# Application of 3D point cloud scanning for asset management through IFC validation in indoor environments

*7ZM1M0 – RESEARCH & DEVELOPMENT PROJECT*

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**Date: 26 January 2023**

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# Colophon

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Course: RESEARCH & DEVELOPMENT PROJECT
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# 1. Introduction

Building Information Modelling (BIM) has been improving the construction industry and its workflows in many, if not all of its branches. Through a methodology where interconnected information is added in a meaningful way to compose a digital project, a building project and operations involving it (automated extraction of floor plans, quantities, and details, for instance) become much more efficient.  Notably, improvements can be seen in coordination of the different disciplines involved in the construction process, improved technical visualization and technical drawing extraction, better collaboration between stakeholders, better simulations, cost estimations, progress monitoring, and issue management and Facility Management (FM) ( Borrmann et al., 2018).

Whereas the methodology of BIM gained traction by changing the new building construction industry, much of the housing and real estate stock was built at a time where 2D representations were prevalent. Even for the cases where BIM models were available, in situations where renovations at a section of a building are performed, the contractors may not share their drawings of the new section, or drawings can still be done in 2D (Thomson, 2018). Then, the original BIM file of the building will contain obsolete information for the renovated area. In this scenario, the as-is situation of the building is unknown and the available information on material quantities, measurements in the layout and information on building elements becomes unreliable.

Incongruencies in BIM models can also be the result of poor in-situ surveying to assemble a BIM model of a building that had no such model available, or human mistakes when creating a BIM model from available 2D drawings (that are often incomplete).

To execute a major renovation, a building disassembly to reuse the materials, or other FM purposes, it is important to have precise information of the as-is state of the building. To circumvent the challenges mentioned above, a quick way to compare the as-is condition of the building to the available BIM model is desired so that Facility Managers can be aware of the validity of the model available and perform the necessary changes.

## 1.1. Research Question and sub questions

To investigate the possible solutions that can improve the process of updating an outdated BIM model into its current as-is state, and check if the geometry available is valid, the following question is proposed:

*What could be an effective process to check discrepancies in available BIM models when compared to their as-is state, in a simple way and using accessible tools?*

For which the following sub questions can be raised:

- *What is the best way of surveying the as-is condition of a Building?*
- *Can Point Clouds obtained by mobile phones' sensors be used to evaluate discrepancies between a BIM model and it's respective as-is state?*
- *To what extent can this checking process be automated? What changes can be made by a programming tool that automates the checks?*
- *What is the most accessible workflow to overlay the BIM model and as-is geometry and measure discrepancies?*

## 1.2. Literature Review

Even though much progress has been achieved by the construction industry in the last decades with the advent of BIM, the development of BIM has been focused on planning new buildings (as-planned models), and little attention has been given to BIM tools that allow management of existing (as-is) buildings (Volk et al., 2014; Scherer & Katranuschkov, 2018; Werbrouck et al., 2020). This might have happened due to the previous (existing) building stock having its data stored in sparse and often incomplete 2D data, and to avoid all the rework of creating and assembling this data, the BIM process was started with its focus on the new building development market.

Another challenge that hampers the development of as-is BIM models for the existing building stock that was built at the pre-BIM era, is the burdensome and expensive process of conducting surveying of the spatial information, to then pass this information onto BIM models, in a partially if not completely manual process. The elevated costs to perform geometry surveying in high definition, the specialized staff required to do this survey, and uncertainties on information about the building are seen as some of the limiting factors to achieve broader as-is BIM model development for Facility Management (Volk et al. 2014, El-Din Fawzy, 2019; Kavaliauskas et al., 2022). Nonetheless, point cloud acquisition is seen as the best resource in digitalizing geometries of real world objects (Werbrouck et al., 2020). Furthermore, Werbrouck et al. (2020) consider the upcoming advancements in BIM tools to soon become as important to the management of existing buildings as they currently are for new building construction.

With the recent efforts of society and institutions to make the built environment and industry more sustainable and energy efficient, an increased demand of work in renovation and facility management is expected for two reasons: Buildings are expected to be used for a longer lifespan in order to reduce waste and raw material use, and many existing buildings are also expected to undergo renovations and retrofitting to make them more sustainable (better insulation, heat pump installation, double or triple glass installation on windows, etc). Scherer and Katranuschkov (2018) consider the improvement of BIM application to retrofitting of buildings a process of utmost importance to achieve the necessary upcoming sustainable and energy efficiency goals, and the creation of BIM models of existing buildings as an important challenge to be overcome. The current moment could therefore pose a nice opportunity to look for better workflows and technology applications to collect the as-is condition of buildings.

As mentioned above, point cloud collection is considered the best method of representing real world geometry, when it is desired to digitally collect and use this geometrical information. Often a Scan-to-BIM or Scan-vs-BIM approach is used. Scan-to-BIM refers to the process of creating BIM models based on the scan of an environment, and Scan-vs-BIM implies the comparison of an existing BIM model and the as-is retrieved information of the building. A Scan-to-BIM approach is often used in older buildings that do not have an available BIM model (Werbrouck et al., 2020), whereas a Scan-vs-BIM approach is often used to track construction progress (Golparvar-Fard et al. 2009; Kim et al. 2013; Chen & Cho, 2018; Dülger, 2020). However, Scan-vs-BIM approaches can also be used in facility management (Son et al., 2015; Chen & Cho, 2018), and to correct differences between as-built and as-planned models (Bosché et al., 2015, Chen & Cho, 2018), and to update outdated models, which can occur after a renovation is done (Thomson, 2018).

