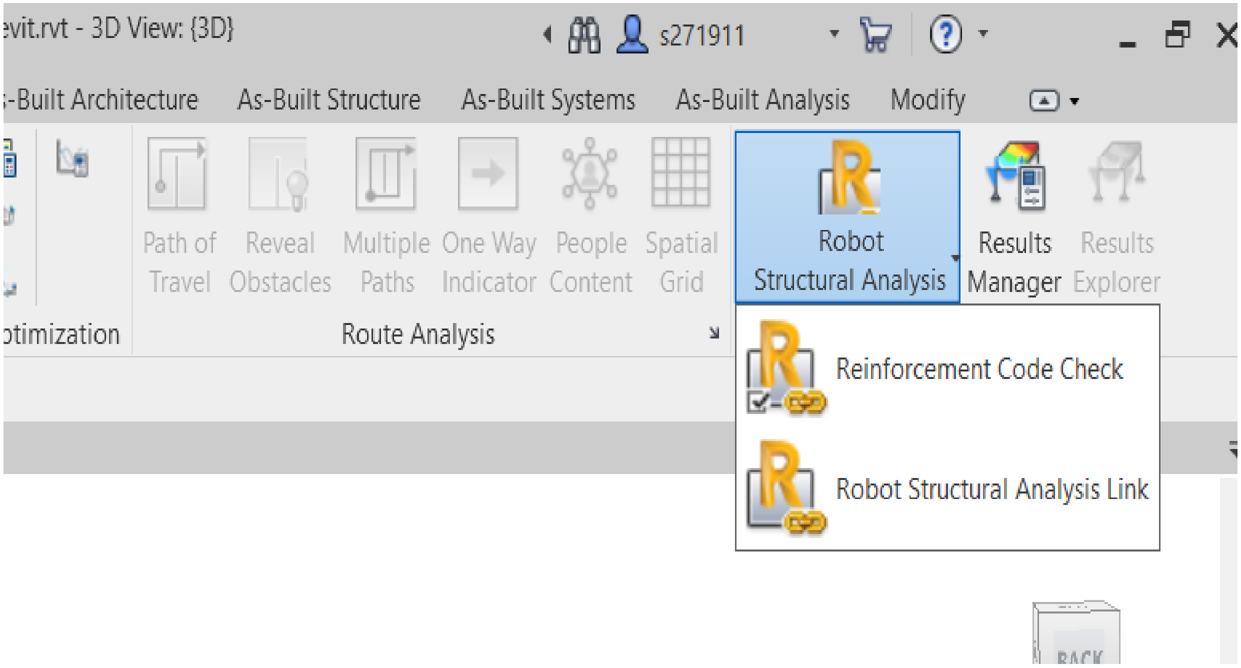

Figure 37: Robot structural analysis link in Revit

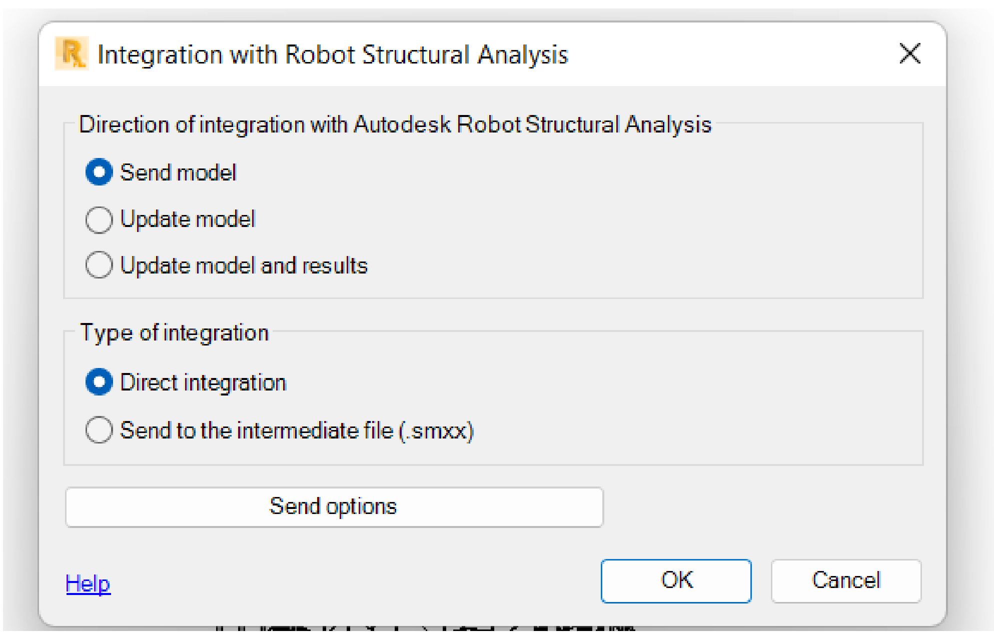

Figure 38: Integration of model in Revit with Robot Structural Analysis

The column and beam elements that had a complex truss structure, that was created as families in Revit during manual modelling were not automatically detected in ROBOT. This creates a problem in the model as the complex beam or column with bracings was reduced to a single axis and was disjoined from the connecting elements. This can be solved by inserting an equivalent element instead of the complex element or additional modelling in FEM software which can be a tedious task in the absence of a pointcloud as a reference in FEM software.

