Tampere University of Applied Sciences

The Utilisation of Aerial Photography and Laser Scanning in BIM Modelling

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MASTER'S THESIS
May 2020

Construction Engineering

ABSTRACT

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Construction Engineering

MERCKX, RUBEN:
The utilisation of aerial photography and laser scanning in BIM modelling

Master's thesis 56 pages, appendices 7 pages
May 2020

The use of BIM model in the designing process of new buildings has been growing significantly. The reasons for this growth can be found in the increased productivity and improved information sharing. The model can be used to create all plans, sections and elevations necessary on the construction site without the need of drawing them all independently.

To use the benefits of BIM modelling in projects containing existing buildings, the existing building has to be modelled. This is done by using scan-to-BIM, which uses point clouds. These point clouds can be created using 3D-laser scanning and/or aerial photography. Laser scanning is the best way to document the indoor environment of a building. Documenting the outdoor environment of a building using laser scanning can pose its challenges, especially for the roof. Using aerial photography is a solution, this uses close range-photogrammetry where photos can be used to construct a 3D model when objects are visible in multiple photos. Combining both point clouds to a single point cloud is possible by georeferencing both clouds, using the coordinates of the targets from the scanning and the ground control points of the aerial photography.

Working in a point cloud has limited possibilities so converting the point cloud to a BIM model opens up these possibilities. The geometry inside the model is clearer and information can be added. This is done by using BIM software such as Autodesk Revit and modelling walls, doors and windows where the scans show them. This manual process is time-consuming and can be facilitated by using a special point cloud to BIM conversion software, which helps with the placement of walls and detects wall thickness.

In order to test this kind of software, a model was made of an old train station in Tampere which will be moved in the summer of 2020. The building was scanned and aerial photographs were available. These scans and aerial photographs were used to make a single point cloud, which was then used to model the building in Revit using the Faro As-Built software as a tool.

Key words: 3D laser scanning, UAV, building information modelling, point cloud

CONTENTS

GLOSSARY or ABBREVIATIONS AND TERMS (choose one or other)

3D laser scanning	Three-dimensional distance measuring using laser
BIM	Building Information Modelling
BVLOS	Beyond Visual Line Of Sight
GCP	Ground Control Point
GPS	Global Positioning System
LIDAR	Light Detection And Ranging
MLESAC	Maximum Likelihood Estimation Sample
Point cloud	Set of points in space
UAV	Unmanned Aerial Vehicle
VLOS	Visual Line Of Sight

1 INTRODUCTION

1.1 What is BIM?

To define the definition of Building Information Modelling (BIM), one should define the terms it is comprised of: Building refers to any manmade construction project, including building but also other infrastructures such as bridges. Information refers to all possible data about the project, ranging from the traditional plans to information about the materials used and cost. Model is used in the meaning of representation (how the information is viewed). (Epstein, 2012, p. 5) From the model, the usual plans, sections, elevations and perspectives can be extracted. These plans are automatically updated after making changes in the model. This method is less prone to error than changing all plans by hand and the use of clash detection between multiple disciplines minimises problems during the construction phase. Clashes where for example utility pipes are on the same place as load bearing beams are now easier detected earlier in the design phase when these problems are easier and cheaper to solve. (Epstein, 2012, p. 8)

Because a BIM model is made in three dimensions, it helps with the visualisation of the project for all stakeholders. All stakeholders can store their information in the BIM model or database, making it a perfect tool when information is needed by another stakeholder later in the projects lifecycle (see figure 1).

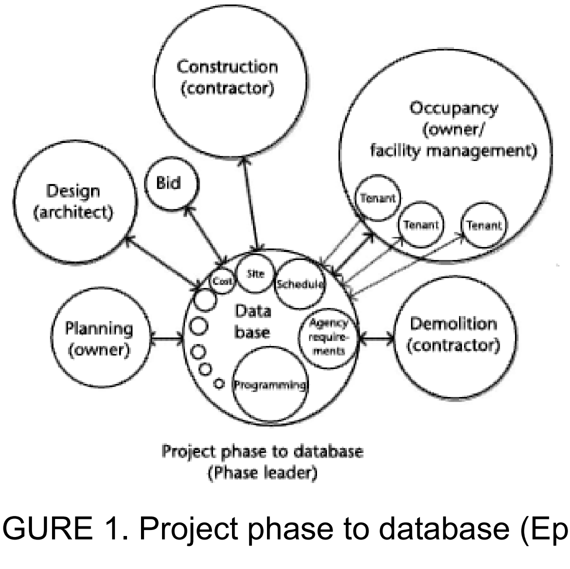
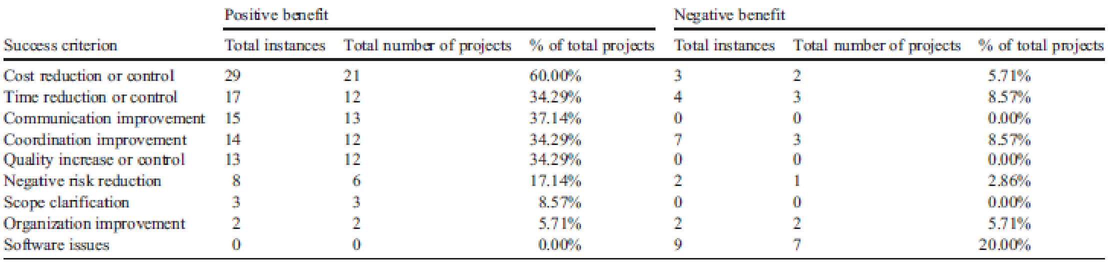


FIGURE 1. Project phase to database (Epstein, 2012, p. 30)

1.2 Benefits of BIM in the design phase

The benefits of Building Information Modelling (BIM) in the design phase, such as increased productivity and easier sharing of information, are well known. BIM models also help with the visualisation of complex projects. (Bryde, Broquetas and Volm, 2013, p. 972) Other benefits are illustrated in the table below where the researchers examined 35 cases over the 2008-2010 period and include cost- and time reductions, minimalisation of risk and improved quality of the finished product. The table shows that the benefits are greater than the drawbacks. The negatives only outweigh the positives in the case of software issues. This can be explained by the fact that BIM was an emerging technology during the research period, which means there were not yet sufficient number of experienced professionals in the field. It is also noteworthy that only 2 projects within the 35 cases had a total negative score, meaning that the use of BIM for these projects had an overall negative effect. The researchers could however not find a strong pattern to conclude the use of BIM is only profitable for large scale projects. (Bryde, Broquetas and Volm, 2013, p. 977)



	Positive benefit			Negative benefit		
Success criterion	Total instances	Total number of projects	% of total projects	Total instances	Total number of projects	% of total projects
Cost reduction or control	29	21	60.00%	3	2	5.71%
Time reduction or control	17	12	34.29%	4	3	8.57%
Communication improvement	15	13	37.14%	0	0	0.00%
Coordination improvement	14	12	34.29%	7	3	8.57%
Quality increase or control	13	12	34.29%	0	0	0.00%
Negative risk reduction	8	6	17.14%	2	1	2.86%
Scope clarification	3	3	8.57%	0	0	0.00%
Organization improvement	2	2	5.71%	2	2	5.71%
Software issues	0	0	0.00%	9	7	20.00%

FIGURE 2. Success criteria ranking of BIM use (Bryde, Broquetas and Volm, 2013, p. 976)

Although BIM is frequently used in the design phase, it might also have potential during the construction phase or after the construction phase is over. It can, for example, be useful to consider facilities management during the design phase and reduce costs for maintenance during the operational phase of the building by minimising alternations that would otherwise occur. BIM can be used in fields such as maintenance and repair, energy management, safety and space management. An information model can help maintenance by assembling all relevant information such as the relevant documents and maintenance guidelines. (Wang *et al.*, 2013, p. 3)

1.3 Scan to BIM

To use BIM in renovation projects or for documenting cultural heritage, another process is used to achieve a suitable BIM model. Instead of designing the building, scans are made using laser scanners or UAV’s (Unmanned Aerial Vehicles) to make a model of the existing building. This “as-is” model can then be used to design changes to the existing structure or kept the way it is as an information source. All steps of this process are discussed in more detail in Chapter 2.

1.4 The use of BIM models

BIM models can be used for multiple purposes such as as-built models, checking for differences between the designed building and the constructed building, looking for mistakes on the construction site or renovation. In a more traditional sense they are used as an information source during the construction phase and a tool for generating plans.

1.4.1 As-built model

The As-built or As-is model visualises the building the way it is built, this might be different from how it was modelled during the design phase because of problems during the construction phase or any other last-minute changes. This model can be made using 3D-laser scanning. In order to build a structured point cloud with this laser scanner, three aspects to consider are shapes, relations and attributes. (Hichri, Stefani, De Luca and Veron, 2013)

Representing the shape of the object

- Parametric vs non-parametric representation

Parameters such as height can be used to represent an object. Non-parametric representation uses a mesh to represent the same object. (Hichri, Stefani, De Luca and Veron, 2013)

- Global vs local representation

Global representation describes the entire object while local representation only characterises a portion of the object. (Hichri, Stefani, De Luca and Veron, 2013)

- Explicit vs implicit representation

Explicit representation uses, for example, triangular meshes while implicit representation uses for example histogram of normal surfaces. (Hichri, Stefani, De Luca and Veron, 2013)

Representing relations between objects

The spatial relationships used in BIM are hierarchy, topological and directional relations. (Hichri, Stefani, De Luca and Veron, 2013)

Representing objects attributes

Attributes include information about the used materials such as texture, age and cost. (Hichri, Stefani, De Luca and Veron, 2013)

1.4.2 Differences between constructed and designed building

The existing BIM model, in which the building was designed, is updated to as-built conditions, including adjusting dimensions and relocating certain objects. The accuracy and density of the point cloud should be considered, as small differences between designed and surveyed objects smaller than the accuracy of the scanner might not be real differences. Since the changing of the model is a rather labour-intensive task, minor deviations may not result in changes in the model. Whether or not a deviation should reflect in the changing of the model is based on the judgement of the BIM manager. (Bassier *et al.*, 2019, p. 22)

1.4.3 Defects on-site and Percentage of completion

Three-dimensional imaging and analysis of as-built conditions can lead to early detection of defects on construction sites by performing frequent, complete and accurate assessments of the as-built condition. To detect defects, the as-built data shall be associated with the corresponding components in the design model and identifying deviations between both models. (Yue *et al.*, 2006, p. 2) For percentage of completion, the progression between consecutive point clouds is assessed. These uses both need photos or scans made during the construction phase when obstacles such as scaffolding make it difficult to avoid occlusions. (Bassier *et al.*, 2019, p. 24)

1.4.4 Renovation

When renovating an existing building, a BIM model of the building may be useful for interactive design of the new parts. It is possible to verify if the changes (e.g. a new elevator) fit in the existing building. (Tammi, 2020) The model can also be used as a starting point for other renovations such as adding a side building or demolishing a part of the building.

1.5 Scope of this paper

While the use of BIM models is growing in designing new buildings, the use of them in existing buildings is rather limited. One of the main reasons for this is the fact that the totality of the scan-to-BIM process is time-consuming, making the benefit of using BIM smaller.

The scanning itself is hard to automate because the scanning itself is automatic but the scanner has to be moved by an operator. In buildings with a lot of rooms, it is possible that this moving has to be done as often as 70 times. While Mobile mapping systems (MMS) help in the automation of the scanning process, terrestrial laser scanning still has higher accuracy, range and consistency. Other capabilities like capturing RGB are benefits which should not be ignored. Bassier et al. concluded that, in 2015, the use of terrestrial laser scanning was the best solution for Scan-to-BIM applications. They noticed that dynamic systems were evolving fast and had great potential for mapping applications. (Bassier *et al.*, 2015, p. 22)

This lies outside of the scope of this paper. However, there exist multiple ways to save time in postprocessing. Firstly, the post-processing of the scans itself is partly automated by software manufacturers such as Faro (Scene) and Autodesk (Recap). After this step, the 3D model is now a so-called point cloud consisting of millions of individual points. To make a usable BIM model out of this point cloud, another step must be taken. The operator will model walls, ceilings, floors by hand where the point cloud shows these. Automating this step would lead to time savings making the scan-to-BIM process more interesting. In recent years, a lot of research has been done looking for algorithms to detect walls, ceilings and floors automatically. Faro has made a software solution claiming to detect these features to facilitate the scan-to-BIM process which was released in June 2018. In this paper, the entire process will be discussed from scanning an existing building to delivering a useful BIM model. Special attention will be given to the use of the Faro As-Built Solutions for the automatic detection of building parts. An evaluation of the software will be made using the following questions:

- Are simple features such as walls, ceilings and floors detected?
- Are features such as doors and windows detected?
- Are nonhorizontal of nonvertical features such as stairs, sloped roofs and beams detected?
- How does the software deal with occlusions in the scans?
- Are the detected features placed correctly and how do they connect?
- How is the detection of pipes?
- Can the accuracy be checked?

As there is no time in this research to model the building both with and without the software, a comparison on how much time the total process takes is impossible. An estimation of how much time each step takes will be given.

2 PROCESS

2.1 Laser scanning

3D laser scanning, also known as LIDAR (Light Detection And Ranging), uses laser beams to register point clouds with a high accuracy up to millimetre level with a speed of around a million points per second. (Tammi, 2020)
There are different types of laser scanners ranging from handheld scanners for small objects all the way to mobile and aerial laser scanners for large areas. The terrestrial laser scanner lays somewhere in the middle of this spectrum and can be used for either large objects or sites and buildings. (Tammi, 2020)

When using multiple scans, for example to get both sides of an object, there are two options to make a single point cloud. The first and most accurate one is to use artificial targets such as spheres or checkerboards of which at least two can be detected in both scans. To minimise the errors in traversing, working in a closed-loop traverse where the targets of the first scan are also visible in the last scan is recommended. When working with targets is unwanted because of the time spent on site, the adjacent scans need to have an overlap so multiple points can be detected in order to align the scans properly. (Tammi, 2020)
Georeferencing is the process of aligning the achieved point cloud so it follows the selected geographic coordinate system, for example ETRS-TM35FIN. This georeferencing is done by surveying certain points, such as the targets, so the coordinates of these points are known. After the georeferencing process, the coordinates of every point in the cloud can be determined.