When small renovations are done by a contractor, there is no guarantee that the changes will be updated into the existing BIM model, and if they are they can stay with the contractor and not be available to the facility manager, and the BIM model is needed in the future for management reasons or future renovation the models may not be available anymore. For the case of "do-it-yourself" renovations performed by owners the odds of updated BIM models are even lower. Those small renovations can nonetheless include relevant layout and model changes such as changes in interior walls. BIM models that are made based on 2D drawings, can also have wrong information, either by lacking information at the 2D model that was "guessed" when creating the BIM file, or by human error.

Facility management (FM) can therefore be aided by the introduction of better tools and applications of existing tools to keep the as-is version of the building updated for better management. Tools that capture the as-is state and over-lay it with the as-planned project to update the BIM model can also be useful for renovations, even if the updated models were earlier deemed unnecessary for simple management reasons.

Dülger (2020) developed a tool based on the theory laid out by Turkan et al. (2012) and Tuttas et al. (2014) to spot building elements in the construction site in order to follow construction progress. The tool worked overlaying a BIM model of the expected construction progress for a given date with the point cloud scan of that date. Once the geometries are overlaid, a check is performed to identify the presence of built geometry at the places where construction progress is expected to be done that day. This can be done by dividing an IFC element in grids, creating bounding boxes around those grids, and checking for sufficient point cloud density around the bounding boxes of the expected progress. Therefore the tool is not focused on identifying IFC element types, but rather performing a geometric check of "whether there is an as-is volume at the place there should be an as-planned volume or not". This can generate limitations and data confounding when other objects are laid at a place a building element should be. Nonetheless, given the limitations of point cloud surveying (only geometry information can be collected, identification of elements is done by algorithms, notably Machine Learning models), the tool can be considered as having good results. A similar methodology could also be applied to check whether the building elements that were planned to be at a certain position were also built in that position. Alternatively, it can also be checked if changes were made in comparison to the original project by, for instance, a renovation.

## 1.3. Objectives

The current research aims to explore the currently available tools and literature for Scan-vs-BIM procedures, and investigate how point cloud data collection by remote sensing technology works and can be applied to check and update indoor environments of BIM models. It is desired to test a workflow that is as accessible as possible, as indoor scanning of environments is often seen as expensive and requiring expert knowledge (El-Din Fawzy, 2019; Kavaliauskas et al., 2022).

Furthermore, it is sought to better understand the functioning of available tools that make use of programming languages to execute automated checks, and investigate if (and how) they can be used to solve the research question proposed. To make the research methodology more concrete, a case study is developed based on a real BIM model and point cloud data collected.

### 1.4. Research Methodology

The stages that subdivide this work in order to investigate the research questions are: Literature review to better understand the tools available; on-site collection of data to validate the methodology approached; BIM model collection and processing of data; exploration of available tools to see the best methodology.

The literature research pointed out that the best method to collect as-is information of a building is by point clouds. Those can be obtained by photogrammetry or laser/LiDAR scanners. A LiDAR scanner from a mobile device is chosen for this research, both because LiDAR and laser scans are better at depth recognition, and because testing technology more easily available (such as mobile phones) can pave the way towards more accessible and user centric data collection, which can help in solving the current deficit in as-is models.

The point cloud data is collected from a room at the building Atlas from the Eindhoven University of Technology, for which a BIM model is available. Tools used to check the BIM model based on the as-is surveying were CloudCompare and a python tool developed by Dülger (2020).

### 1.5. Research Limitations

Laser scanners and LiDAR scanners are based on light beams and the return time of a beam, through which the depth and distance of a point is measured. However, depending on the reflective properties of surfaces, the measurement of distances is inaccurate, especially for glass surfaces such as glass windows, facades and doors. Furthermore, point cloud scans are restricted to collecting geometric information on visible elements – material properties and e.g. elements encased inside a wall or ceiling cannot be asserted. Depending on the characteristics of a building, entire MEP and HVAC systems can be embedded in not visible parts of the building, which can be detrimental to have a full picture of the as-is condition of the systems contained in a building. The python tool described in the literature review can provide some use to the research questions proposed, but does is designed and to a large extent limited to a different application.

## 2. Methodology

Starting from the need of more cost-effective as-is surveying applications, that was identified in the literature, the current research looks for a method to assess and evaluate deviations in as-is conditions for already existing buildings by using accessible tools that do not require expert staff or professional surveying equipment. To this end, an available BIM model (of the floors 8 and 9 of the Atlas Building at TU/e) is used, and point cloud data of it is collected using the LiDAR sensor through the Polycam app. Furthermore, CloudCompare is used to do adjustments in the point cloud and overlay it with the BIM model. A python tool that works with overlaid STEP files and point cloud files, and checks if the expected STEP geometry of each element (e.g. each wall) is present in the point cloud or not is applied, as even though it is designed to monitor construction progress, it has a close enough application.

## 2.1 Point Cloud collection

The data is collected using the app Polycam in an iPhone13 Pro. This phone model was chosen because, at the time of this research, devices from the brand Apple (iPads and iPhones) of the label “Pro” were the only mobile devices that possessed a LiDAR scanner sensor.

Due to the advance in Augmented Reality (AR) applications (for which LiDAR sensors are useful), it can be expected that soon more models will adopt this technology and it will become more widespread, besides expected improvements in the sensors. This points in the direction of applications involving point cloud data collection by phones becoming increasingly more accessible, especially for companies, where at some point acquiring expensive professional equipment and hiring a surveying expert might not be necessary, depending on the scope of the work.

Several apps are available that can collect point cloud data, such as magicplan, Polycam, and Pix4D. In this research Polycam was used. Polycam has two different modes of collecting point clouds using the LiDAR scanner: raw LiDAR data and Room Mode. For the raw LiDAR data each surface has to be covered by the scanner in a process that takes mode time than the Room Mode scan. Room Mode uses help of artificial intelligence and user input to locate walls and corners and generate the room geometry based on those points collected in space, instead of scanning every section of a wall. Furthermore, Room Mode also recognizes windows, doors, and many types of furniture. It is also possible to extract raw LiDAR data from a scan performed using Room Mode. To obtain the best results using this methodology, it is recommended to cover the largest area of walls, floor, columns, and roof possible, instead of just the minimum to find the main surfaces and corners. Care should be taken not to take too long, however, as the movement sensors that help tracking the point cloud collection (while the user moves) might stack slight measurement errors, and start confusing in which plane a wall or the floor is. Figure 1 shows the interface of Polycam on Room Mode.