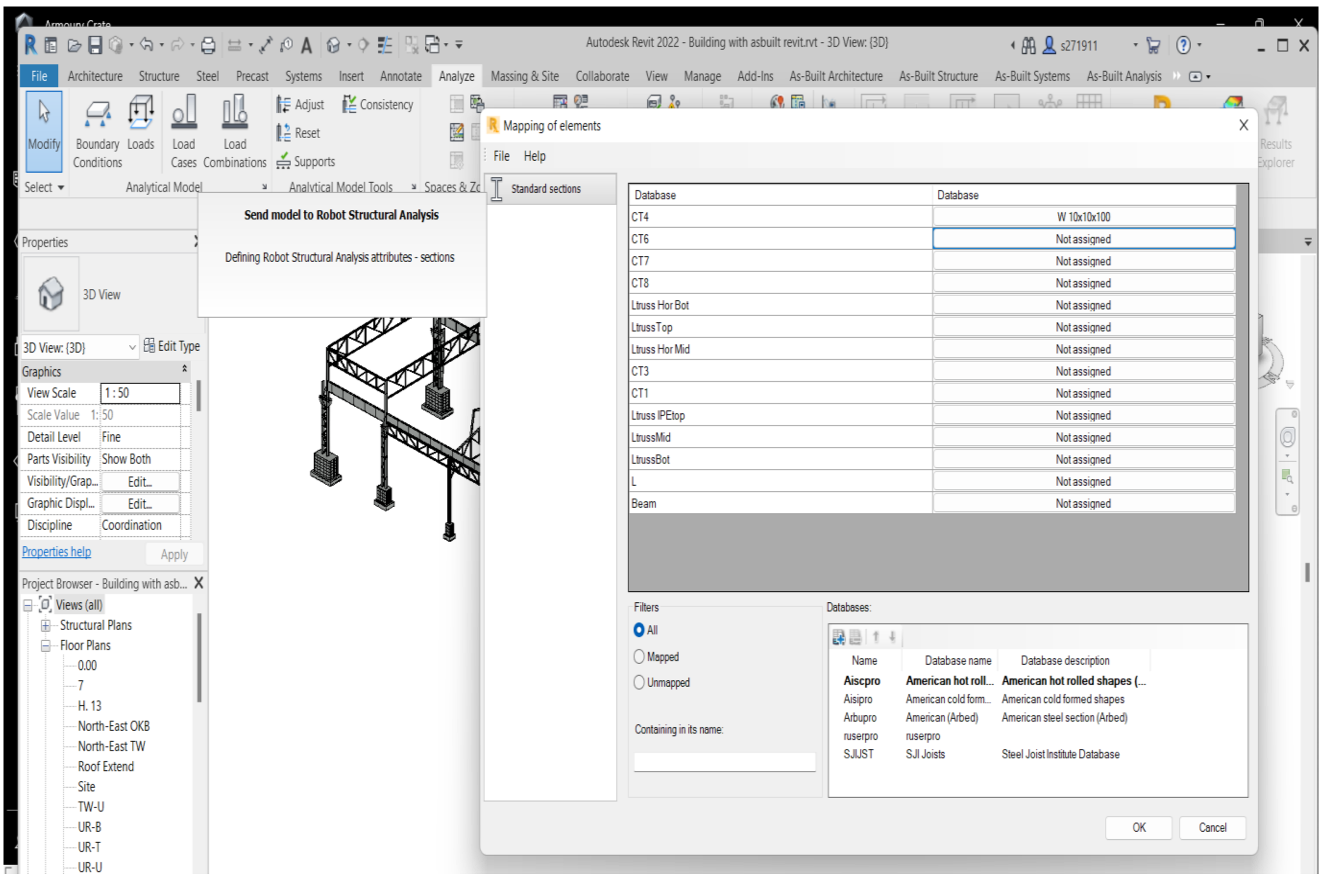

Figure 39: Mapping of Unassigned elements in Robot Structural Analysis

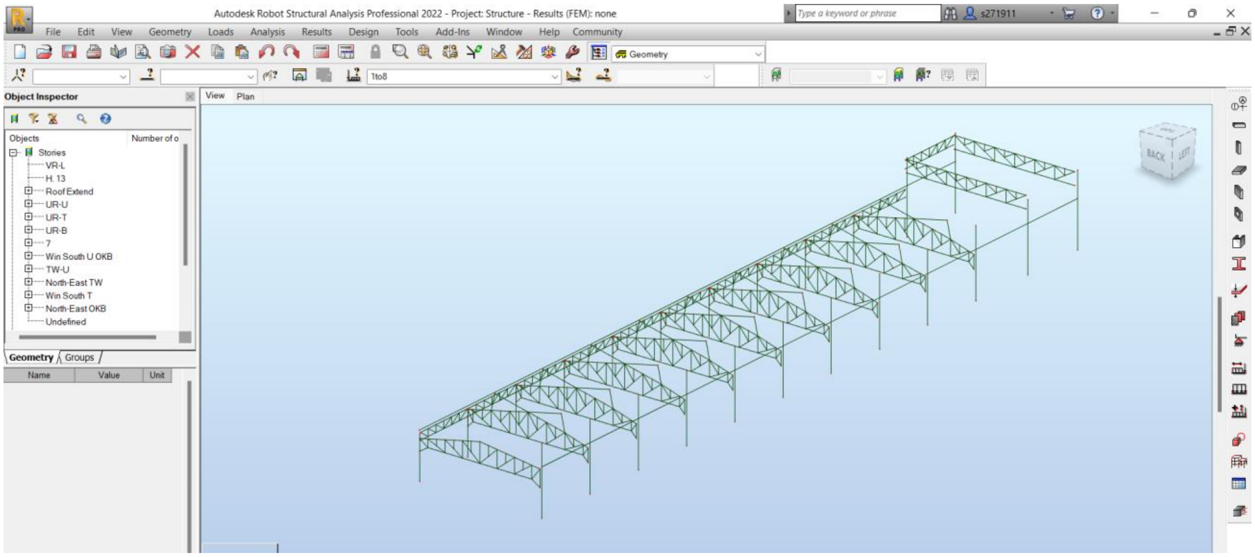

Figure 40: Model in Robot Structural Analysis Professional 2023

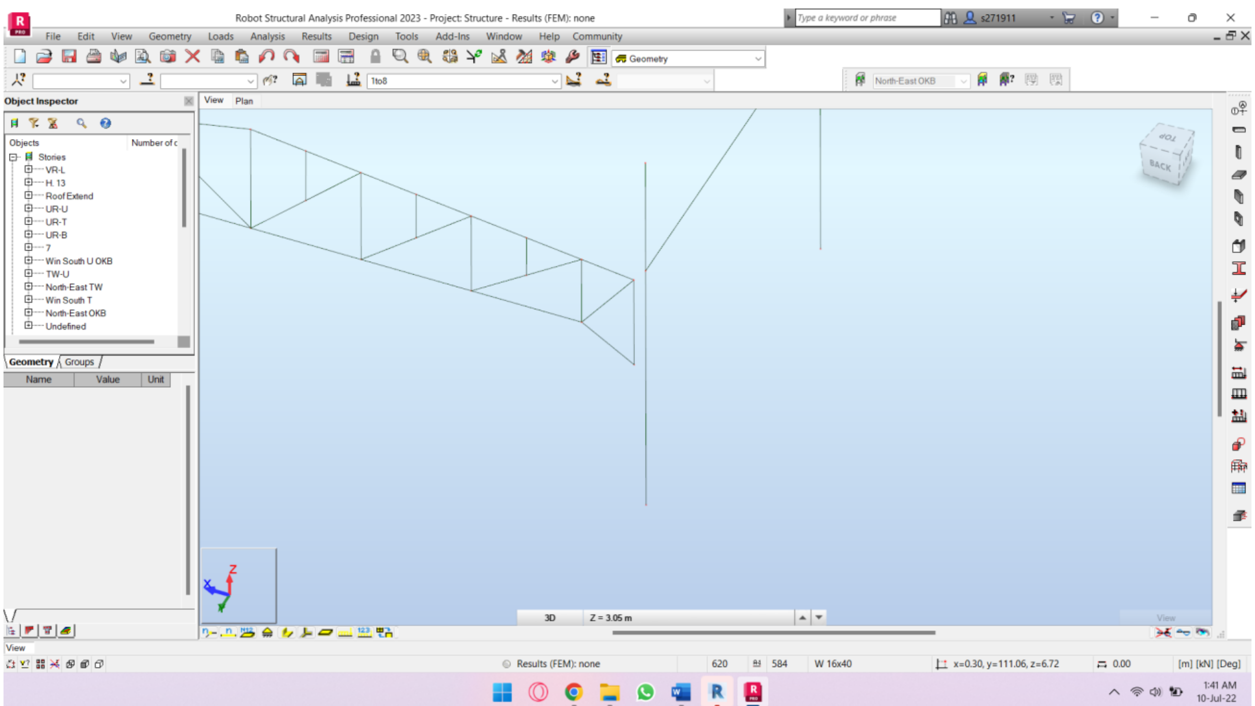

Figure 41: Complex column reduced to a single axis

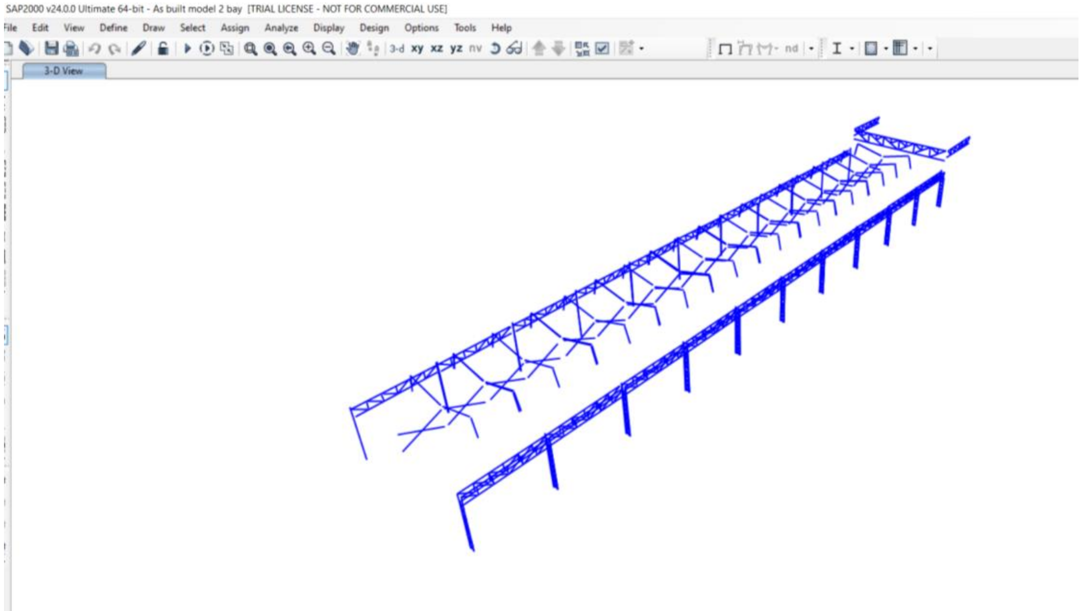

Figure 42: Model transferred to SAP 2000

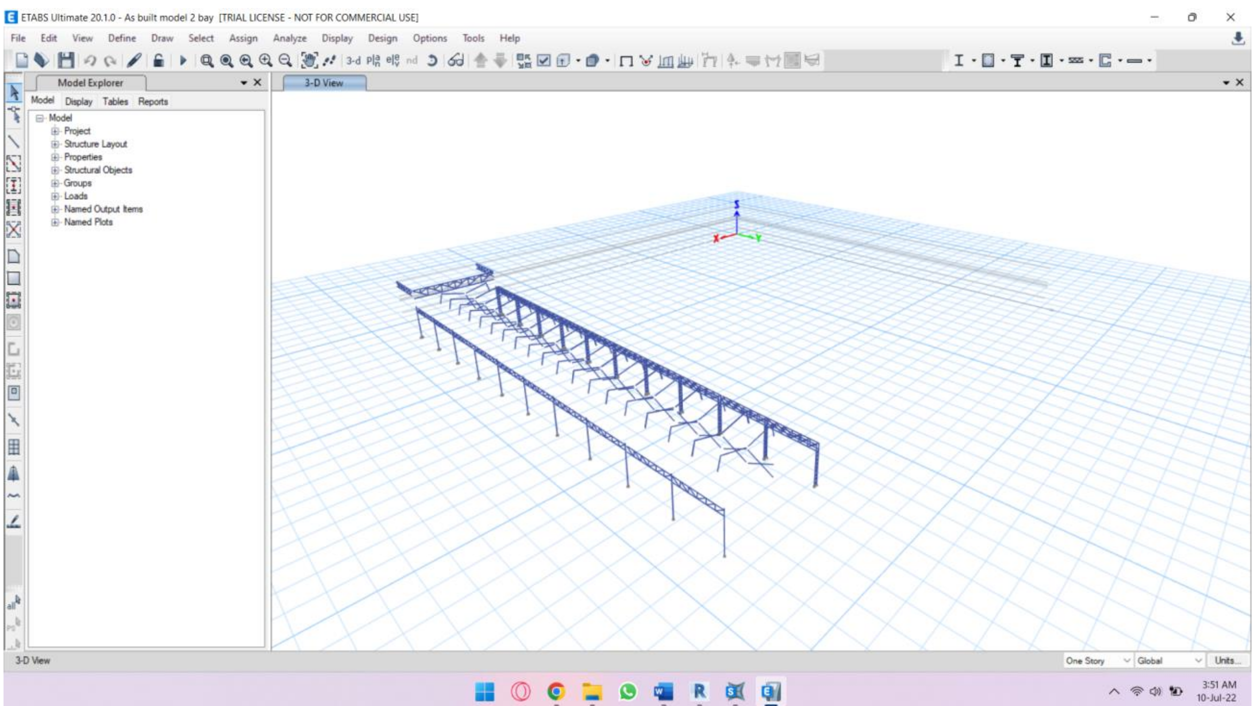

Figure 43: Model transferred to ETABS

9. Results and Discussion