2.2 Close range photogrammetry

Another method to construct a point cloud is close-range photogrammetry, which is based on photographs. Mosaicking is required to combine the small areas covered per image and for this mosaicking to work, every feature has to be visible in at least two photos taken from different positions. In order to receive geospatially valid mosaics, georeferencing is a necessary step. This can be done using two different methods: first direct georeferencing using the navigation sensors of the camera, second indirect exterior orientation estimation using image observations and ground control points (GCPs). (Shahbazi *et al.*, 2015, p. 1)

The shape and position of an object are determined by reconstructing the rays used by the camera to capture the object point P using the image point P’ and the perspective centre O’. When two images are used to find the object point, the method is called stereophotogrammetry. In multi-image photogrammetry the number of images is unlimited. (Luhmann *et al.*, 2013, p. 7)

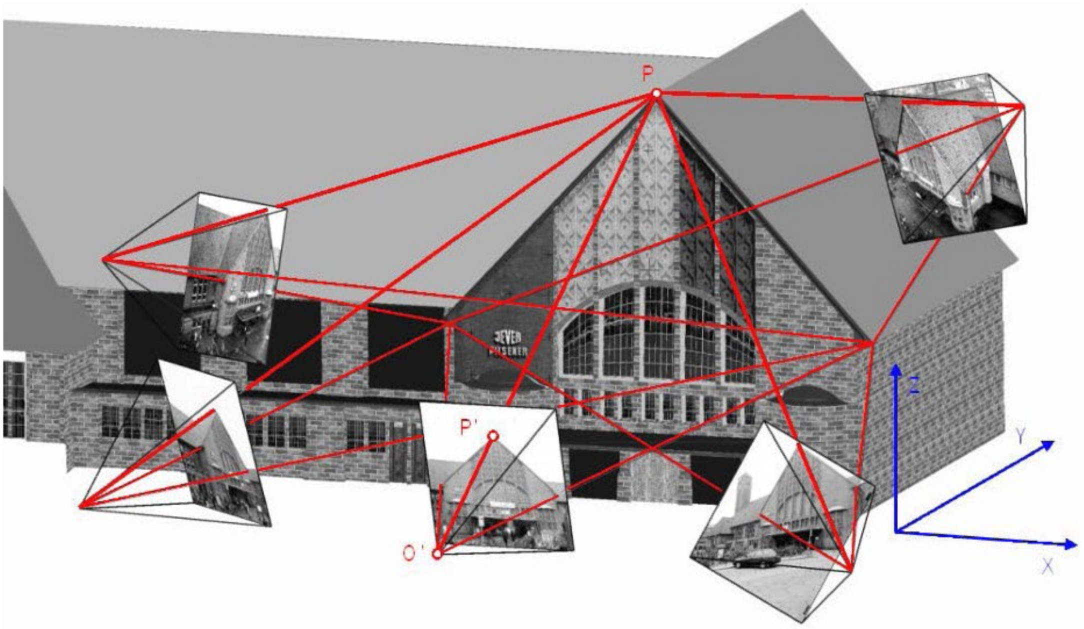


FIGURE 3. Principle of photogrammetric measurement (Luhmann et al., 2013, p. 7)

2.3 Using Drones for making point clouds

One of the uses of close-range photogrammetry is the use of aerial photogrammetry, with the use of UAV’s. these UAV’s are useful tools for surveying buildings or other targets from above. These UAV’s are equipped with a camera and optionally with extra sensors such as LIDAR. Due to the improvement in UAV’s, cameras and the development of vision-based mapping techniques, unmanned aerial imagery is under heavy research as the use of these UAV based mapping techniques can provide data for 3D-modeling. (Shahbazi *et al.*, 2015, p. 1)

When flying drones, certain rules and regulations must be followed. The regulations found on the website of the Finnish Transport Safety Agency are applicable on UAV’s weighing more than 250 grams and does not apply to military aviation. Operators of remotely piloted aircrafts must provide the Finnish Transport Safety Agency with the following information:

- Details of the operator
- Basic technical information about the aircraft
- Nature and scope of operation
- Operation above densely populated area or not?
- Operation above open-air assembly of persons?

Following details must be logged for all flights and stored for two years:

- Date and location of flight
- Commander of the aircraft
- Manufacturer and model of the aircraft
- Start and end time of flight
- Whether flight is a visual line of sight (VLOS) operation or a beyond visual line of sight (BVLOS) operation
- Nature of the flight operation

(Trafi, 2018)

All rules can found on the website of the Finnish Transport Safety Agency. (https://www.droneinfo.fi/en/unmanned_aviation) From July 2020 onward, European rules are set to be applied.

2.4 Point cloud to BIM

While Building Information Modelling is frequently used in designing new buildings, a rise in the use of BIM for historical buildings and cultural heritage is noticeable and this mostly for maintenance, restoration, conservation and modification purposes. Using methods like laser scanning and photogrammetry are suggested because these buildings are already built. (Hichri, Stefani, De Luca, Veron, *et al.*, 2013, p. 1)

Working in a point cloud model has limited possibilities, these possibilities are more versatile in a BIM model because extra information can be added to the model and features can be moved. For this reason, a way to convert the raw point cloud data to a BIM model has to be found. Currently, the scan-to-BIM process is a time consuming and error-prone manual process. (Macher, Landes and Grussenmeyer, 2017, p. 1) In order for this process to be viable in a professional setting, the whole process needs to take up considerably less time. The current software has yet to enhance further to be able to automate the scan-to-BIM process. The ways this automation can be enhanced are:

- Under normal circumstances, the automatic registration of the scans performs well. Unfortunately, this was not the case in the case study and adjustments such as pointing out artificial targets were necessary.
- Automatically detecting planes in the point cloud. This reduces the need for an operator to clean up the point cloud, filters already help in this process but if the software could detect walls, floors, ceilings and other building parts. It could be able to detect and delete most of the stray points without the help of the operator. The Faro As-Built software claims to complete this step.

Macher et al. propose that this automation is possible for ordinary and basic buildings with planar shapes. Historic buildings with nonplanar shapes and more complex architecture are, at least at the moment of the research, out of the question. Moreover, some materials like large glass parts in the façade are difficult to scan and therefore scan-to-BIM is significantly harder. (Macher, Landes and Grussenmeyer, 2017, p. 7) Macher et al segmented a building to achieve room point clouds. In these room point clouds, plane segmentations could be performed and points could be classified as walls, ceilings or floors. To detect the walls from the remaining points, two assumptions were made by Macher et al. They presumed that the points located at the borders of rooms belong to the walls and that occluding elements such as desks and chairs do not reach the ceiling. Once they knew which points were walls, they performed a plane segmentation in which a plane had to consist of a minimum number of points. (Macher, Landes and Grussenmeyer, 2017, p. 10 - 12)

The method of Xiong et al. made an automatic identification and modelling of planar walls, floors, ceilings and significant rectangular openings such as doors and windows. The method creates a 3D model containing the geometric and identity information necessary in a traditional BIM model. Their algorithm works in two phases, in which the first phase extracts planar patches from the point cloud and a machine learning algorithm is used to label the patches as wall, ceiling, floor or clutter and are intersected with one another to form a surface-based model of the room. The second phase consists of analysing the surfaces to identify occlusions and openings. It needs to be noted that the algorithm is only capable of detecting regular-shaped openings such as rectangular windows and has problems with the detection of different shaped windows. This algorithm is different from other algorithms by using context-based algorithms, contrary to other algorithms using rules such as “walls are vertical and meet perpendicular with floors and ceilings” which are difficult to maintain in a cluttered environment with noisy scans as a result. (Xiong *et al.*, 2013, p. 2- 4)

Assi et al. developed an algorithm to detect openings in indoor point clouds. Their algorithm was capable of reaching 100% accuracy on unobstructed windows. Only 69% of (partially or completely) obstructed windows were segmented. To enhance the accuracy on the obstructed windows, they suggest using patterns inside the façade. When windows of the same type are detected on the same floor, their centres should be on the same height. This method will increase the accuracy with each detected window. (Assi *et al.*, 2019)

While these solutions are certainly viable, the approach of Macher et al. promising in cases with limited clutter. It is however labour intensive and was a way of researching the possibilities. Using these algorithms and programmes cannot be done for every scan-to-BIM project. The method proposed by Xiong et al. is realisable in a variety of cases as it is designed to handle cluttered, real-world environments. The research conducted by Assi et al. focusses on the specific task of modelling the windows, a task where the algorithm of Xiong et al. gives unsatisfactory results. In practice, it is not feasible for an enterprise to make a comparable algorithm to use this research for real-life applications. What is feasible, is using a software package like Faro As-Built to get similar results.

Faro says about this software solution it guarantees a direct workflow from the captured data into usable CAD and BIM models all while minimising the amount of rework and increasing the output quality. The software has plugins for both AutoCAD Software and Autodesk Revit. The Revit plugin has multiple functions including model creation, alignment, editing and analysis. Clash detection can be performed directly with the point cloud data in Revit. Users can create 3D model lines and construction points using point snap in the point cloud in order to create the BIM model, enhancing the accuracy of the placement of these points. Walls and structural elements like beams and columns can be automatically modelled in the software. There is also a feature for modelling pipes and vents. (FARO, 2020b)

Another problem regarding using scans for BIM modelling is the fact that not everything is visible in scans. There can, for example, be pipes inside walls and floors. These cannot be automatically put into the BIM model. This would however also be impossible to do manually using the point cloud as the sole information source.

3 CASE STUDY: TAMPEREEN VANHA TAVARA-ASEMA

FIGURE 4. Tampereen vanha tavara-asema (Wikipedia, 2020)

Tampereen vanha tavara-asema, the old freight station of Tampere in Finland is an Art Nouveau station constructed in 1907. (Wikipedia, 2020) The building, situated on Vellamonkatu 2 in Tampere, is owned by the city of Tampere and has had multiple uses during the past decades. (Lyytinen, 2003, p. 22)

With the completion of a new freight station, the building lost its use and was set to be demolished. In 2013, the city of Tampere was handed a petition with over 8 500 signatures against the demolition of the building. However, for traffic reasons, the city wants to straighten a nearby road. This is made impossible by the current placement of the building. Because of the petition, it was no longer possible to demolish the building. To solve the traffic problem without demolishing the building, the city of Tampere changed its original plan and the city will move the building in the summer of 2020. (Wikipedia, 2020)

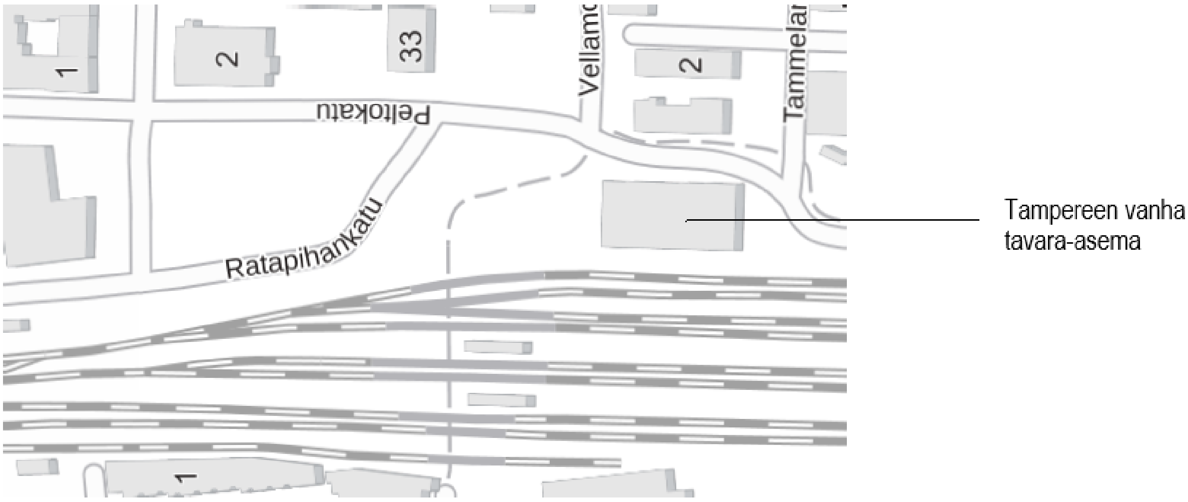


FIGURE 5. Current situation (The National Land Survey of Finland, 2020)

FIGURE 6. Situation after moving (Pesonen, 2020)

3.1 Laser Scanning

The laser scanning of the building interior was made for training purpose by Kalle Tammi and Ilkka Tasanen of Tampereen ammattikorkeakoulu (TAMK) together with a team of surveyors from Tampereen Infra Oy. These scans were not made with the intention of making a 3D model of the building. On top of this they were made in challenging conditions, without electricity in the building and blocked windows.

The fact that these scans were not made by the person doing the processing and making the model poses extra difficulties. The extra information such as wall thickness and materials are therefore unknown to the modeller.

3.1.1 Faro Focus 3D X330

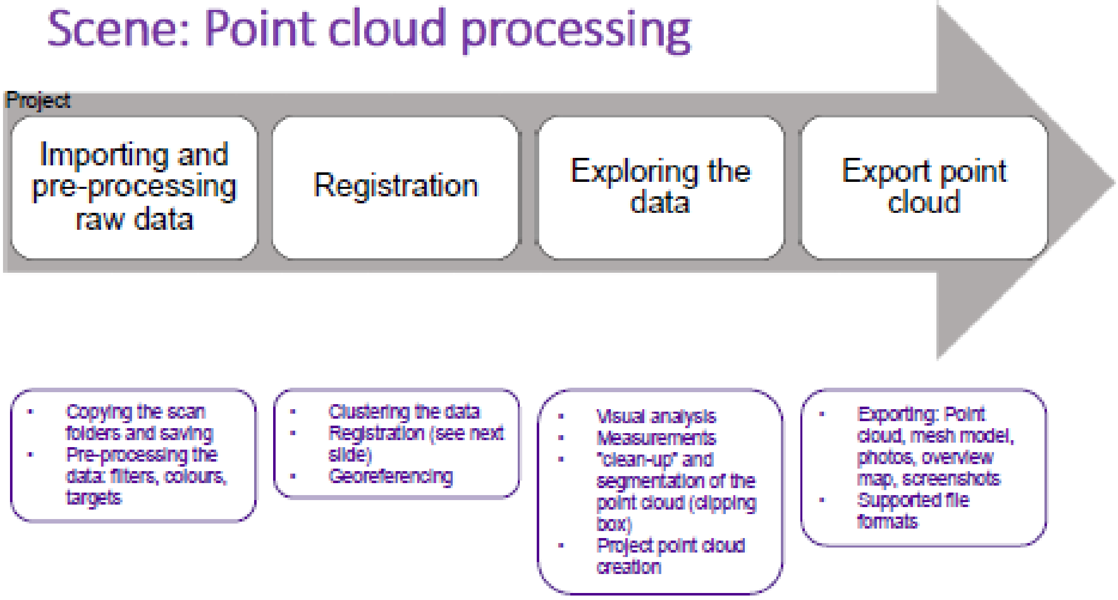
FIGURE 7. Faro Focus 3D X330 (FARO, 2016)

The used scanner was a Faro Focus 3D X330 with a range of focus between 0.6 and 330m, a ranging error of approximately 2mm at a distance of 10 meters and integrated GPS to facilitate postprocessing. The Faro Focus 3D X330 is a phase-based geodetic laser scanner. (FARO, 2016, p. 1)

With this scanner, 78 scans were made. The scans on the ground floor were executed using targets, these targets make it easier for the processing software to put scans together. On the first floor, no targets were used.

3.1.2 Faro Scene

All 78 raw scans were fed into Scene. The workflow in Scene is divided into 5 steps: importing the scans, processing the raw data, registration, exploring the data and exporting the point cloud.



Scene: Point cloud processing

Project

Importing and pre-processing raw data

- Copying the scan folders and saving
- Pre-processing the data: filters, colours, targets

Registration

- Clustering the data
- Registration (see next slide)
- Georeferencing

Exploring the data

- Visual analysis
- Measurements
- "clean-up" and segmentation of the point cloud (clipping box)
- Project point cloud creation

Export point cloud

- Exporting: Point cloud, mesh model, photos, overview map, screenshots
- Supported file formats

FIGURE 8. Workflow in Scene (Tammi, 2020)

After importing the scans, they were put into clusters. A way of doing so is room by room as this makes sure the software only tries combining scans from the same room which makes the process faster. Processing is done by the Scene software, once the wanted settings are chosen by the operator.

After the automatic processing is done, the operator should take some steps to enhance accuracy and solve some problems where the software made the wrong decisions. It is recommended to disable auto clustering, as this is better done by the operator himself. When scans are not automatically put together, it is helpful to change the settings when placing the scans or manually putting the scans roughly where they should be. One of these settings which can be changed is the maximum search distance. This setting defines in what radius the software will look for matching points. If a scan is outside this radius, Scene will not consider this scan and consequently will not put this scan in the correct place. When a sub-cluster is not able to be placed correctly, it is useful to check individual scans for problems. For instance, the spheres could be registered as a wrong size or the checkerboards could be off centre. It is also possible a target is not detected by the software or the software can detect a target where there is none.

Once the sub-clusters are placed correctly, they should be locked so the software only moves the sub-clusters and tries placing them together. If the sub-clusters are not locked, the software will move every scan independently. This is very taxing for the computer, takes more time and completely circumvents the use of the sub-clusters because the scans of the sub-clusters are already put together.