Point clouds can be exported in several file formats, such as .xyz, .laz, .pts, .ply. If the raw data of the Room Mode scan is not extracted, the point cloud model given will be a model with measurement adjustments given by the algorithm, to make the walls more regular and perpendicular, as shown in Figure 2. When the raw data is extracted, the walls retain the uniformity of point clouds given by Room Mode, and the data has more details and is less artificial (no added furniture by AI), as Figure 3 shows. Raw files are much larger though, with Figure 2 containing 78.660 points and Figure 2 containing 1.788.811 points. Raw files also contain RGB information on each point.

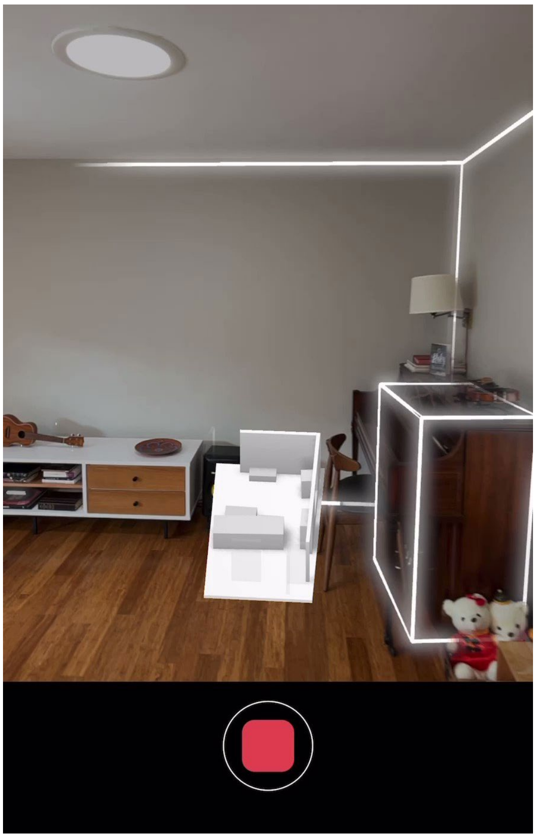

*Figure 1: Wall identification with simultaneous 3D model generation on Polycam*

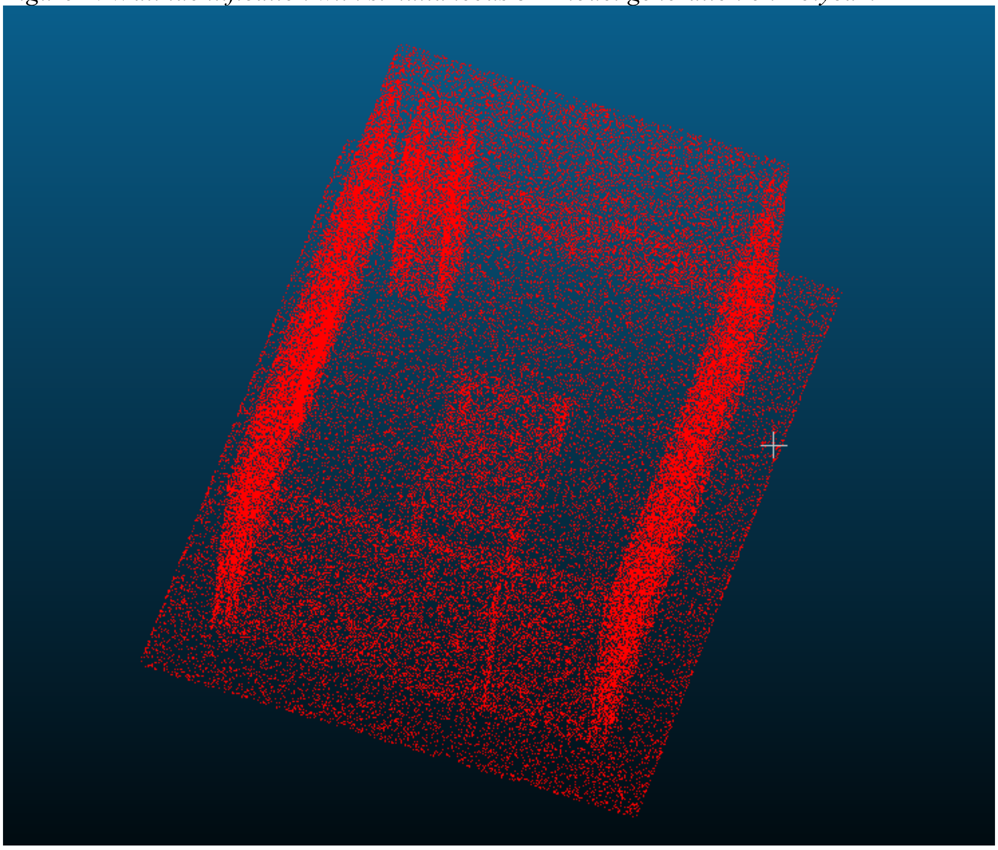

*Figure 2: not-raw Point cloud obtained using Room Mode*

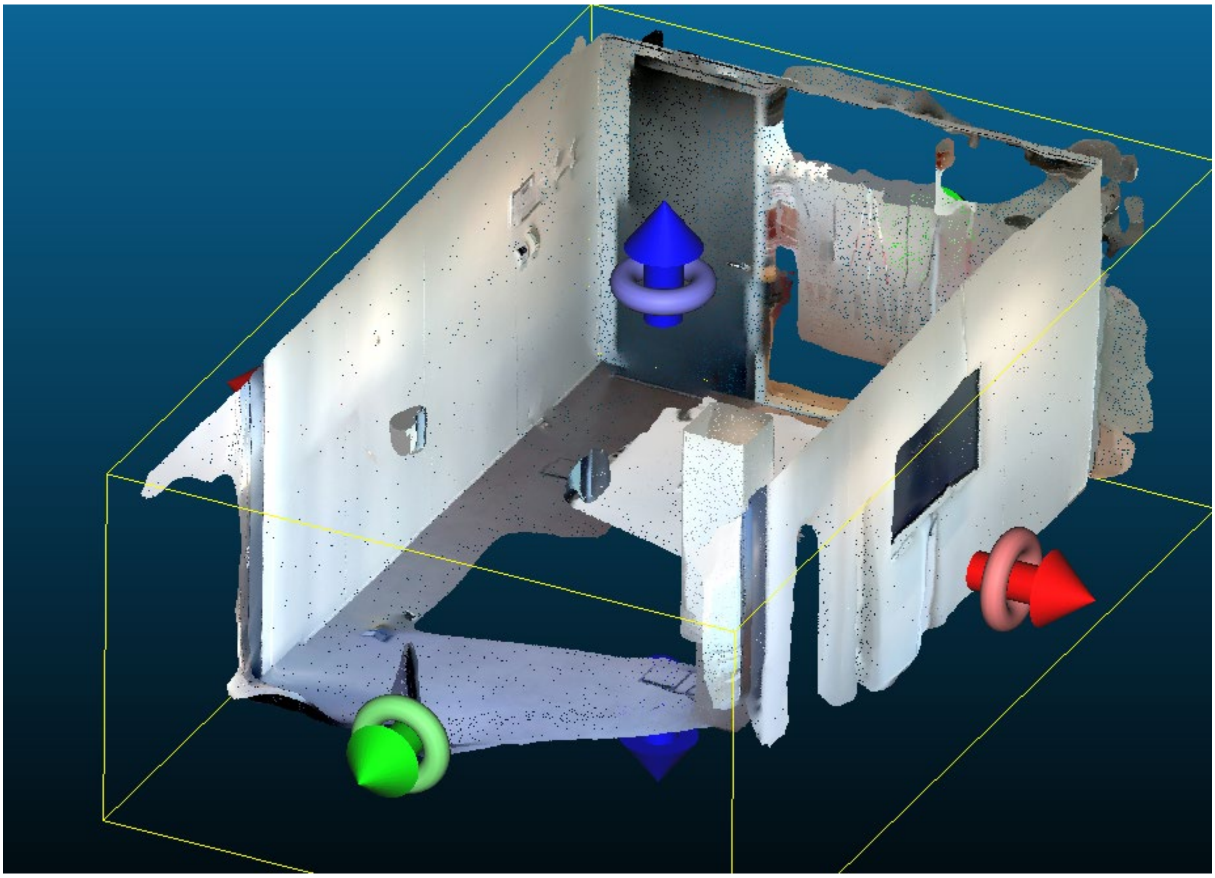

*Figure 3: Raw LiDAR data from Room Mode*

The room chosen to collect the data for the case study was the room 8.304 in the Atlas building, due to its size (larger room would take a longer time to test different types of data collection, as raw LiDAR data), and presence of some unique elements as the column, that can allow a comparison of BIM model and as-is geometry. The process of collecting data once for a room of this size (3,6 x 5 m) takes usually less than 10 minutes (even though data was collected more than once due to errors and different modes of collecting data).

Advantages of collecting LiDAR data are also that the point cloud already has measurements and real life scale assigned to it, because it is based on directly assessing distances of points. Photogrammetry techniques, due to their photography-based method, need to be scaled after collection, and that often require the use of targets at the collection site, whose distance has to be known. This further demonstrates the use of LiDAR sensors to make the as-is creation (or adaptation) of BIM models easier and faster.

## 2.2 BIM data used

The BIM model used was a BIM model of the floors 8 and 9 of the Atlas Building at TU/e, that is sometimes made available for assignments done by students. Because the python tool envisioned to be used later requires simplified STEP files with only 6 faced objects (no circular holes on walls, chamfers, etc), and because it is easier to overlay the point cloud of Atlas 8.304 with a BIM model of just that room, instead of the entire building, a simplified BIM model of Atlas 8.304 was created with simple walls, a floor, and a column, following the exact dimensions of the original IFC file. This simplified file was created in Revit, and then converted to IFC. After converting it to IFC, it was exported into STEP format using the software FreeCAD. The original IFC project of Atlas can be seen in Figure 4. Figure 5 shows room 8.304 at the original IFC file and at the simplified BIM model developed.