At the conclusion of the modelling process, a BIM model with high accuracy and precision and a level of detail between LOD 300 and 350 was obtained, in accordance with the document G202—2013—Project Building Information Modeling Protocol Form from AIA. This allowed it to be integrated with a restoration work methodology and benefit from the advantages that BIM brings to these projects. In LOD 300, the elements are precisely defined by their relative positions and exact dimensions. The information about each element is precisely described in LOD 350, along with the relationship and connections between each element and other components. The full set of plans, including the floor plans, sections, and elevations, were generated in addition to the BIM model. When dealing with buildings, the scan-to-BIM process proves to be incredibly effective because it not only reduces the amount of time spent on the survey in the field but also on the office side of things by using BIM software to create the necessary technical drawings and three-dimensional reconstruction of the structure. Developing a BIM model that is ready to have its level of detail increased, if necessary, in the future, was the proposed workflow. When modelled in greater detail, some of the elements reached the LOD 350 (Columns and Beams), while others stayed at the LOD 300. (Trusses). Aside from the geometric reconstruction of the building, the final model includes all the elements categorized according to their use, with their actual geometry and, whenever possible, structural and support elements. The BIM model is not static, the LOD of the BIM model can be increased at any time by updating both geometric and non-geometric data (such as physical and material performance characteristics, costs, compositions, etc.).