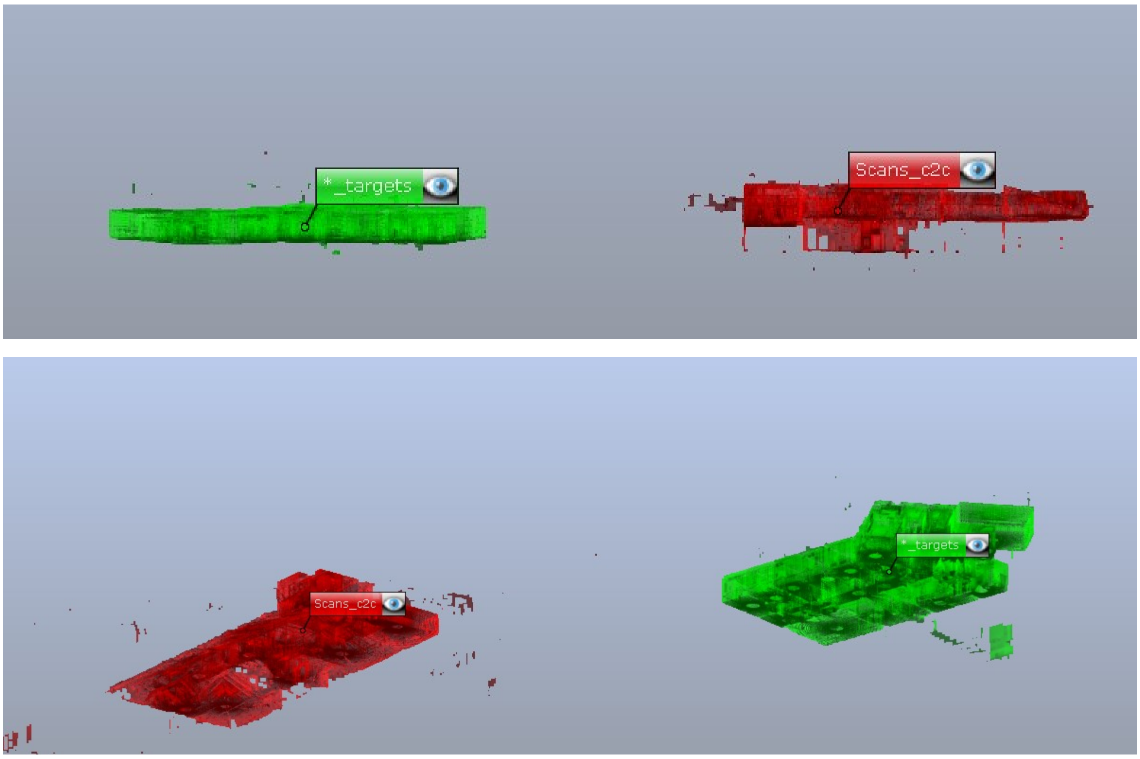
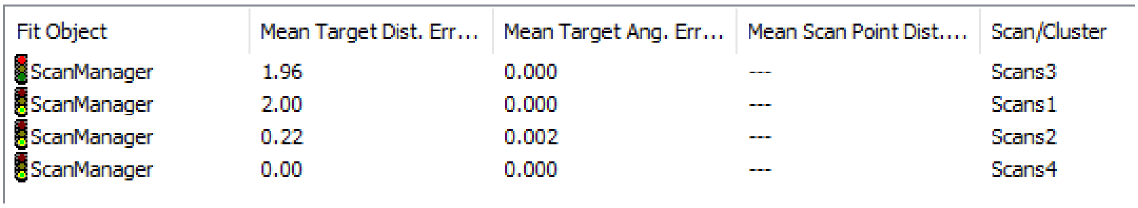


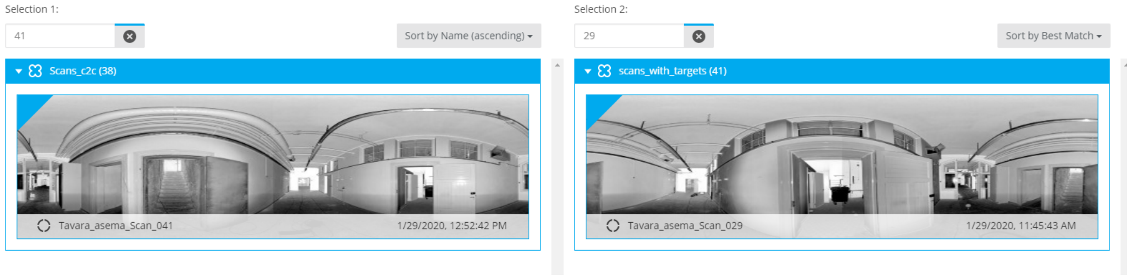
FIGURE 9. Subclusters



Fit Object	Mean Target Dist. Err…	Mean Target Ang. Err…	Mean Scan Point Dist.…	Scan/Cluster
ScanManager	1.96	0.000	---	Scans3
ScanManager	2.00	0.000	---	Scans1
ScanManager	0.22	0.002	---	Scans2
ScanManager	0.00	0.000	---	Scans4

FIGURE 10. Accuracy of target based scans

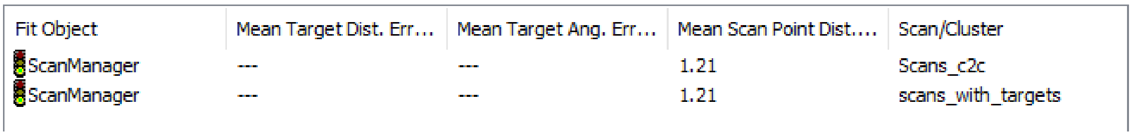
During the registration step, the operator can choose to cluster the scans by himself or let the software cluster the scans automatically. Most of the registering can be done by the software itself but then it needs help from the operator in cases such as combining scans of the ground floor with those of the upper floor. To combine both clusters, a manual registration of scans 29 (target based) and 41 (cloud to cloud but there are targets visible) was performed. These scans were made in the same room but scan 29 is clustered with the ground floor while scan 41 is clustered with the upper floor. Putting these scans together will make sure both floors are combined accurately. For the manual registration, at least 2 targets should be visible in both selected scans. Here the usual theory of more targets gets better accuracy is still applicable.



Selection 1: 41
Sort by Name (ascending)
Scans_c2c (38)
Tavara_asema_Scan_041 1/29/2020, 12:52:42 PM

Selection 2: 29
Sort by Best Match
scans_with_targets (41)
Tavara_asema_Scan_029 1/29/2020, 11:45:43 AM

FIGURE 11. Manual registration



Fit Object	Mean Target Dist. Err…	Mean Target Ang. Err…	Mean Scan Point Dist.…	Scan/Cluster
ScanManager	---	---	1.21	Scans_c2c
ScanManager	---	---	1.21	scans_with_targets

FIGURE 12. Accuracy of the total project

After the registration of the scans we get the 3D view with a mean scan point distance 1.21mm showed from different perspectives in appendix 1, of which one is shown here.

FIGURE 13. 3D view before cleaning

There were still ample stray points floating around this building. To solve this, the operator can select stray points and use filters. First, all points that were far from the building were deleted, as these are points scanned through windows or doors.

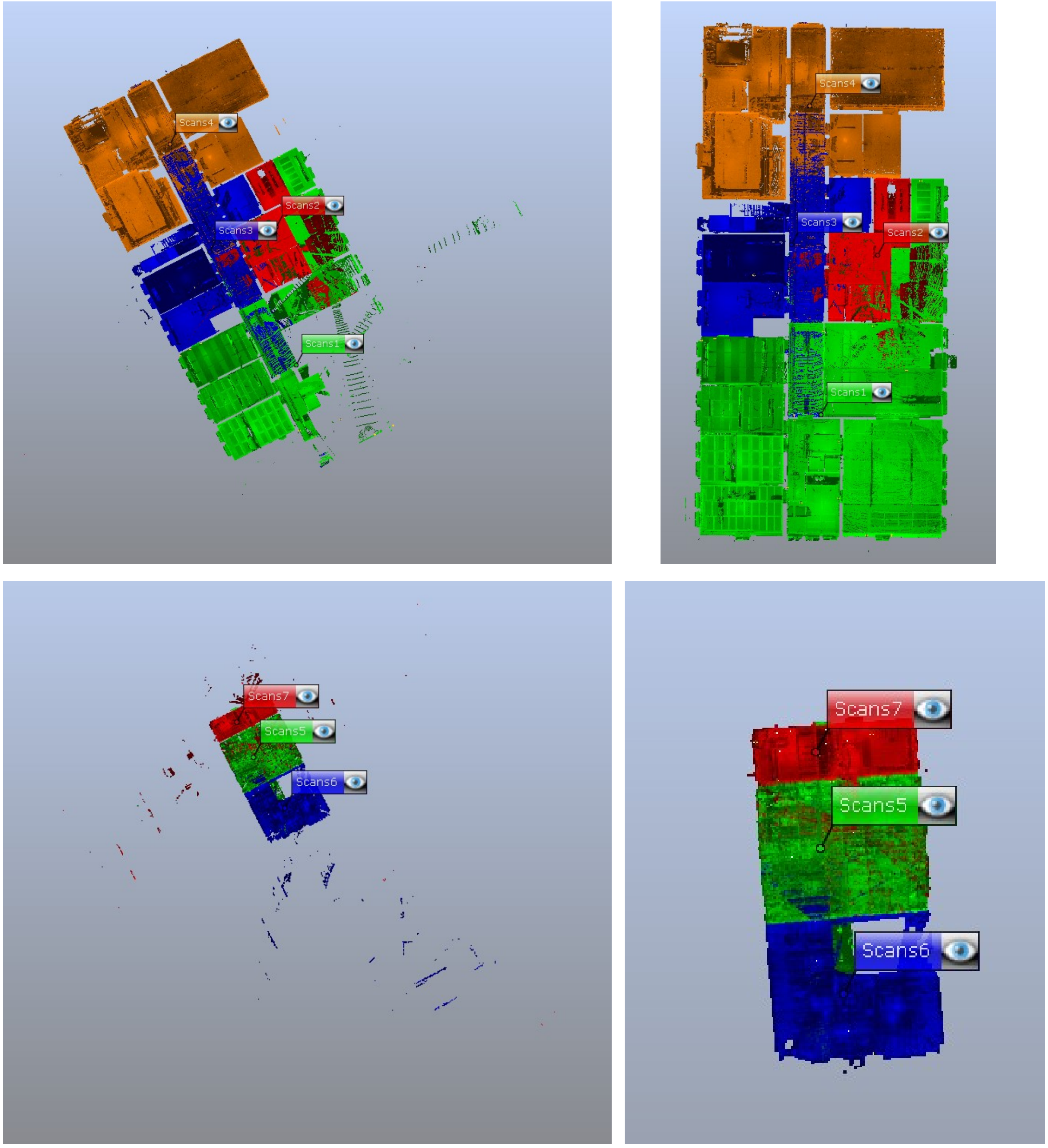


FIGURE 14. Comparison before and after deleting stray points

After deleting stray points, the model shown in appendix 2 and figure 15 is achieved.

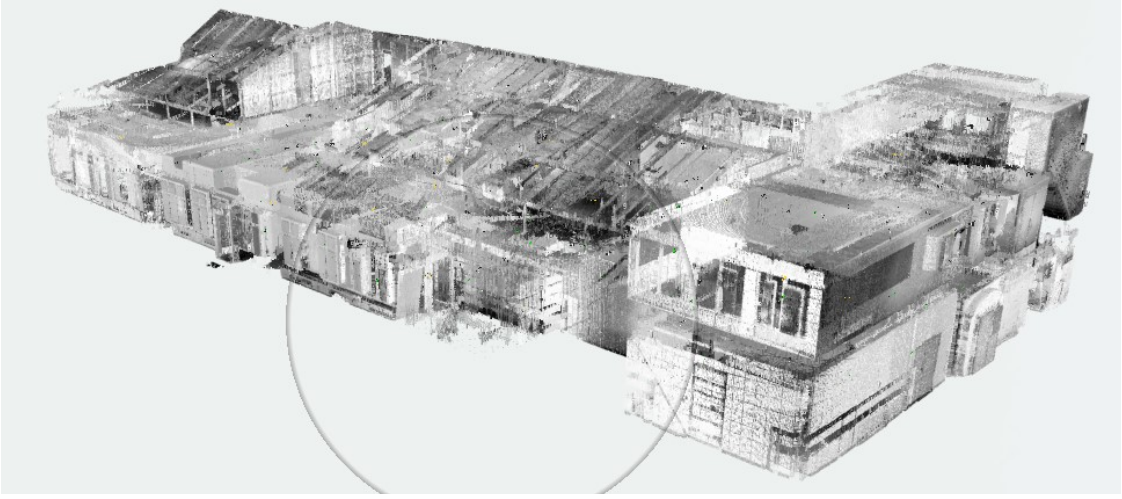
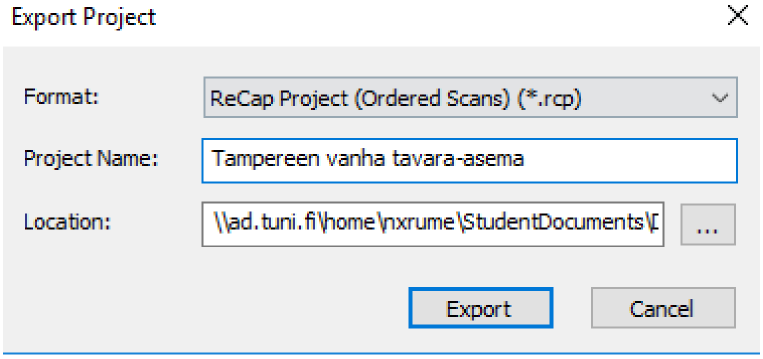


FIGURE 15. 3D view after cleaning

Because the scan was cleaned up in Scene by deleting the stray points, the point cloud can be exported directly into Autodesk Recap.,



Export Project

Format: ReCap Project (Ordered Scans) (*.rcp)

Project Name: Tampereen vanha tavara-asema

Location: \\ad.tuni.fi\home\nxrume\StudentDocuments\

FIGURE 16. Export to Autodesk Recap

To simplify the process of putting both the scans and drone footage together, both are georeferenced.

3.2 Aerial photogrammetry using drones

3.2.1 Drone used

The outside of the building is documented using drone images by Mr. Timo Hakkarainen from Tampereen Infra Oy. The drone used for making the photographs of the outside of the building was a Geodrone X4L v4 with the Sony A6000 camera. This drone has a flight time of up to 66 minutes in which up to 90 hectares can be mapped in a single flight. With a dry weight of 2.2 kg and a maximum take-off weight of 6.6 kg. The drone can be used at temperatures as low as -10°C and with winds up to 12 m/s. The ground resolution with a flight height of 160m is 3cm/pixel. (VideoDrone Finland Oy, 2017, p. 1 - 2) The Sony A6000 camera is a 24.3MP camera. (Sony, 2020)

Because this mission was conducted in a densely populated area, the description of operations, safety assessment and operational instructions must be kept for a period of at least three months after the conducting of the mission and presented to the Finnish Transport Safety Agency upon request. (Trafi, 2018)

FIGURE 17. Geodrone X4L v4 (VideoDrone Finland Oy, 2017)

3.2.2 Post-processing

The drone operator, Mr. Timo Hakkarainen, provided an orthophoto showing the location of the GCP´s, as well as their coordinates. This improves the accuracy of the point cloud and ensures that the point cloud is correctly georeferenced, which is necessary to combine this point cloud with the one made by laser scanning in the previous step.