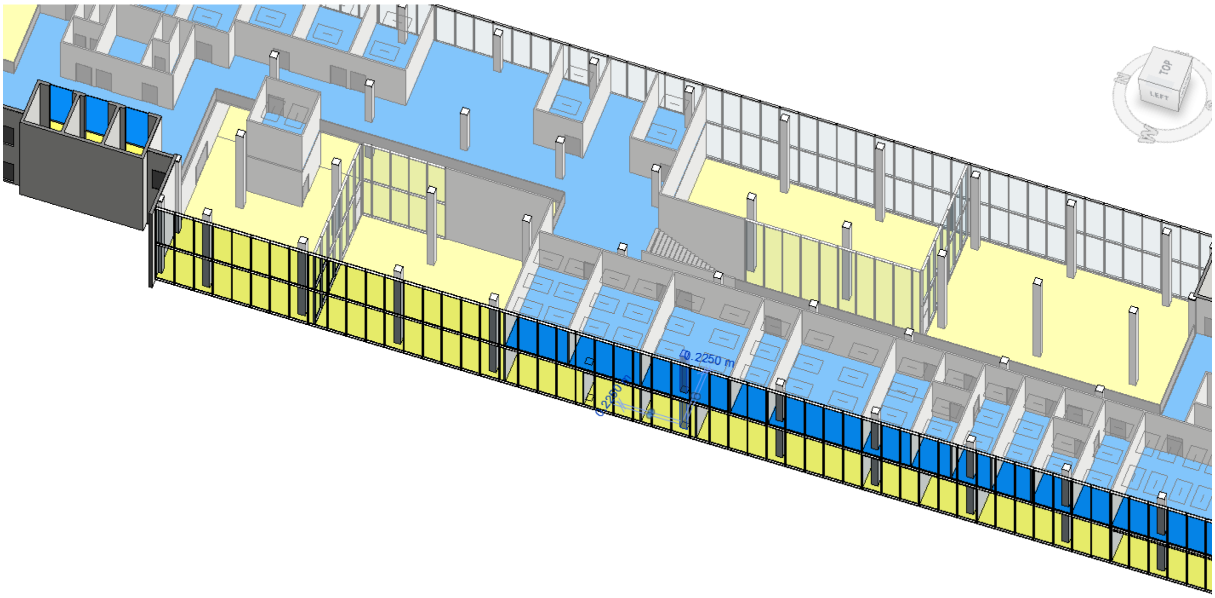

*Figure 4: IFC model of Atlas 8 and 9*

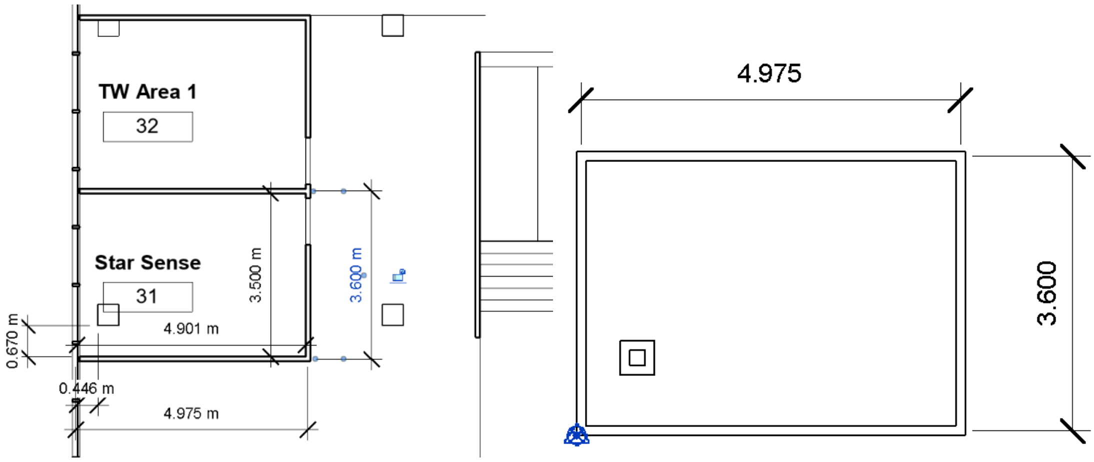


*Figure 5: to the left, Atlas 8.304 at the original IFC file, and to the right the simplified model*

## 2.3 Point Cloud adjustment and CloudCompare

To compare the geometries of point cloud and as-planned (or existing) BIM model, it is important to overlay them so that they match as much as possible. This can be done in CloudCompare, which is an Open Source free software that allows several operations using point clouds. STEP files are also a file format CloudCompare can work with, which makes it really useful for applications in the built environment. To overlay both geometries, both the point cloud and the STEP file of the building are opened in CloudCompare, and then they can be aligned using the "Translate/Rotate" tool. Even though point clouds obtained from laser scanning or LiDAR sensors already have an inbuilt scale and measurements, it may be necessary to scale either the point cloud or the STEP file depending on the unit the STEP file was drawn in (centimeters, millimeters or meters). CloudCompare also has other useful tools to compare distances, crop views (used in Figure 3 to show the interior of the model, cropping the ceiling away), convert point cloud files, and clean points from point clouds.

## 2.4 Python tool and other tools available

To perform the check of the BIM model it will be attempted to use the tool developed by Dülger (2020), which could help automating the checking process and automate the identification of elements that are not at the position they are expected to be. This tool is based on python and Open Cascade (pythonOCC), and uses PyQt5 to create an user interface that allows cheks to be performed and information to be extracted and exported about those elements. The tool can extract a list of their IDs and also color code the elements that differ in geometry, as Figure 6 shows:

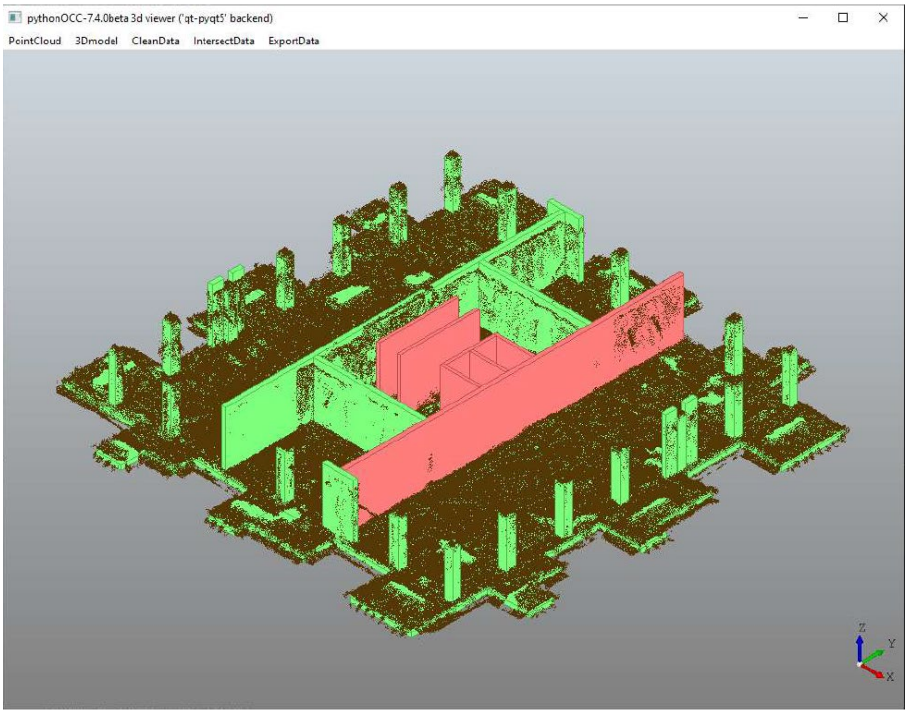


*Figure 6: Not identified elements shown in red and identified elements shown in green*

Limitations of the tool is that it does not identify the displacement of elements out of place, and it requires reworking models into simplifies 6 faced elements, to perform its geometry check. The tool also requires some manual steps done in CloudCompare, such as overlaying point cloud and BIM model. Besides, the tool is originally intended for construction progress applications.

# 3 Results

The data collected had satisfactory quality, and as expected when consulting problems that often occur with LiDAR scanneers, some difficulties were found with glass surfaces. This was particularly the case for the façade of the Building, that is completely covered in Glass. Some of the measurements in Room Mode resulted in false wall recognition/ the model not being able to recognize where the wall ends as the sensor has trouble capturing back the light once it crosses the glass. Figure 7 shows such an example of a wall whose end is not properly captured.

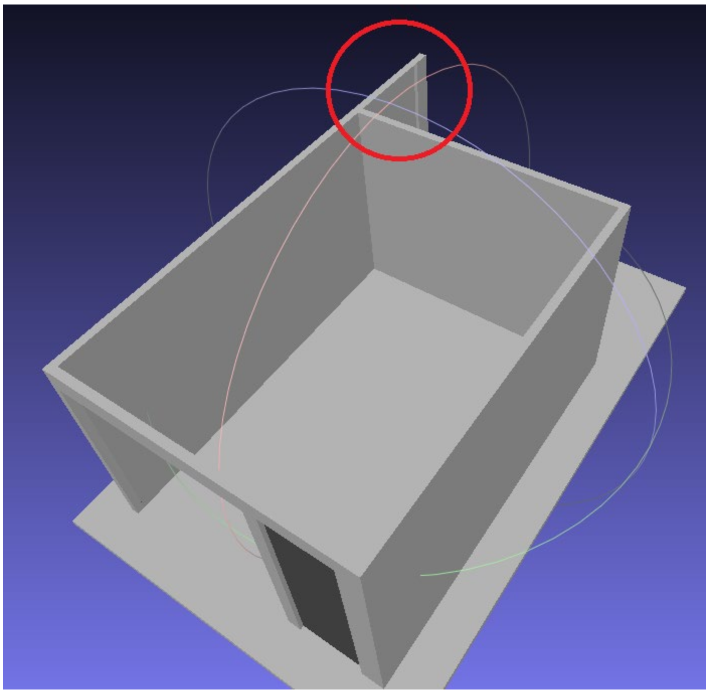

*Figure 7: defective recognition of the end of the wall*

However, even with the mentioned limitations, when repeating the surveying process and avoiding pointing the sensor too much at the glass, and focusing on the corners around of it instead, the data was successfully captured, and even some areas such as a column face that was very close to a wall (making it difficult to approach with the sensor) could be properly scanned.

Bigger problems were found trying to apply the python tool. Due to its development in previous versions of packages and limited types of geometries accepted, the only thing that was possible to use the tool was to visualize the overlaid point cloud and STEP file in the PyQt5 viewer, as Figure 8 shows. The overlaying of the geometries, however, was done in CloudCompare, the pyhon tool could only be used to also visualize this overlaying. The python tool did display the IDs of present IFC elements, but it was not possible to cross the geometries and identify which ones were at the expected as-planned position and which ones were not.

On Cloud Compare, however, results were much better, and the geometries can be quickly compared to find differences. Cloud compare also has the advantage of not requiring the model to be simplified into elements with only 6 faces (even though a conversion of IFC to STEP file is required, but that can easily be done in FreeCAD. Figure 8 shows the deviation found at the position of the column in the room, which was 44 cm closed to the wall in the real building than in the available IFC model, the column is also much bigger in the real building. Even though there is a limitation on the accuracy of the LiDAR scanning, this discrepancy in the original BIM file could be verified on site, with the column being very close to the wall. Furthermore, the fact that there was a big difference at the position and dimension of the column, but a small difference of less than 5 cm (as shown in Figure 9) in the length and width of the room shows that the accuracy of the scanning is reasonably good and the deviation was in fact at the column position in the available BIM model.