Once this methodology has been established and put into practice, it is then possible to explore other particular aspects of the procedure, like the modelling optimization of other building components. Additionally, when using multidisciplinary teams to broadly apply the BIM methodology within projects, there is a significant expansion potential. the development of machine learning, in particular. Scan-to-BIM is still primarily a manual process that requires a lot of user time and effort. Due to the enormous amount of data that needs to be managed, the difficulties and challenges of reconstructing occluded portions of buildings, and the absence of semantic information in point clouds, the manual approach is required. The automation of modelling optimization has been a persistent research area with little advancement to date. The variety of building typologies and the demand for a general strategy that works for all of them present a challenge. Another is the ambiguity and mistakes in the data that was gathered. Walls are the most straightforward objects to automate experiments on because they have the fewest parameters and the least amount of shape variation but I t is also very important to consider methods for the automatic generation of structural geometries that are more complex because doing so manually can be time-consuming in all these circumstances. The plugins of Revit that make the modelling process semiautomatic still has a long way to go in their functionality to be a staple software for use. They also need to be made more accessible to the public.

While many promising techniques have been created, the survey of representations and algorithms suitable for automated as-built BIM creation reveals that there is comparatively little research specifically addressing the issue in an AEC context. It is unclear how effective such methods would apply to the more general problem of modelling a full facility because the systems that have been proven frequently concentrate on special purpose circumstances, such as simulating kitchens or building façades. It is equally challenging to predict how other potential approaches will perform when confronted with more complex and realistic data sets because they have only been evaluated on a small number of relatively simple samples.

We noticed and discussed several technological shortcomings in automated as-built BIM production capabilities from Python and plugins. The areas where this subject needs more research are highlighted by these gaps. The primary concerns are 1) modelling more complex structures than simple planes; 2) handling realistic environments; 3) representing models using volumetric primitives instead of surface representations; 4) developing methods that are easily extensible to new environments; 5) creating reference test beds that span the use cases for as-built BIMS; 6) representing nonideal geometries that occur in real facilities, and 7) developing quantitative methods for tracking the progress of the field.

Although the strategies outlined in this thesis hold promise for automated as-built BIM production, there is still a long way to go before automated as-built BIM construction can be regarded as a problem that has been solved. As these technological gaps are filled, automated as-built BIM creation algorithms will move into commercial solutions, where professionals in the AEC sector can benefit from the benefits of automation.

10. Conclusion

The BIM technique makes it possible to access design data that the CAD system would not permit, such as a complete 3D model of the entire building with embedded data and features that can be converted into data formats and used for analysis in subsequent steps. The model can be rebuilt more rapidly and effectively by employing a methodological approach to modelling that is organized and practical. To guarantee accurate models and workable answers to difficult challenges, the software's tools must be proficient. Building integration inside a workflow and the ability to make use of all the advantages that BIM offers are made feasible by the production of a BIM model using scan-to-BIM methods.

It takes a high level of software expertise, as well as knowledge of architectural and building methods, to convert the point cloud to a BIM model. Due to their extensive understanding of these subjects, architects, engineers, and construction professionals can produce models that are consistent and have the necessary level of detail. This is even more crucial when it comes to models that will incorporate BIM methodologies, as a 3D model that does not adhere to BIM's requirements could imperil the entire procedure, even if it was created using BIM software.