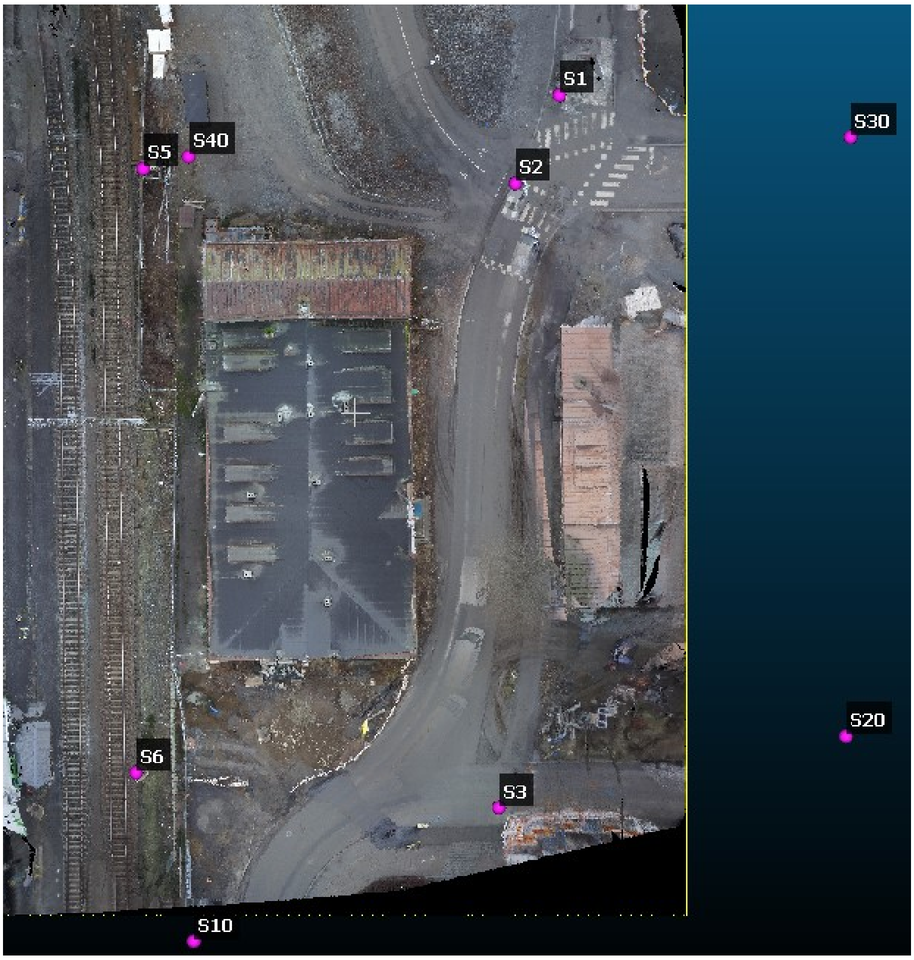


FIGURE 18. Ground Control Points

Agisoft Metashape Professional was used for the postprocessing of the drone footage. Other possible software solutions are, amongst others, Recap photo and Pix 4D. The choice for Agisoft Metashape was made considering the universities valid software licence and the experience in the use of this software by the thesis promotor. After pointing out the location of the GCP´s on multiple photos, a dense point cloud of 683 416 points (lowest quality) can be constructed. This is not bad and probably would have been enough, but the quality was enhanced to “low quality” to be sure. Higher quality is not necessary in this project. After making this dense point cloud we get a point cloud consisting of 2 861 403 points which was thought to be enough, after using this point cloud in the Faro As-Built software it became clear that this resolution was suboptimal and a higher quality level would have been preferable. The achieved model is illustrated in the figure below and in appendix 3.

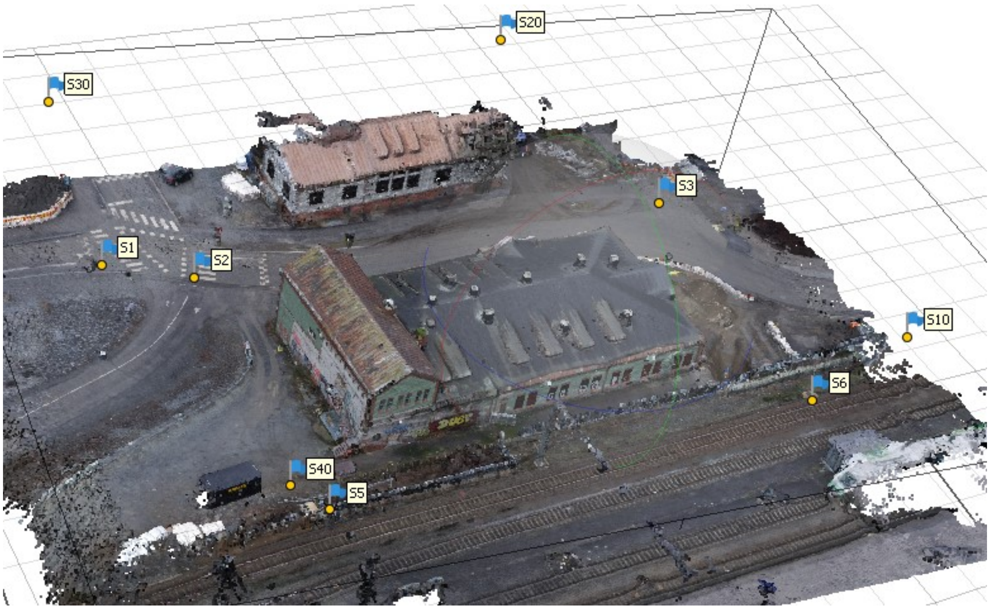


FIGURE 19. Point cloud exterior

3.3 Processing (combining scan + drone)

To combine the point clouds of the 3D scanning and the drone images in Scene, both clouds should be in the same coordinate system. When the coordinates have large numbers (e.g. 24 488 035.886) this can cause some processing and visual problems. A way to avoid these problems is translating the coordinates so what is left of the coordinates is 8035.886. This must be done the same for both point clouds. As seen in the figure below there was a small offset between both point clouds after combining both. Small translations are therefore necessary, these can be done accurately by aligning doors and windows because these are visible in both point clouds. As the georeferencing of the terrestrial laser scanner was done using a total station these coordinates have a high accuracy. It was estimated that the accuracy is highest for the terrestrial laser scanner and the cloud that is moved is therefore the drone cloud.

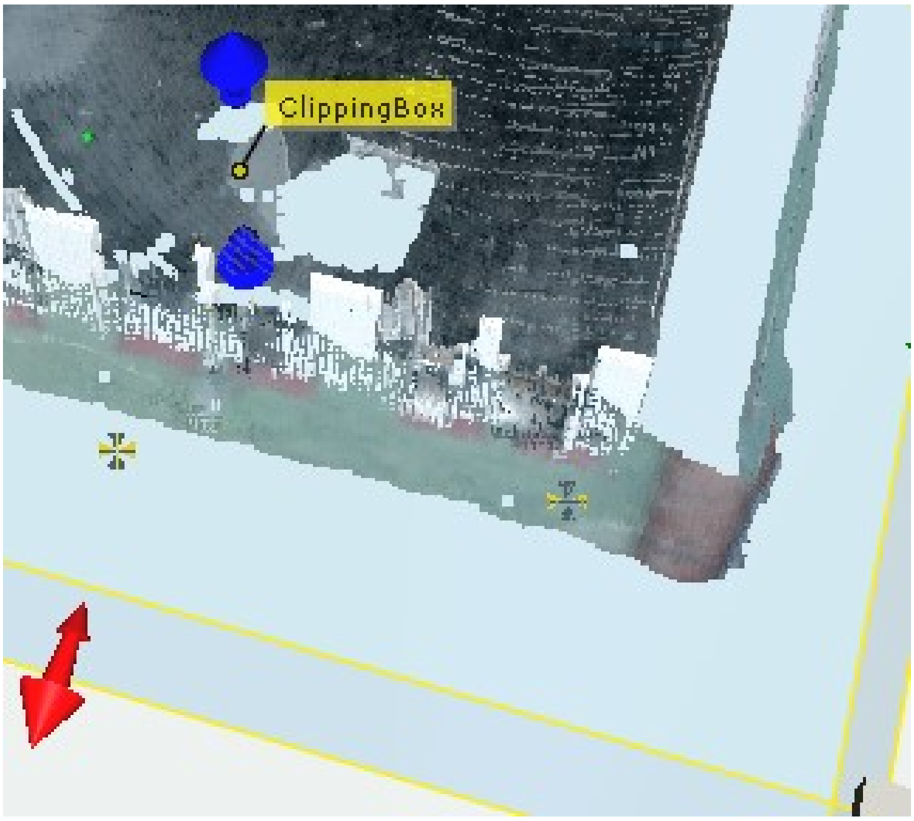


FIGURE 20. Offset between point clouds

3.4 Point cloud to BIM

After the point cloud contains all information needed, it can be exported as a ReCap project file format (.rcp file) to use in Autodesk software. The first step in Revit is aligning the project after this the function “prepare point cloud” is used to enhance the view. After this step, the visibility of the walls is improved. The ground floor consists of multiple rooms with a simple floorplan.

FIGURE 21. Preparing the point cloud

To create walls, the As-Built software detects the thickness of a wall after selecting two points on the wall in plan view and estimates the location. The height of the wall is defined between two levels. To make sure this is correct, the levels should be put on the right height using the points on floors and ceilings in the scans. Satisfying results for the inner walls are achieved, it is more difficult to detect the thickness of the outer walls as the resolution of the drone images is, in some places, insufficient. The walls are not perpendicular after this creation but this can be fixed by using the align walls feature of the software. This feature works perfectly in the event of a simple room with four walls but when creating the complete floorplan of the ground floor not all walls can be made perpendicular.

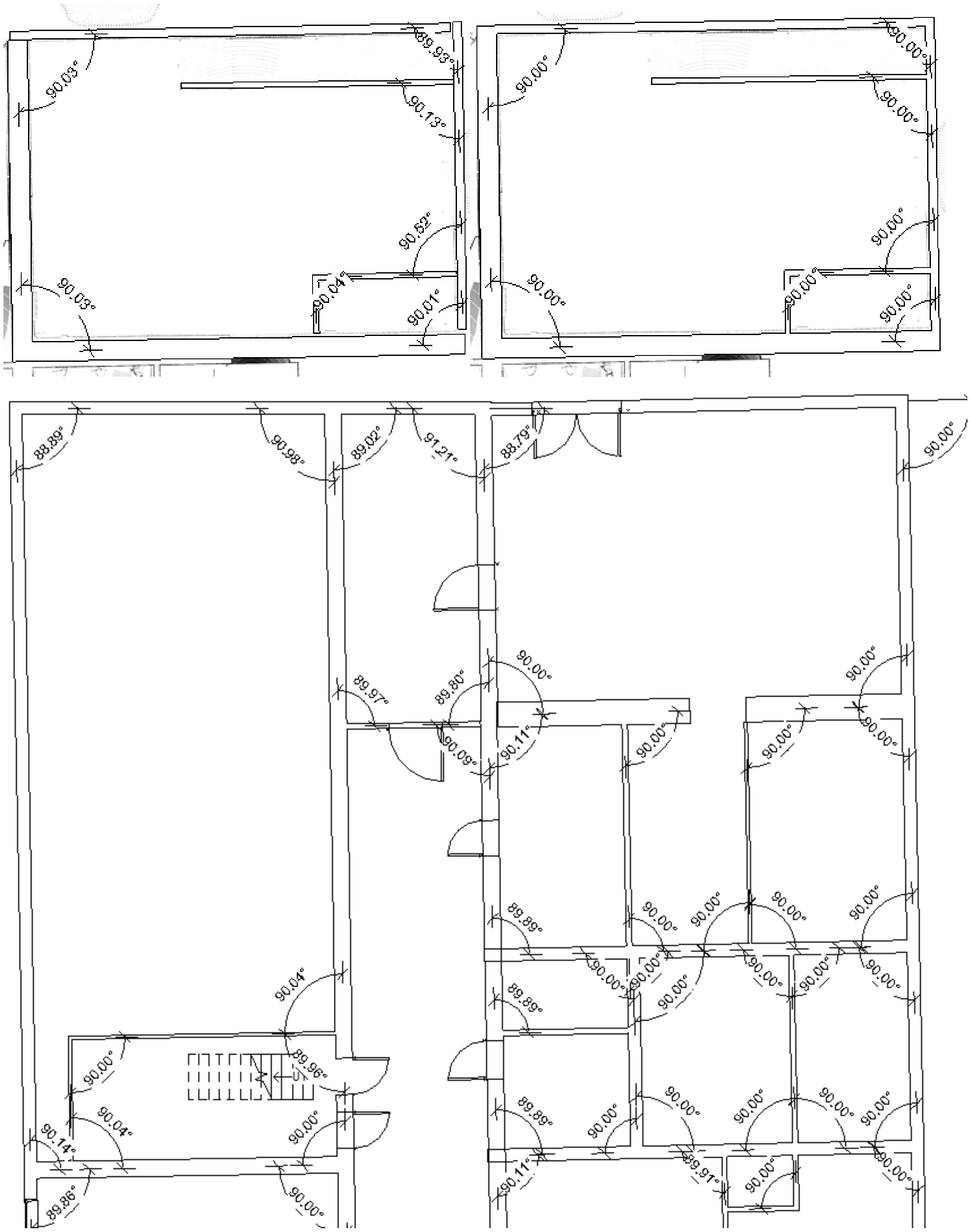


FIGURE 22. Walls after aligning

Adding doors and windows is pretty straightforward and is done by selecting points on the corners of the door or window in the point cloud using the door or window features from the As-Built software. In order to visualise the doors as they are scanned, the correct type of doors and windows can be loaded in as families into Revit. Because the building in question has lots of different types of doors, windows and wall openings, it would be labour intensive to do so with limited benefits. An example of such a difficult door is shown in the picture below. In the case where there are only a few types of standard doors and windows, importing them as families would be possible if the visualisation of the doors and windows is wanted.

FIGURE 23. Special opening

The modelling of the stairs is not optimised within Faro As-Built. As discussed in the webinar, this is not yet possible in the As-Built. (FARO, 2020a) It is however possible to design the stairs in Revit and align them with the scans by changing for example the number of steps and the total height, this is a rather cumbersome task.