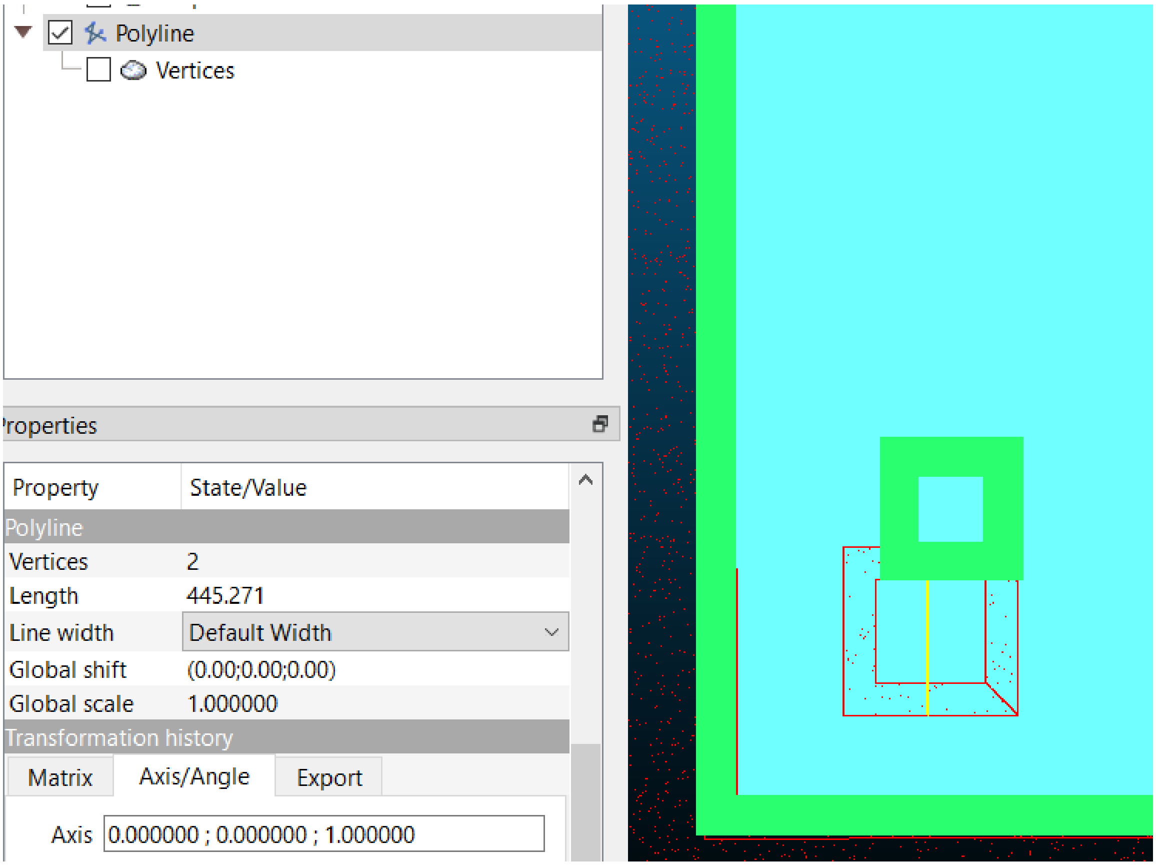


*Figure 8: distance difference between the real column and the BIM column, also size difference*

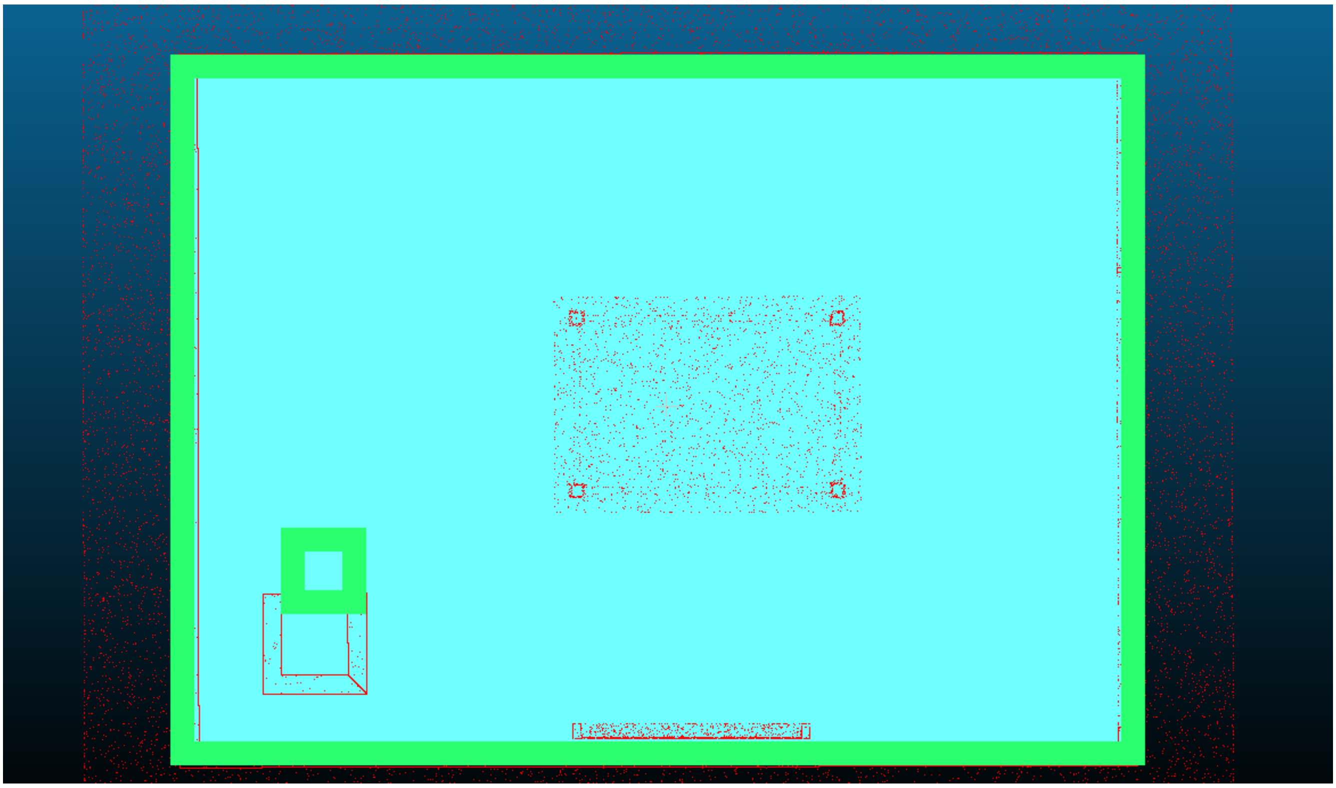

*Figure 9: Similarities and differences in the geometries of overlaid point cloud and BIM file*

# 4 Limitations

The application of the python tool envisioned was not completely successful, and even though CloudCompare proved to be useful, some manual steps are still required, and BIM file format need to be converted from IFC into STEP file.