In this study, a fundamental modelling method that is primarily manual is shown. The 3D reconstruction was done by plugins using semi-automatic procedures. There are various types of elements in a BIM model, and there is a distinct approach to interacting with each of them. Future research should examine several automatic and semi-automatic approaches for streamlining modelling, as well as how to include other software and plugins into the BIM process and determine which elements may be solved in which ways. It is also intriguing to research and evaluate new modelling techniques used on buildings from various eras and typologies. To meet the modelling requirements of industrial structures, it is also crucial to further research parametric family creation studies, particularly for more complex beams, columns, and trusses. The method will benefit from the use of parametric families that can swiftly adjust to real circumstances.

References

[1] A. KALIAKOUDA, “Workflow from point cloud to BIM,” KTH ROYAL INSTITUTE OF TECHNOLOGY, STOCKHOLM, SWEDEN, 2021.

[2] Hichri, N. & Stefani, Chiara & Luca, Livio & Véron, Philippe & Hamon, Gael, “From point cloud to BIM: a survey of existing approaches,” ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XL-5/W2. 343-348. 10.5194/isprsarchives-XL-5-W2-343-2013.), 2013.

[3] Rocha, G.; Mateus, L.; Fernández, J.; Ferreira, V, “A Scan-to-BIM Methodology Applied to Heritage Buildings,” 2020.

[4] A. Borrmann, K. Markus, C. Koch and J. Beetz,, “Building Information Modeling», Technology Foundations and Industry Practice,,” Springer, ISBN 978-3-319-92862-3, DOI: 10.1007/978-3-319-92862-3, 2018., 2018.

[5] C. Eastman, P. Teicholz, R. Sacks and K. Liston,, BIM Handbook, A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, 2018: John Wiley & Sons, Hoboken, New Jersey, 2008.

[6] N. Ioannides, “‘Geomatics and New Technologies for Geospatial Sciences: Case Study of the Marko Winery’,,” MSc Thesis at University of West Attica, Athens, 2019.

[7] “Software Connect, ‘Building Information Modelling Software/ Autodesk BIM 360’.,” [Online]. Available: https://softwareconnect.com/bim/bim-360/.

[8] Wikipedia, “https://en.wikipedia.org/wiki/Autodesk_Revit,” [Online].

[9] Wikipedia, “ArchiCAD,” [Online]. Available: https://en.wikipedia.org/wiki/ArchiCAD.

[10] “Trimble RealWorks User Guide,,” December 2019. [Online].

[11] Barbosa, M.; Pauwels, P.; Ferreira, V.; Mateus, L., “Towards increased BIM usage for existing building interventions.,” Struct. Surv. 2016, 34, 168–190., 2016.

[12] Brumana, R.; Condoleo, P.; Grimoldi, A.; Banfi, F.; Angelo Giuseppe, L.; Previtali, M., “LOD based HBIM to detect influences on geometry and shape by stereotomic construction techniques of brick vaults.,” Appl. Geomat. 2018, 10, 529–543, 2018.

[13] Mateus, L.; Fernández, J.; Ferreira, V.; Oliveira, C.; Aguiar, J.; Gago, A.S.; Pacheco, P.; Pernão, J., “GRAPHICAL DATA FLOW BASED in TLS and PHOTOGRAMMETRY for CONSOLIDATION STUDIES of HISTORICAL SITES. the CASE STUDY of JUROMENHA FORTRESS in Portugal,” Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. ISPRS Arch. 2019, 42, 767–773., 2019.

[14] Mateus, L.; Ferreira, V.; Aguiar, J.; Dias, A., “Terrestrial Laser Scanning and Digital Photogrammetry as Tools for the Archaeological Recording—The Case of Convento de Cristo,” In Proceedings of the First International Conference on Best Practices in World Heritage, Menorca, Spain, 9–13 April 2012; pp. 400–412., 2012.

[15] Waldhäusl, P.; Ogleby, C., “3 × 3-Rules for Simple Photogrammetric Documentation of Architecture.,” Int. Arch. Photogramm. Remote Sens. 1994, 30, 426–429., 1994.

[16] Vosselman, G.; Maas, H, “Airborne and Terrestrial Laser Scanning,,” 1st ed.; Whittles Publishing: Dunbeath, UK, 2010; ISBN 9781904445876., 2010.