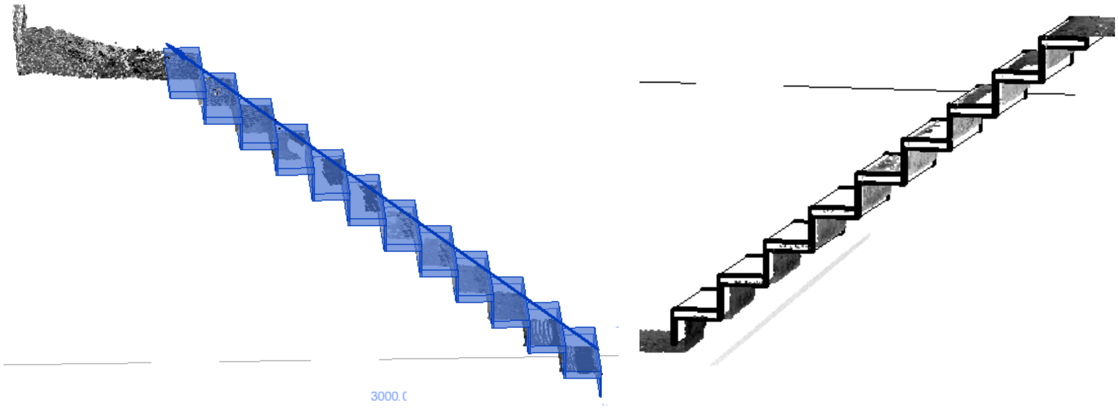


FIGURE 24. Modelling of the stairs

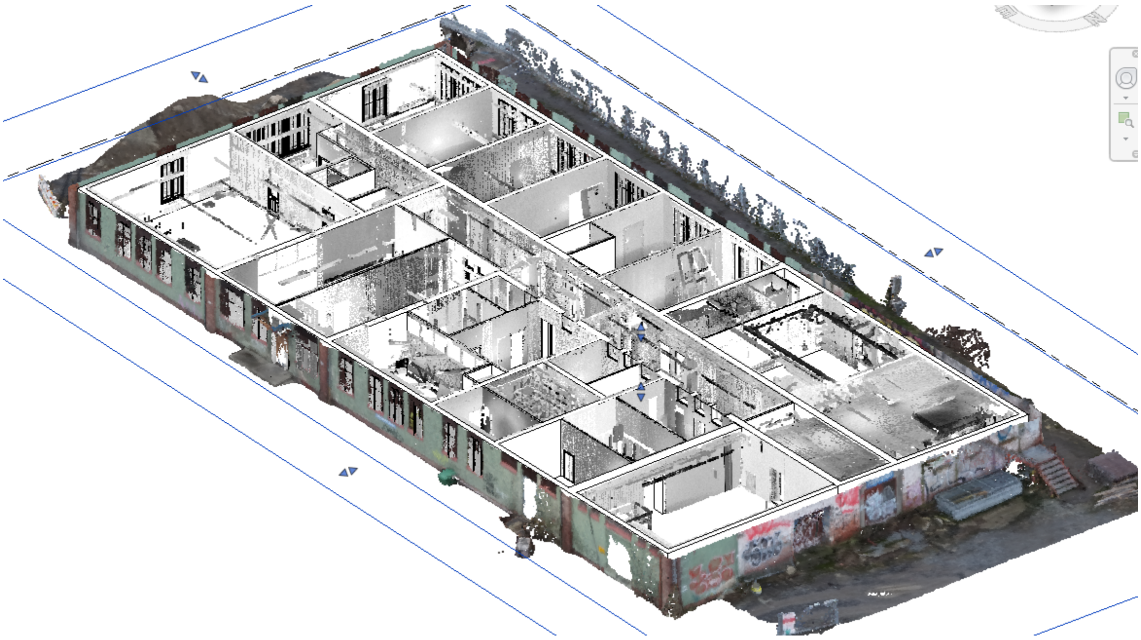


FIGURE 25. Ground floor with point cloud

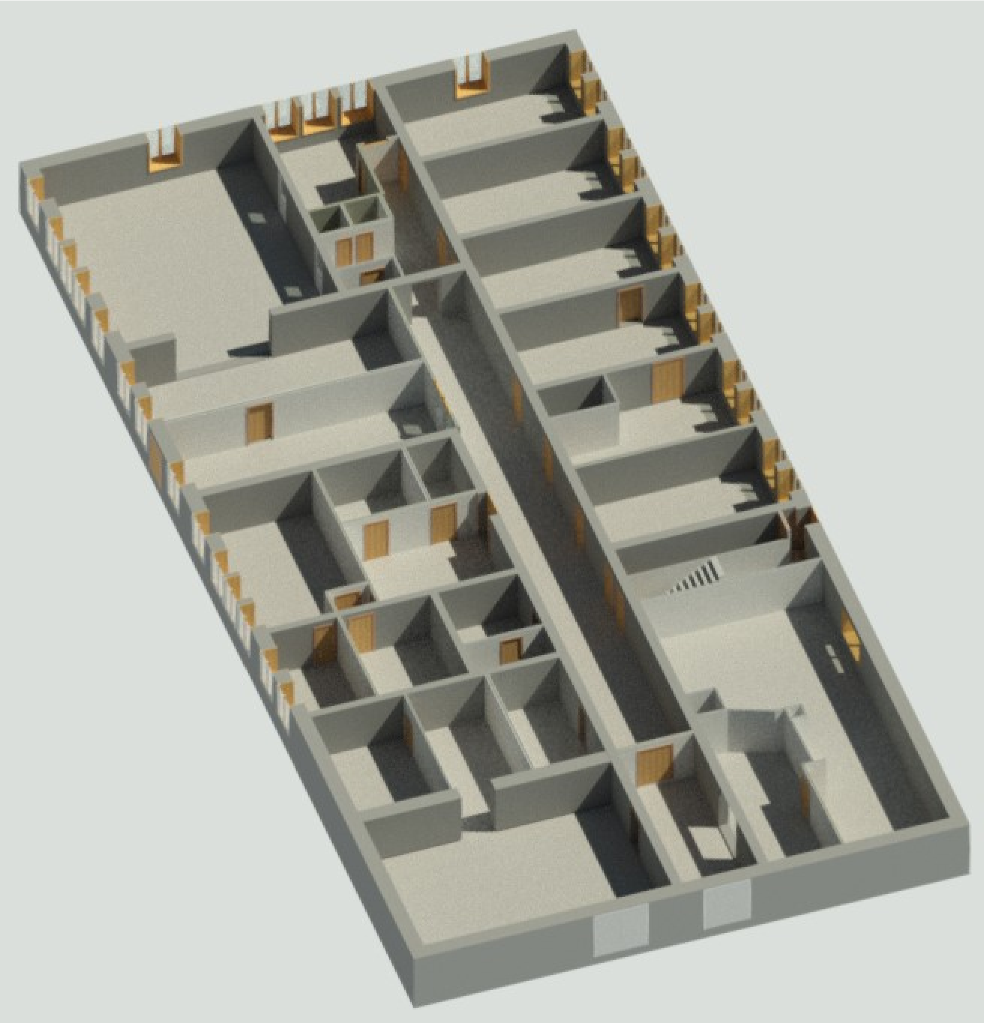


FIGURE 26. Ground floor without point cloud

Adding the floors and ceilings is done using the usual Revit commands of selecting the walls bordering the floor or ceiling. As the levels are placed using the point cloud and the walls stop at these levels, the ceiling should be at the desired height. The placement can be checked by showing the point cloud and verifying whether or not the ceiling is in the same place.

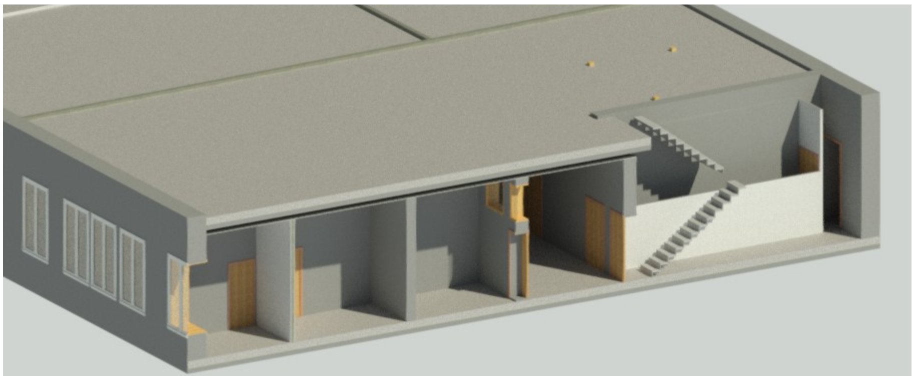


FIGURE 27. Ground floor with floor and ceiling

The roof structure of the building is made with wooden columns and beams. These wooden structures can be modelled by first loading the families of the wooden columns and beams into Revit. Afterwards the feature “Add structural element” can be used similarly as the modelling of the walls, by clicking two points on the same face of the structure. The align structural elements feature will then connect these elements. Afterwards, the columns should also be connected with the floor. Given the relatively low resolution of the scans and the fact they do not contain colour, not all beams in the sloped roof are easy to see. Using coloured scans would partly solve this problem. Some beams are rotated as well, this is easy to solve by selecting the beam in question and changing its rotation to 0 degrees. In appendix 4 the modelling steps for the construction are illustrated, the result is shown below.

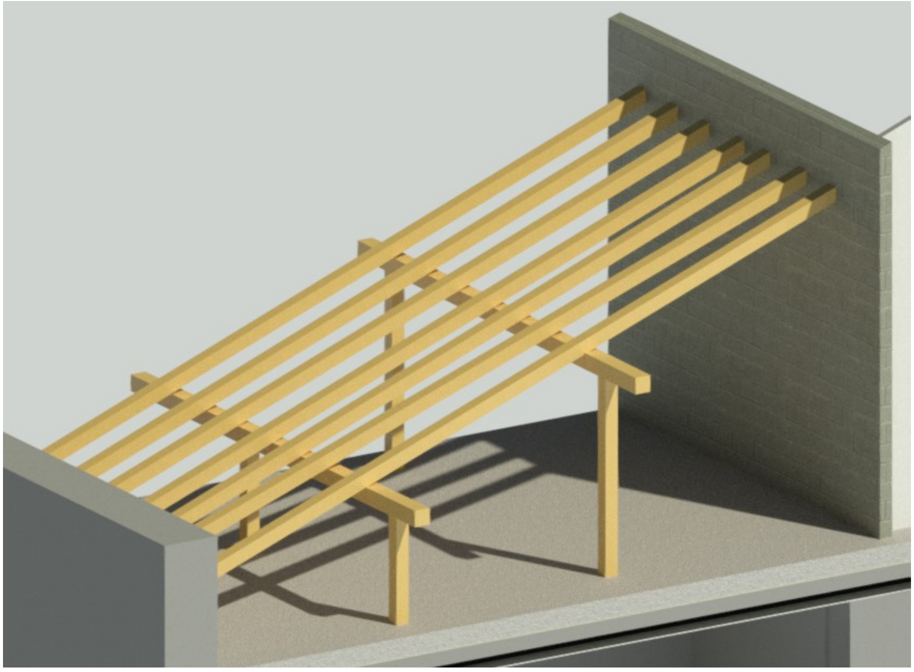


FIGURE 28. rendered roof structure

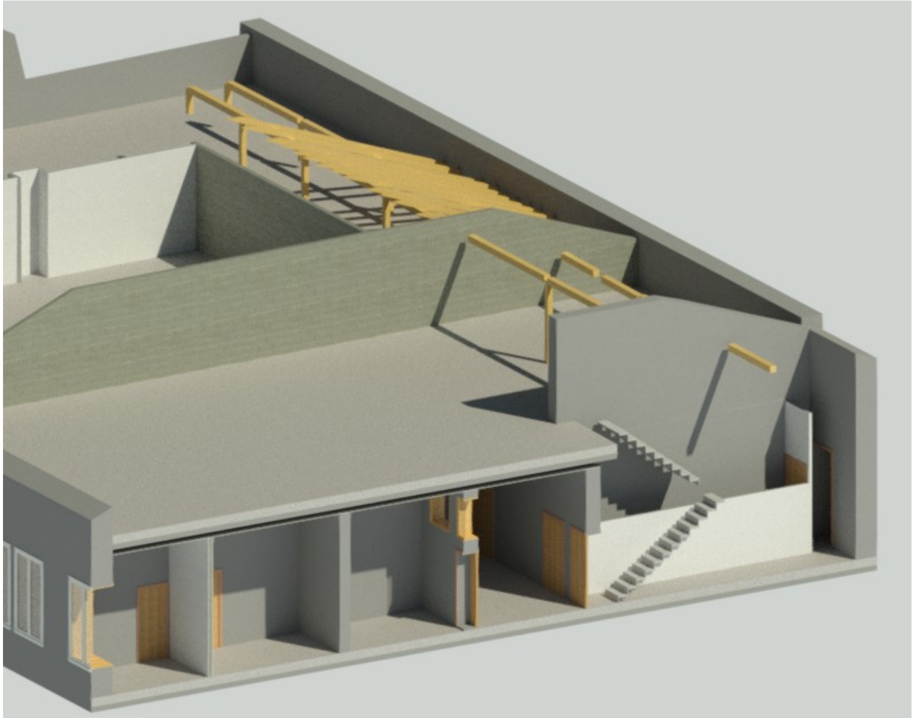


FIGURE 29. Upper floor without roof

Although there is no As-Built feature for modelling sloped roofs, the roof can be modelled using the Revit features. The roof can be modified making it resemble the point cloud, this method is challenging with the accuracy being dependent on the quality of the point cloud and the experience of the modeller. Special roofs are harder to model and will take more time.

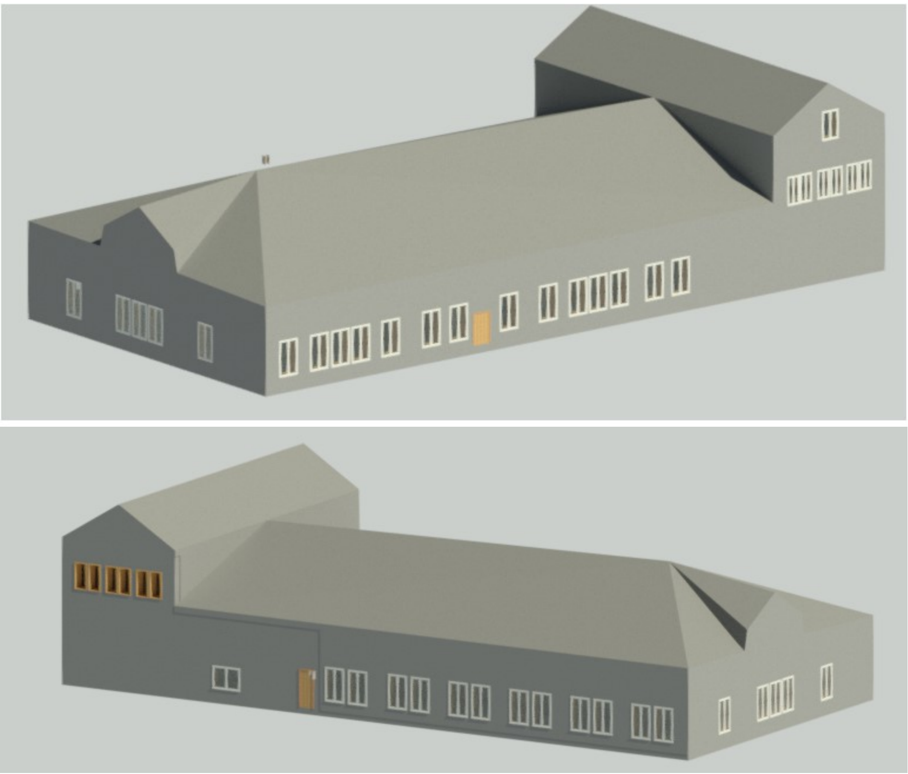


FIGURE 30. Completed BIM model

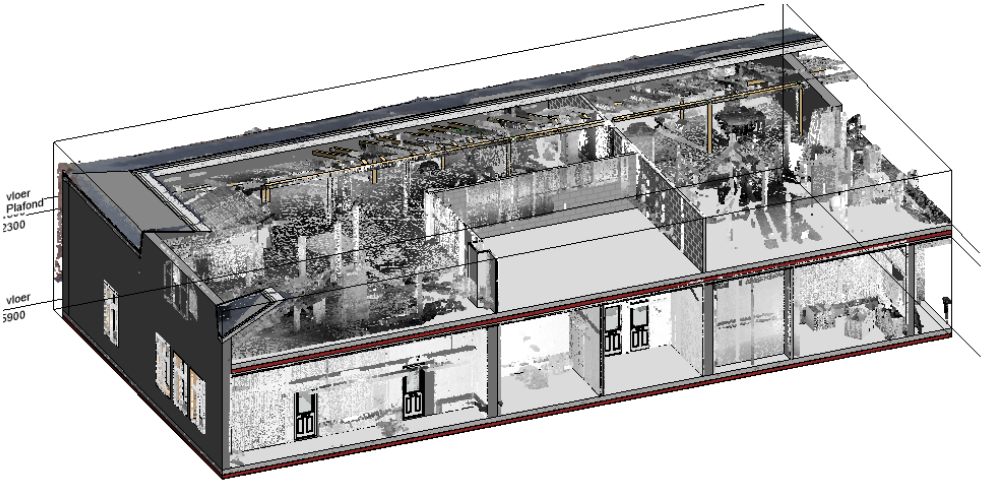


FIGURE 31. BIM model with point cloud

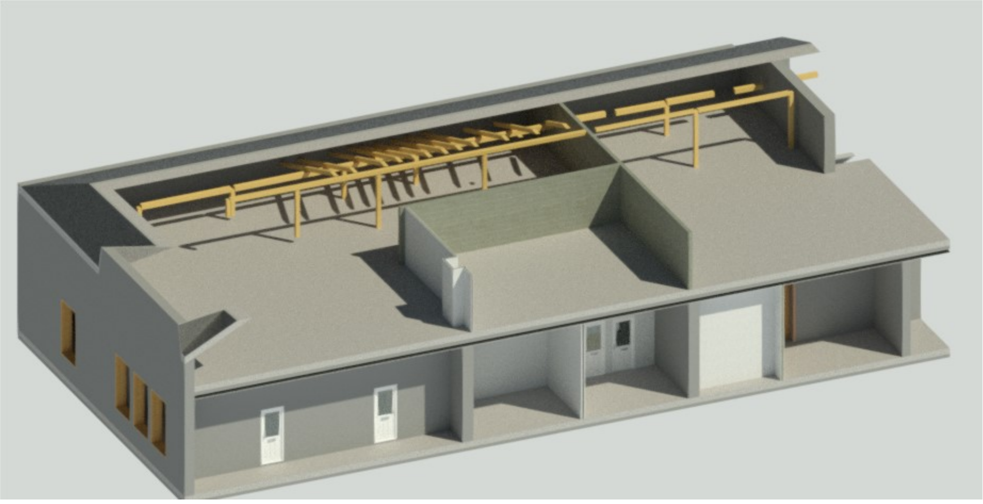


FIGURE 32. BIM model withouth point cloud

4 DISCUSSION

In this paper, the entire process was discussed from scanning an existing building to delivering a useful BIM model. Special attention was given to the use of the Faro As-Built Solutions for the automatic detection of building parts.