Care needs to be taken with glass surfaces, nonetheless, the workflow was successful on a room that has an overwhelming presence of glass, which indicates the possibility of going around this limitation.

A further limitation in data collection is the degree of precision of the sensors. This can hamper precision in the validation of larger models, and also limits the amount and types of elements that can be validated, the LOD (Level Of Detail) of the detected elements is also limited.

Semantics in point clouds are limited as only geometry is captured, so either models trained with human help are necessary, or human input at part of the process (so in both ways there is a need of human input at least to kick-start the process).

# 5 Conclusions

The process and research described demonstrate that performing geometry checks for BIM models can be done easily and quickly with tools that are becoming increasingly more accessible and increasingly more accurate. In the process utilized a real significant deviation could be identified in an existing BIM model, and by use of point cloud collection the deviation could be measured. This indicates a simple workflow towards update of BIM models into their as-is state, that can be adopted by companies more accessibly than professional surveying, where extreme precision is note necessary. Furthermore, the future of those applications is promising, with technology and sensor quality improving over time.

Besides, even though a high degree of automation is desired and timesaving, in this case studied, a simpler validation model could be established without a scripting check in python: the model validation using CloudCompare is easier, faster, and composed of less steps to deliver satisfactory results – the BIM model does not need to be reworked before performing the check and the routine that uses the python tool requires prior manual adjustments in CloudCompare anyways.

In this research some of the tools applied in point cloud collection and application in Scan-vs-BIM procedures could be studied, and an interesting study-case with recent technologies could be used to propose a practical and accessible workflow to check the as-is condition of buildings. Even though the application was limited, some experimenting with python tools was also possible and the practical application of a free cloud comparing tool could be established.

# 6 References

Borrmann, A., König, M., Koch, C., & Beetz, J. (2018). *Building Information Modeling: Technology Foundations and Industry Practice* (1st ed. 2018). Springer.

Bosché, F., Ahmed, M., Turkan, Y., Haas, C. T., and Haas, R. (2015). "The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components*." Automation in Construction,* Elsevier B.V., 49, 201–213.

Chen, J. & Cho, Y. (2018). "Point-to-point Comparison Method for Automated Scan-vs-BIM Deviation Detection." *Proceedings of 17th International Conference on Computing in Civil and Building Engineering, Tampere, Finland*, June 4-7.

Dülger, S. (2020). *Using Point Cloud to Automatically Update the BIM 4D Model* (Thesis). https://www.ofcoursecme.nl/mdocs-posts/using-point-cloud-to-automatically-update-the-bim-4d-model/

El-Din Fawzy, H. (2019). 3D laser scanning and close-range photogrammetry for buildings documentation: A hybrid technique towards a better accuracy. *Alexandria Engineering Journal*, *58*(4), 1191–1204. https://doi.org/10.1016/j.aej.2019.10.003

Golparvar-Fard, M., Peña-Mora, F., & Savarese, S. (2009). D4AR–a 4-dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication. *Journal of information technology in construction*, *14*(13), 129-153.

Kavaliauskas, P., Fernandez, J. B., McGuinness, K., & Jurelionis, A. (2022). Automation of Construction Progress Monitoring by Integrating 3D Point Cloud Data with an IFC-Based BIM Model. *Buildings*, *12*(10), 1754. https://doi.org/10.3390/buildings12101754

Kim, C., Kim, C., and Son, H. (2013). “Automated construction progress measurement using a 4D building information model and 3D data.” *Automation in Construction*, Elsevier B.V., 31, 75–82.

Scherer, R. J., & Katranuschkov, P. (2018). BIMification: How to create and use BIM for retrofitting. *Advanced Engineering Informatics*, *38*, 54–66. https://doi.org/10.1016/j.aei.2018.05.007

Son, H., Bosché, F., and Kim, C. (2015). “As-built data acquisition and its use in production monitoring and automated layout of civil infrastructure: A survey.” *Advanced Engineering Informatics*, Elsevier Ltd, 29(2), 172–183.

Thomson, C. (2018, October 30). *How point clouds are changing BIM, construction & facility maintenance*. Vercator. Retrieved January 25, 2023, from https://info.vercator.com/blog/how-point-clouds-are-changing-bim-construction-and-facility-maintenance

Turkan, Y., Bosche, F., Haas, C. T., & Haas, R. (2012). Automated progress tracking using 4D schedule and 3D sensing technologies. *Automation in Construction,* 22, 414–421. https://doi.org/10.1016/j.autcon.2011.10.003

Tuttas, S., Braun, A., Borrmann, A., & Stilla, U. (2014). Comparision of photogrammetric point clouds with BIM building elements for construction progress monitoring. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XL–3, 341–345. https://doi.org/10.5194/isprsarchives-xl-3-341-2014

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings — Literature review and future needs. *Automation in Construction*, *38*, 109–127. https://doi.org/10.1016/j.autcon.2013.10.023

Werbrouck, J., Pauwels, P., Bonduel, M., Beetz, J., & Bekers, W. (2020). Scan-to-graph: Semantic enrichment of existing building geometry. *Automation in Construction*, *119*, 103286. https://doi.org/10.1016/j.autcon.2020.103286