[17] A. Baik, “From point cloud to Jeddah Heritage BIM Nasif Historical House—Case study,” Digit. Appl. Archaeol. Cult. Herit. 2017, 4, 1–18., 2017.

[18] Macher, H.; Landes, T.; Grussenmeyer, P., "From Point Clouds to Building Information Models: 3D Semi-Automatic Reconstruction of Indoors of Existing Buildings," Appl. Sci. 2017, 7, 1030., 2017.

[19] Ochmann, S.; Vock, R.; Wessel, R.; Klein, R., "Automatic reconstruction of parametric building models from indoor point clouds.," Comput. Graph. 2016, 54, 94–103, 2016.

[20] Fryskowska, A.; Stachelek, J., "A no-reference method of geometric content quality analysis of 3D models generated from laser scanning point clouds for hBIM," J. Cult. Herit. 2018, 34, 95–108, 2018.

[21] Rodríguez-Moreno, C.; Reinoso-Gordo, J.F.; Rivas-López, E.; Gómez-Blanco, A.; Ariza-López, F.J.; Ariza-López, I., "From point cloud to BIM: An integrated workflow for documentation, research and modelling of architectural heritage," Surv. Rev. 2016, 50, 212–231, 2016.

[22] López, F.J.; Lerones, P.M.; Llamas, J.; Gómez-García-Bermejo, J.; Zalama, E, "A Framework for Using Point Cloud Data of Heritage Buildings Toward Geometry Modeling in A BIM Context: A Case Study on Santa Maria La Real De Mave Church.," Int. J. Archit. Herit. 2017, 11, 965–986., 2017.

[23] Tang, P.; Huber, D.; Akinci, B.; Lipman, R.; Lytle, A, "Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques.," Automat. Constr. 2010, 19, 829–843, 2010.

[24] M. Rajala and H. Penttilä, "Testing 3D Building Modelling Framework in Building Renovation.," In Proceedings of the 24th eCAADe Conference, Volos, Greece, 6–9 September 2006; pp. 268–275, 2006.

[25] Xiong, X.; Adan, A.; Akinci, B.; Huber, D, "Automatic creation of semantically rich 3D building models from laser scanner data.," Automat. Constr. 2013, 31, 325–337.), 2013.

[26] Hélène Macher, Tania Landes, Pierre Grussenmeyer, "From Point Clouds to Building Information Models: 3D Semi-Automatic Reconstruction of Indoors of Existing Buildings.," Applied Sciences, MDPI, 2017, 7 (10), pp.1030. 10.3390/app7101030. hal-02320638, 2017.

[27] "NIBS, The National Institute of Building Sciences," 2008. [Online]. Available: http://www.nibs.org/index.html.

[28] "INTEROPERABILITY MATTER: LEVELS OF DATA SHARING, STARTING FROM A 3D," [Online]. Available: https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XLII-2-W3/623/2017/isprs-archives-XLII-2-W3-623-2017.pdf.

[29] C. Thomson, "From Point Cloud to Building Information Model: Capturing and Processing Survey Data Towards Automation for High-Quality 3D Models to Aid a BIM Process," 2016.

[30] "Building Information Modeling (BIM) for existing buildings — Literature review and future needs," [Online]. Available: https://www.researchgate.net/publication/259518042_Building_Information_Modeling_BIM_for_existing_buildings_-_Literature_review_and_future_needs_Autom_Constr_38_March_2014_109-127.

[31] F. Poux, "Guide to real-time visualization of massive 3D point clouds in Python," [Online]. Available: https://towardsdatascience.com/guide-to-real-time-visualisation-of-massive-3d-point-clouds-in-python-ea6f00241ee0.

[32] Qian-Yi Zhou, Jaesik Park, Vladlen Koltun, "{Open3D}: {A} Modern Library for {3D} Data Processing," arXiv:1801.09847, 2018.

[33] B. Becerik-Gerber, F. Jazizadeh, N. Li and G. Calis, "Application areas and data requirements for BIM -Enabled Facilities Management," 2012.

[34] K. Shahrukh, "Applicability of the BIM methodology in Construction Management for "PROMENADE" (Steel bridge with photovoltaic roof)".