The process in general was very time consuming for this project. The processing of the scans in Faro Scene was time-consuming due to the use of both target-based and cloud to cloud methods and the suboptimal conditions in which the scans were made. A combination of these made it impossible for the processing to be completed automatically. When the conditions are better and the scans are made in high resolutions and with the use of targets in the complete project, this step can be semi-automatically completed by the software and does not take as long.

Another aspect which complicated the process was the use of both laser scanning and drone footage. While this is certainly possible, the lack of shared targets made the cooperation difficult. Both point clouds were georeferenced but combining the point clouds proved challenging and the accuracy, especially on the z-axis, was restricted. As the point clouds were made using different softwares, combining them is not ideal. When possible, using laser scanning for the exterior of the building would solve this problem. Drones can nonetheless be useful for capturing large construction sites. In this case, having common targets with the interior laser scans would simplify the alignment.

4.1 Results

To make a BIM model of this point cloud, Faro As-Built for Revit was used. An evaluation of the software was made by answering the following questions:

Are simple features such as walls, ceilings and floors detected?
Nothing is automatically detected, however, walls are modelled by clicking 2 points inside the wall. The software will then estimate the thickness of said wall.

The process is not automatic but it is easier than without the As-Built software because the software uses the lines of the scans to estimate both thickness and location of the wall. The operator does not have to estimate these things, he can however change if the thickness of the walls are known. Ceilings and floors are modelled on the top and bottom of the already modelled walls by clicking on the walls which are the borders of the ceiling or floor.

Are features such as doors and windows detected?

Doors and windows can be modelled by clicking 2 points diagonally on the corners of the door or window. The operator can choose to create a new family when doing so to have a window family with the right dimensions. By deselecting this option, all windows can be made the same dimensions to avoid multiple window families with minimal differences.

Are nonhorizontal or nonvertical features such as stairs, sloped roofs and beams detected?

There is no function for stairs in the As-Built software. Stairs can be designed in Revit and changed so they look like the scanned stairs. This is a time-consuming process with low accuracy.

Sloped roofs are not foreseen in the As-Built software. It can be modelled using the normal Revit commands and using the point cloud as the goal. This method can achieve satisfying results, but accuracy remains dependent on the quality of the point cloud and the skill level of the modeller. A dedicated As-Built tool would be useful in the case of complicated roofs with dormers, which would be more challenging and time-consuming.

Beams and columns, such as the roof structure of the building of the case, are modelled using the “Add structural element”. This is done by clicking two points on the same face of the element. There is a feature for aligning these elements and the columns can be connected to the floor or ceiling the same way walls can be connected.

How does the software deal with occlusions in the scans?

As long as the corner points of the wall are visible and the thickness of the wall is visible in a part of the wall, it can be modelled and occlusions are no problem.

Windows and doors can be found as long as the occlusions do not prohibit the operator from selecting 2 corner points diagonally.

Are the detected features placed correctly and how do they connect?

At first, the walls are placed using only information about that wall itself and it does not hold other walls into account. The align walls feature can be used, which tries to make walls perpendicular to each other and join unjoined walls. The doors and windows can be easily moved with the arrow keys in the case of translations. If the size is wrong it is easier to delete the object and add it again.

How is the detection of pipes?

Before the pipe system can be modelled, the pipes, fittings and valves have to be loaded into Revit. When modelling visible pipes, and especially intricate pipe systems, there are often a lot of occlusions. These do not pose problems as long as the operator can still see the beginning and end of the pipe and it is made sure it is the same pipe. Because the scans are taken from ground level and the pipes are usually placed near the ceiling, the resolution is limited. This can pose problems for small pipes as there are not enough points anymore to detect the pipe. Another problem is when multiple pipes are crossing or stacked on top of each other, in this case only the lowest pipe is detected.

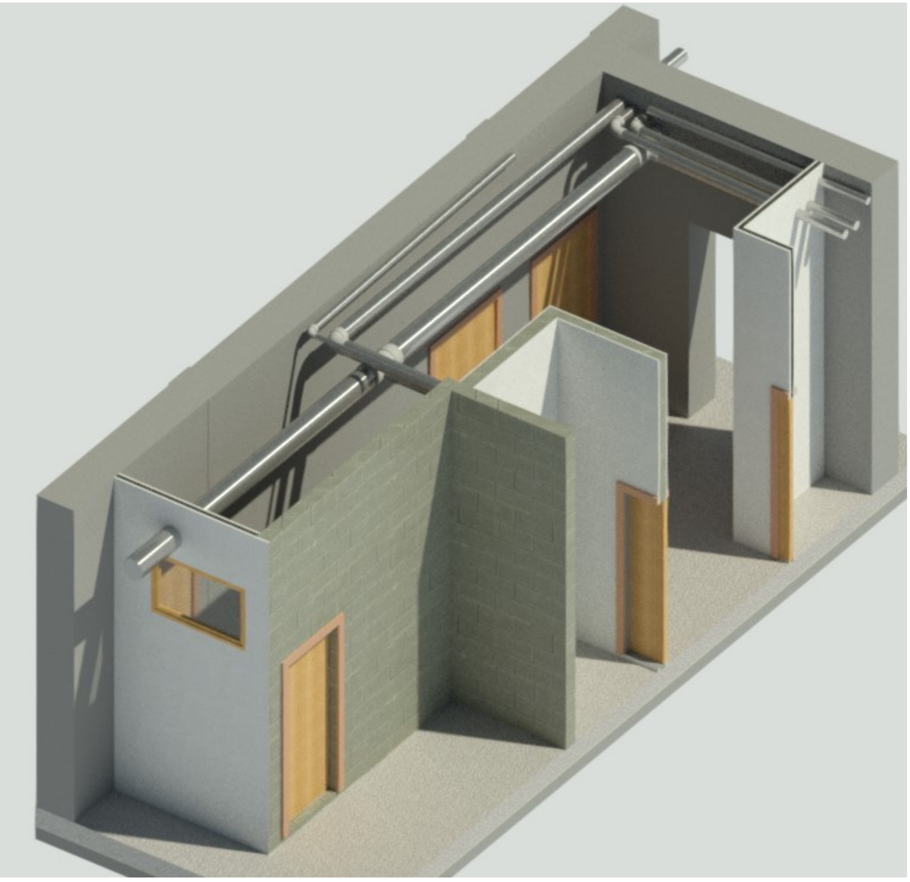


FIGURE 33. Pipes on the ground floor

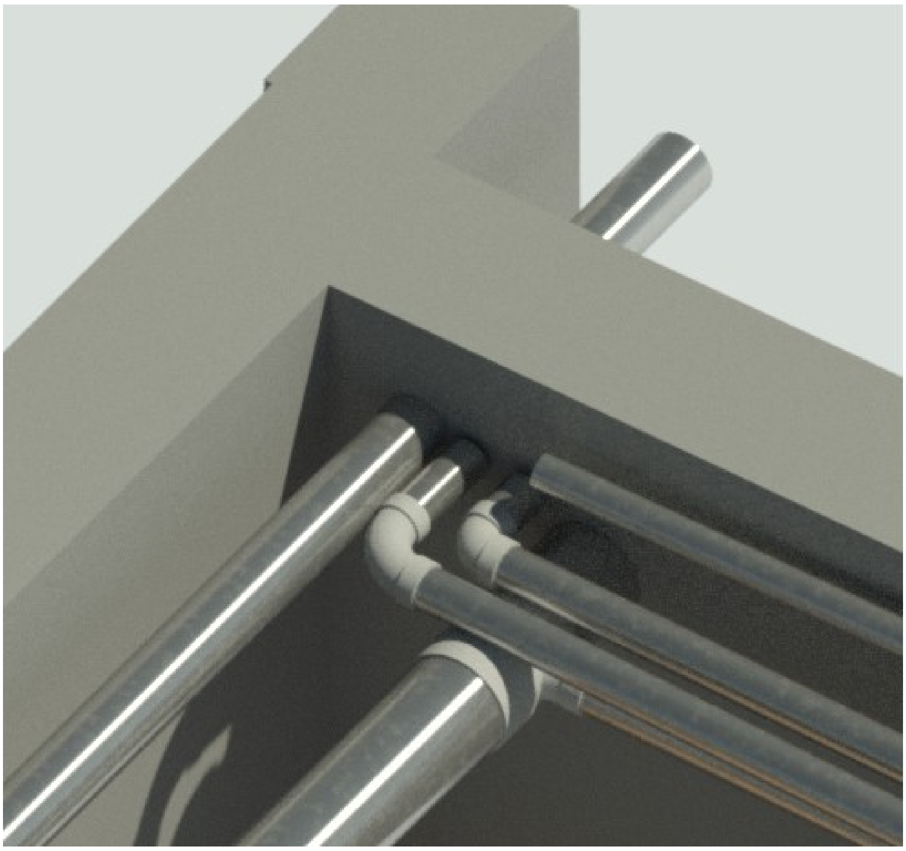


FIGURE 34. Detail of the pipes

there are two pipes of which one end is not connected to anything due to a lack of visible points. The scans were made to model the entire building and were therefore not perfect for this application. When making scans for the modelling of pipe systems, resolutions and scan positions can be chosen to maximise the visibility of all pipes.

In this study, it was chosen to only model a small part of the pipes because this is not the core of the research and there is not enough time to model all pipes. A section with pipes of multiple diameters and some pipe fittings was chosen. When modelling big pipe systems, it is advised to research papers specialised in this field.

Can the accuracy be checked?

Faro As-Built includes a feature which measures the distance between a certain object and the point cloud, this gives an idea of how accurate the model is in respect of the point cloud. Doing so is a check of the modelling process and assumes the point cloud is of high quality and is the “correct solution”. Because of this and the fact the combination of the drone point cloud and the scanned cloud posed accuracy problems, the check is performed on an interior wall.
This check can be found under the name Surface Analysis in the As-Built Analysis ribbon in Revit.

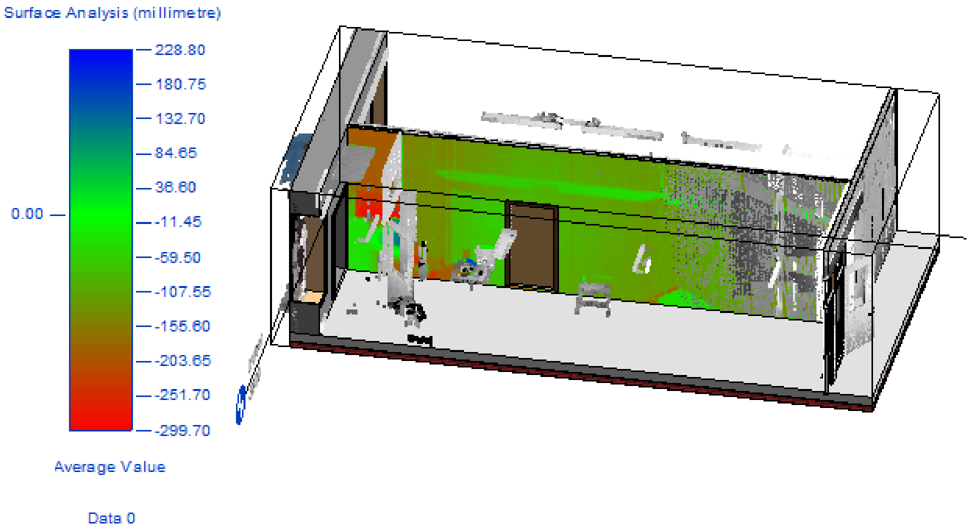


FIGURE 35. Accuracy of wall

It is visible that most of the wall is coloured green, which means a maximum deviation of 100mm. The places that are not green are cupboards or clutter. The scale has to be changed to see the accuracy of the model.

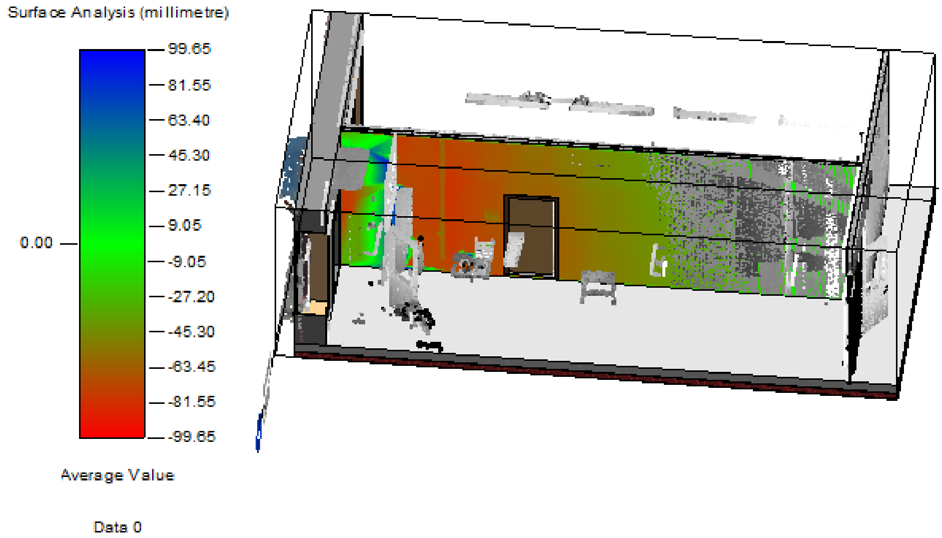


FIGURE 36. Changed scale

A big section of the wall is red, while no parts of the wall are coloured blue. This can be solved by moving the wall to the back.

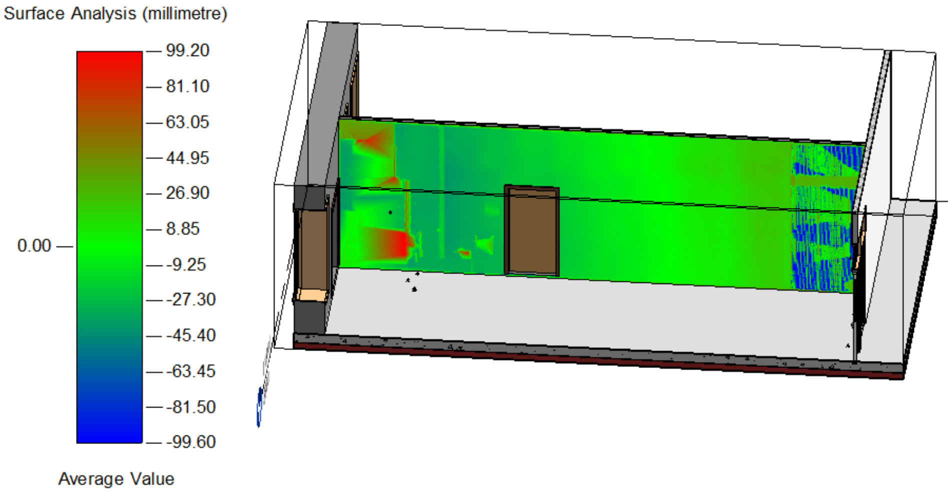


FIGURE 37. Accuracy after moving wall

After moving the wall, the whole wall is coloured green except for the zones on the sides where cupboards and clutter are located. The scale is so big that the green zone means a distance of maximum 30 mm, which is still a rather big error.

After changing the scale, it is visible that most of the wall is maximum 15mm away from the point cloud. When interpreting this figure, it can be interpreted that the wall is rotated as the left side is blue en the right side red. This might be a result of making the walls perpendicular with the align walls feature.

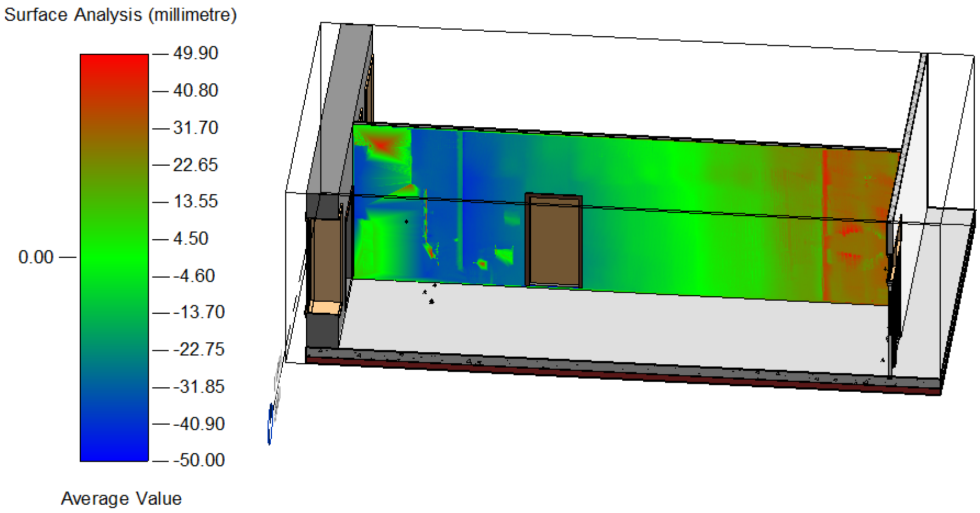


FIGURE 38. Accuracy after moving, changed scale

Time consumption

As there is no time in this research to model the building both with and without the software, a comparison on how much time the total process takes is impossible. An estimation of how much time each step takes will be given. It has to be noted that this was done by an inexperienced user, some steps needed a trial-and-error approach and in some cases even some research in order get them right. Modelling these objects a second time would take considerably less time.

- Ground floor
  - Modelling the walls and aligning them: 3 hours.
  - Doors and windows: 4 hours
  - Floor and ceiling: 15 minutes
  - Pipes: 2 hours
- Upper floor
  - Modelling the walls and aligning them: 1 hour
  - Roof structure: 4 hours
  - Doors and windows: 1 hour
  - roof: 2 hours

4.2 Summary

In general, the software is certainly useful in the process of scan-to-BIM. Complete buildings are easily modelled with, amongst others, walls, doors and windows. The software can also be used to model pipes and structures in an industrial setting when the scans are suitable for these applications in terms of scan position and resolution. Some caveats in the arsenal of the Faro As-Built software include the modelling of stairs and roofs.

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LIST OF FIGURES

APPENDICES

Appendix 1. 3D View after registration

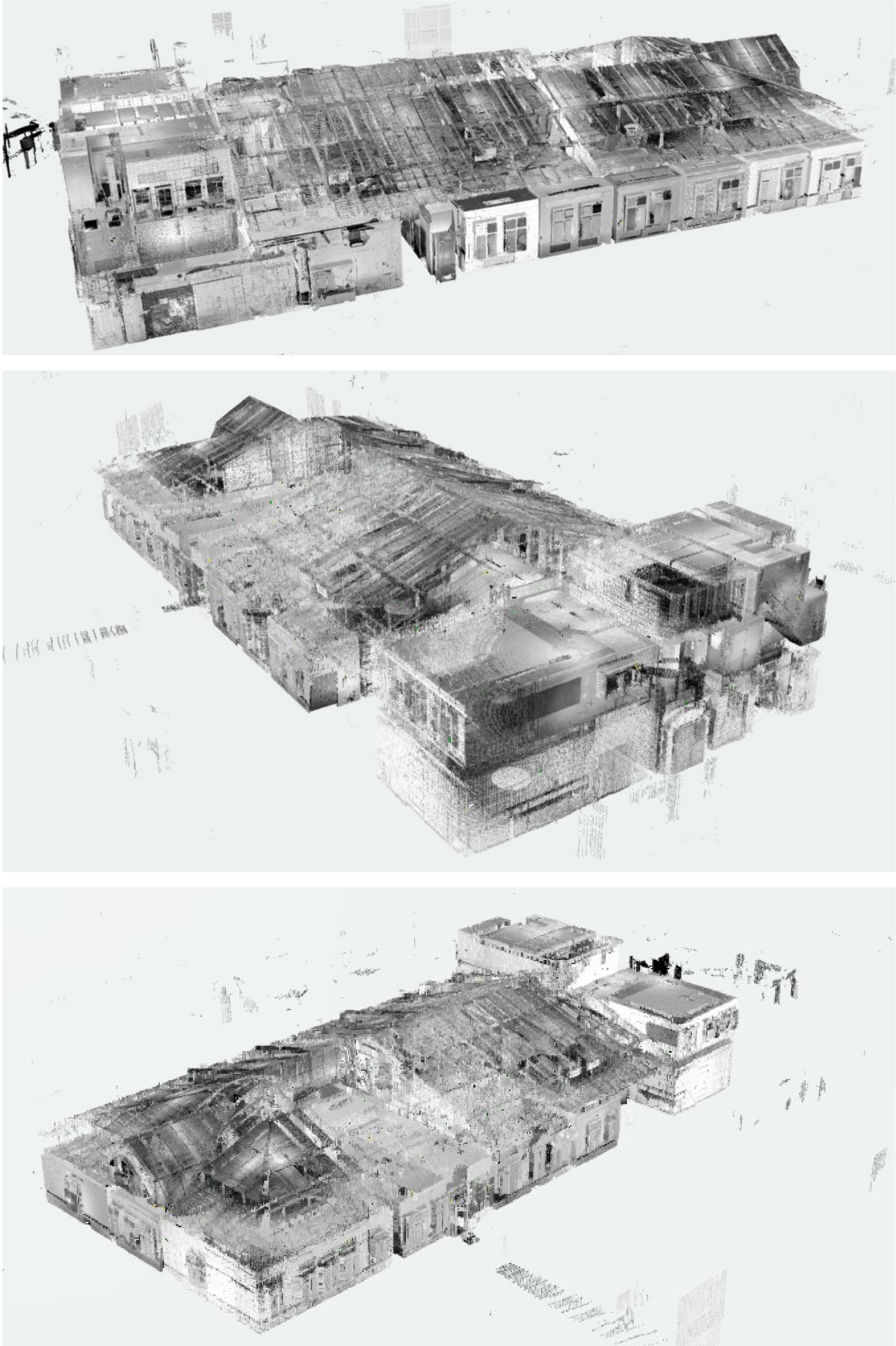
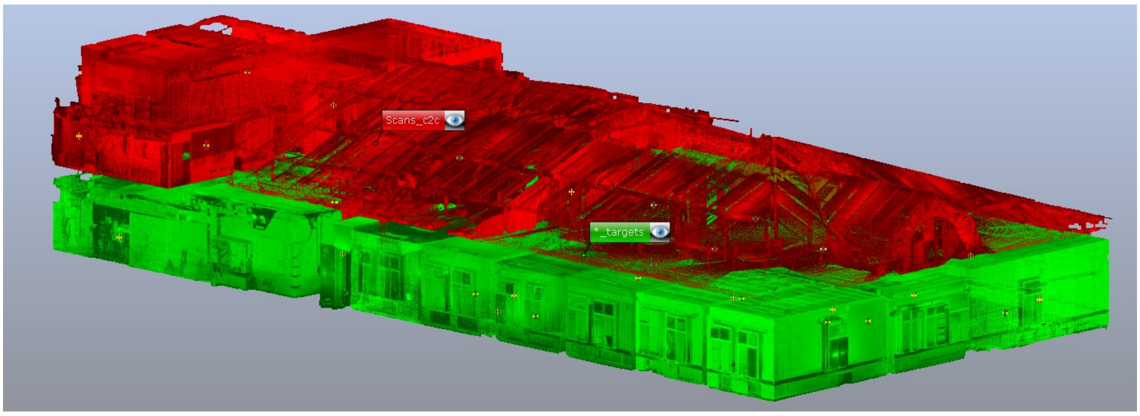
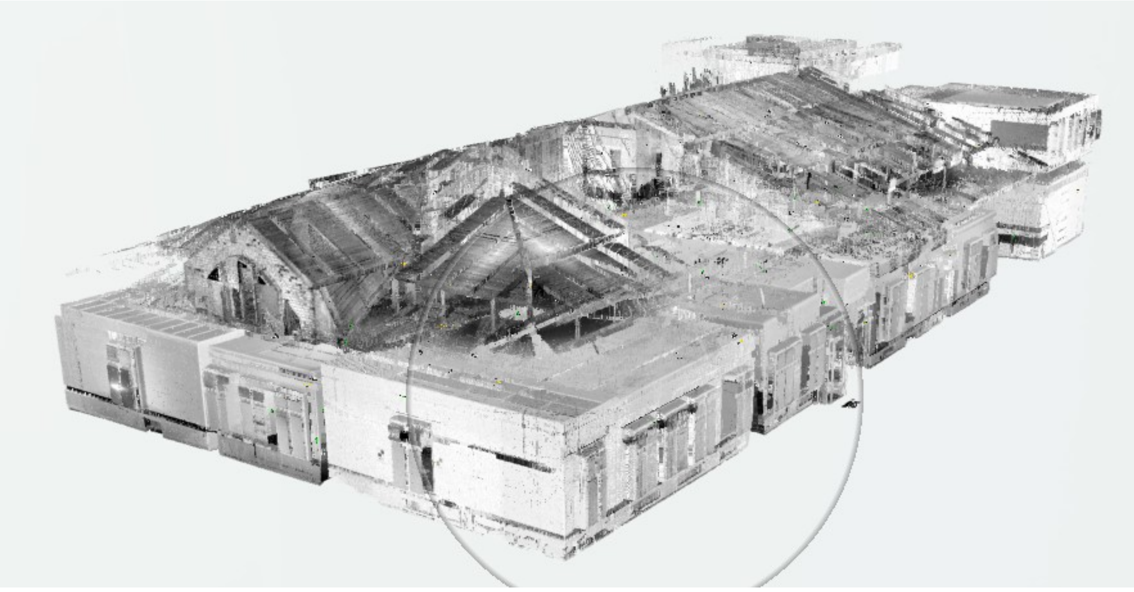
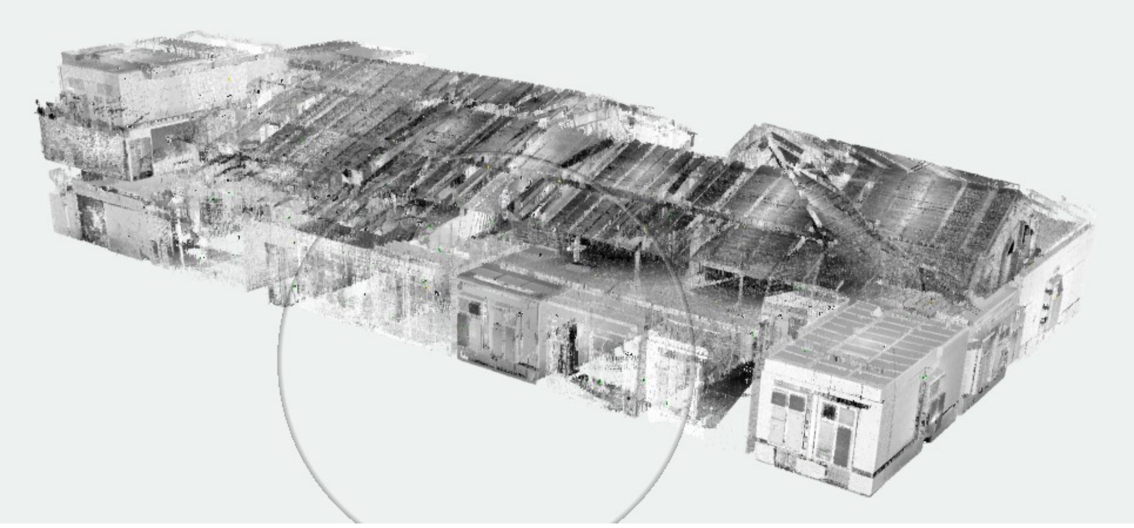


FIGURE 39. 3D view before cleaning

Appendix 2. 3D View after cleaning stray points







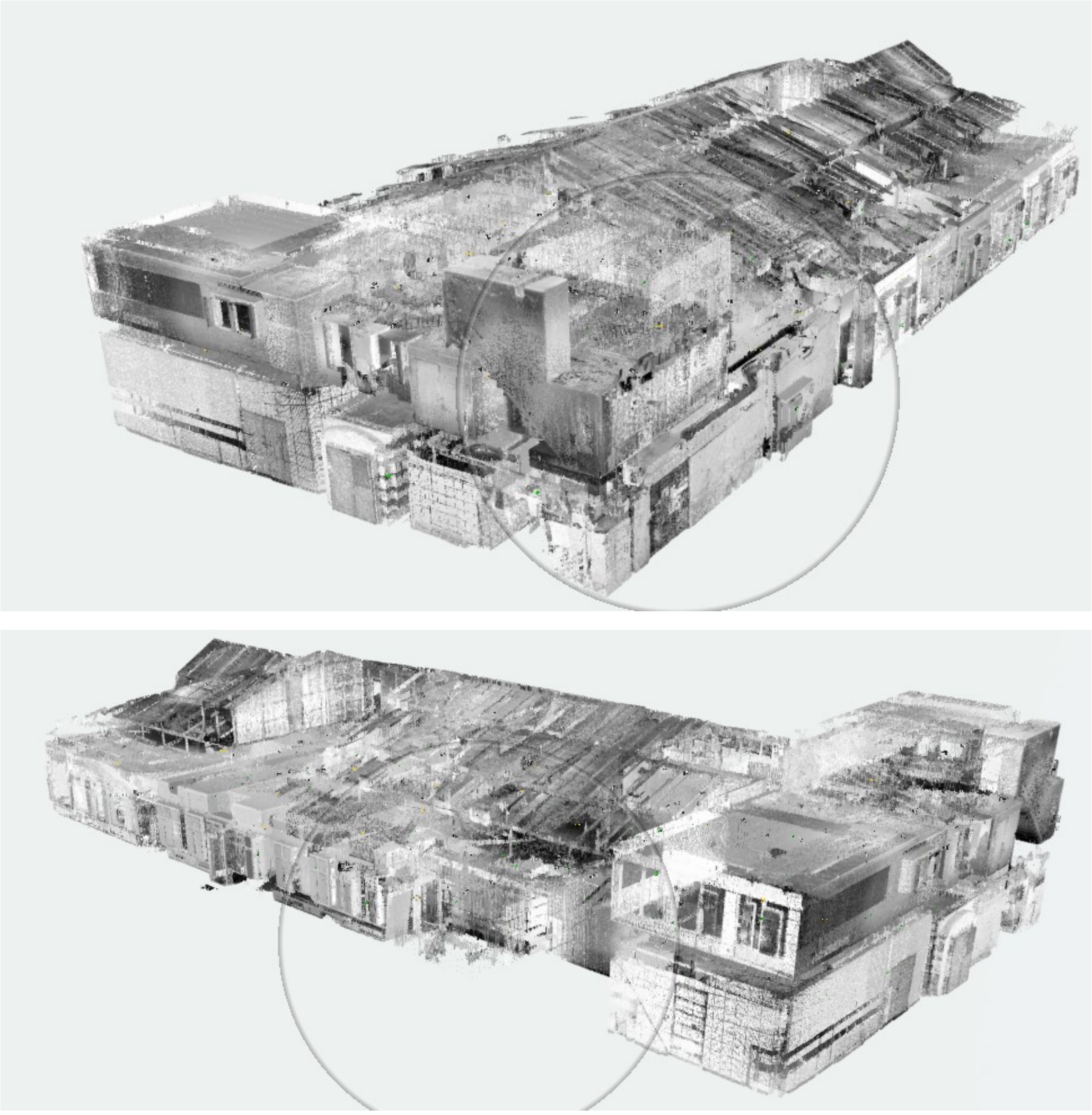


FIGURE 40. 3D view after cleaning

Appendix 3. Point cloud of the drone

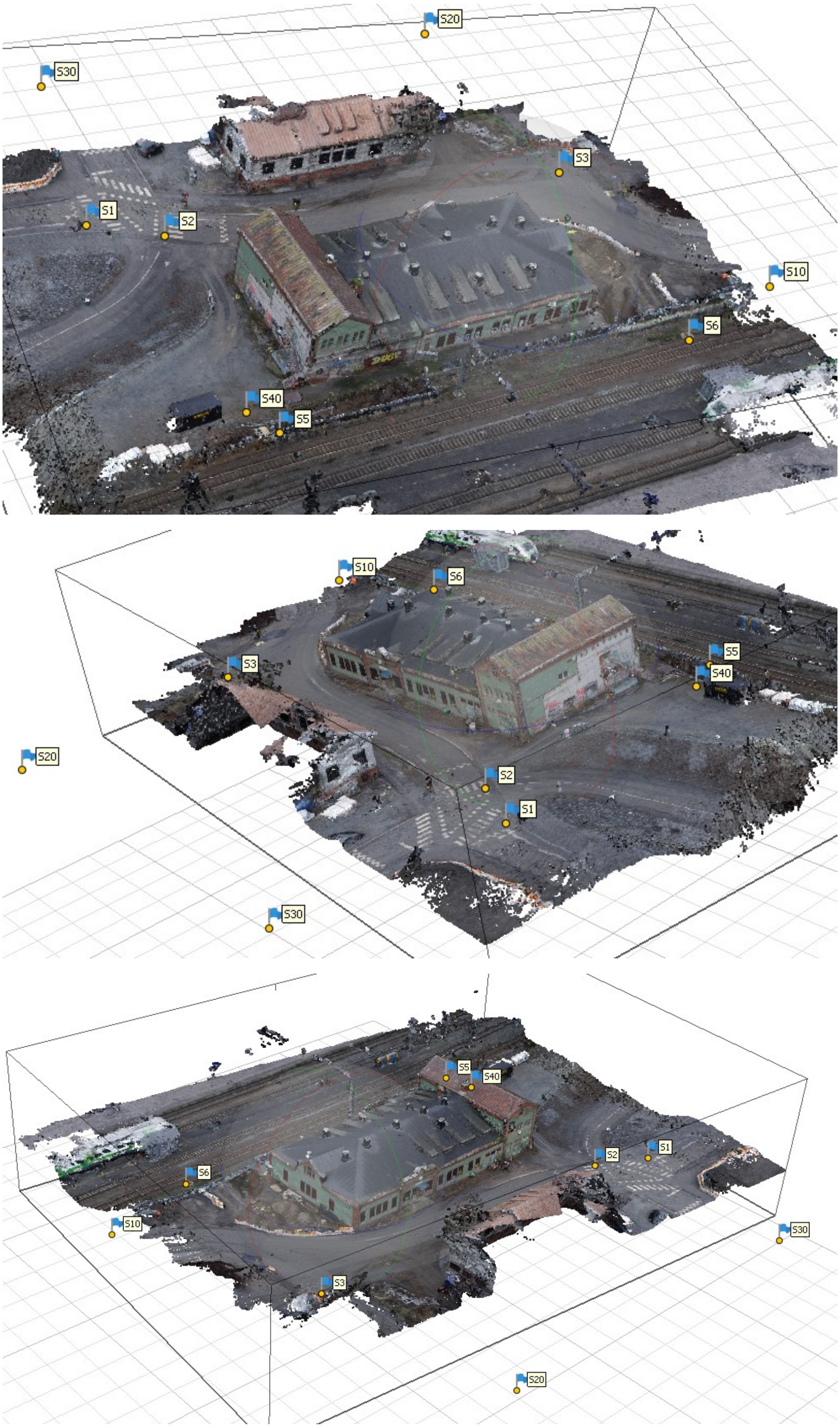


FIGURE 41. Point cloud drone

Appendix 4. Step-by-step modelling roof structure

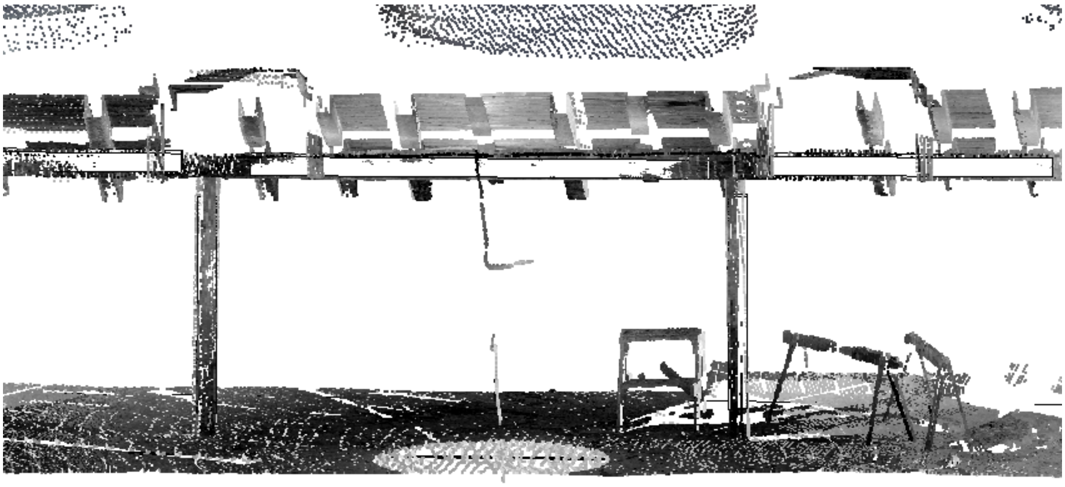


FIGURE 42. Columns and beams in the point cloud

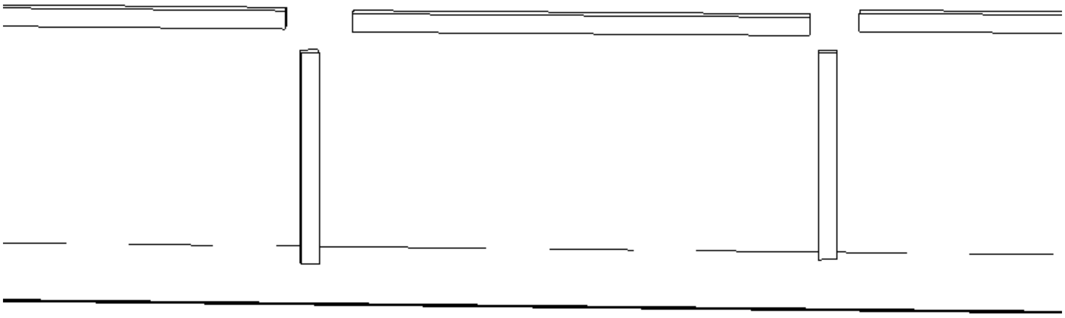


FIGURE 43. Columns and beams without the point cloud

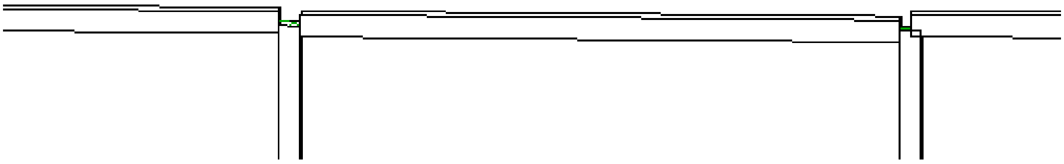


FIGURE 44. Columns and beams after alignment

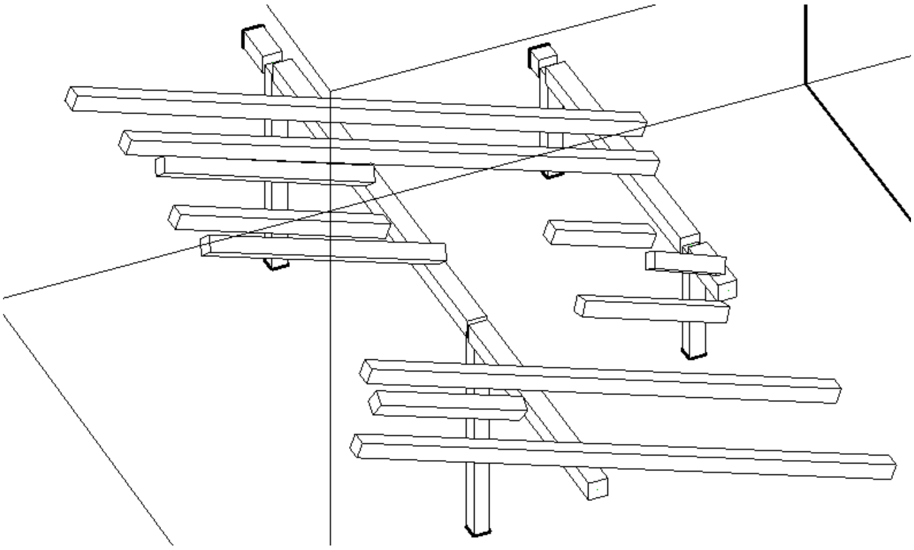


FIGURE 45. Roof structure as detected

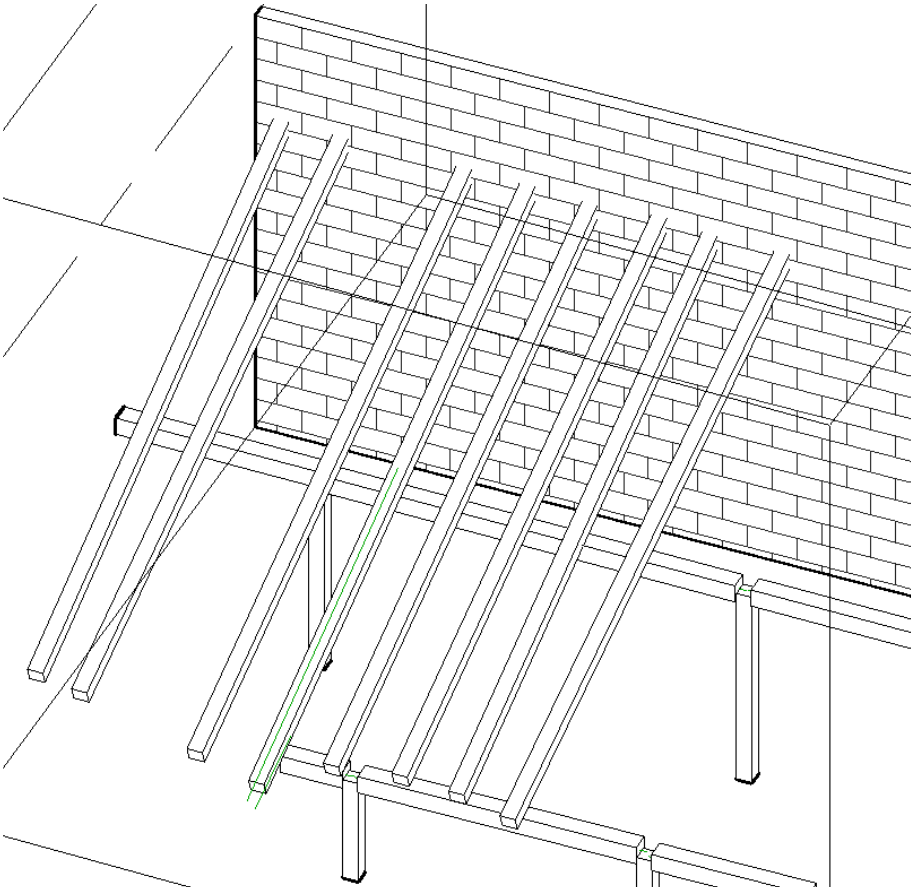


FIGURE 46. Modelled roof structure

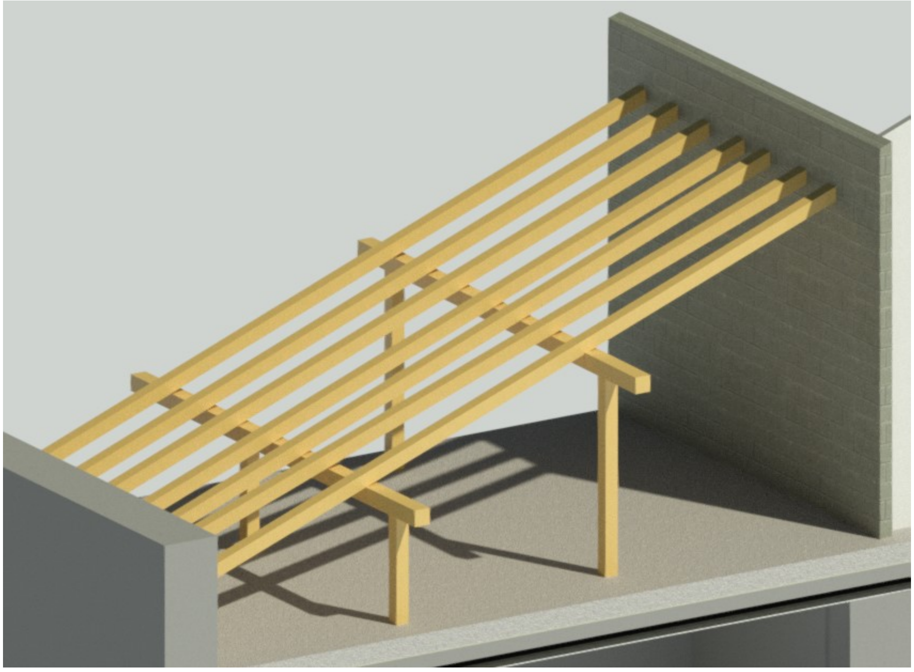


FIGURE 47. rendered roof structure