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# Evaluation of measurement techniques for modelling buildings in energy simulation and labelling tool

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**Abstract.** The dwellings built between 1945 and 1980 have the largest energy demand in the EU, which by 2009 represented 70% of the final energy use in buildings. A great portion of these dwellings have not been retrofitted and most of them were not built with any energy efficiency measures, since most of the energy regulations were implemented after the oil crisis in the 1970s. The current renovation rate of residential buildings has not reached targeted goals, due to the numerous barriers that arise in the renovation process. The evaluation and labelling of existing residential buildings represent a big challenge, and the lack of geometric information on buildings is one of the main issues hindering an assessment through simulations. Currently, there is no scientific literature that focuses on improving this task. However, the emergence of new technologies from different fields may streamline the geometric data gathering with the modelling task and greatly improve both accuracy and workload. This study focuses on the revision of geometry measurement techniques, based on the application and quantification of the benefits and barriers that these techniques represent for their use in the building simulation and labelling. The techniques tested were Hololens, handheld laser scanner and handheld laser distance measurer. The evaluation considers time, cost and accuracy as well the tasks related to the post process of the data in BIM, which is not mandatory for building simulation, but it provided multiple benefits.

## 1. Introduction

The European commission has stated that the renovation of existing buildings is the biggest challenge for the coming decades and at the same time represents the largest cost-effective energy saving potential in EU [1]. Due to the large amount of existing buildings that required to be renovated energy policies have introduced building evaluation to increase the renovation rate, by providing information on several benefits such as energy savings, indoor environment improvements and financial support. To address this issue, in 2002 the Energy Performance of Buildings Directive (EPBD) 2002/91/EC was adopted, being the main legislative instrument at EU level to achieve higher energy performance in buildings [2]. Its main objective is to accelerate the cost-effective renovation of existing buildings [3]. One of the most important actions from the EPBD, was the introduction of the Energy Performance Certificates (EPCs). The EPCs need to be issued whenever buildings are constructed, sold or rented out. Despite the positive impact of the certification system, there are still



many issues that need to be improved. There has been an increasing interest in improving the accuracy of the certification system for existing buildings as energy efficiency could influence real estate transactions and motivates homeowners to invest in energy efficiency [4]. One way to pursue more accurate results is to analyse building performance and optimize renovation scenarios based on economic and environmental goals. This precludes an accurate pre-retrofit model, and is one of the major challenges of retrofitting [5].

It has recently been proposed that integrating Building Information Modelling (BIM) with the certification system, in order to obtain a robust model, would speed up the data gathering while keeping cost low [6]. BIM allows the physical and functional characteristics of the building to be digitally generated and managed [7], and has been increasingly employed as a central data source from where building models can be transferred into Buildings Performance Simulations (BPS) [8]. Considering that the creation of a BIM model involves measuring the geometry and collecting technical data of an existing building and transforming those measurements into a high-level, semantically rich representation [9], significant challenges need to overcome in order to integrate the certification system with BIM.

### 1.1. Certification and BIM integration

At present, in order to issue an EPC many tasks must be done by the certifier to collect enough information to produce the certificate. Such tasks include field inspection, collecting the technical and geometric properties of buildings, elaborate assumptions (U-values, thermal bridges, thermal zonification, etc.) perform energy simulation according to the national methodology, define relevant recommendations and sometimes estimated their costs and finally to issue the certificate. As a result, there is a tension between speed/cost, accuracy and reproducibility [10]. In fact, it has been reported that certifiers have gotten different results when assessing the same buildings, in part due to the time and cost that the market has established for an EPC does not enable a thorough assessment to be undertaken [11]. However, the visual inspections are considered the main burden, as this method of data gathering takes time and is more cost-intensive [12]. This simple inspection is normally called a walkthrough, which consists of a visual inspection of the building that might last around one hour, depending on the size of the building/dwelling. Here the certifier collects data on the thermal properties and typical use of the building facilities. Lastly, if the drawings of the buildings are not available, manual measurements of the geometry will have to be performed, as is likely to be the case for old buildings. Many of these tasks depend heavily on the certifier's knowledge, training and experience. However, by using current technology to capture the geometry of the building and providing a quick way to convert the data into a BIM model, efforts can be focused on raising the quality of the technical evaluation of the building, capturing more accurate information and detailing tailored energy recommendations. +

### 1.2. Laser scanning

Obtaining accurate geometry is a time consuming and error prone task. Many discrepancies can be found, especially regarding room dimensions and wall thicknesses, and imprecise and inaccurate measurement tools inevitably lead to gaps and conflicts in the plan drafts [13]. Research on building geometry capturing has shown that there are a wide variety of techniques, including laser scanning, photogrammetry, 3d camera ranging, topographic methods and videogrammetry. However, laser scanning has stood above the rest as one of the most popular methods in several reviews [14]. The advantages of using laser scanning are several, being a method that is less time consuming, as well as the most accurate (can achieve a 3D position accuracy of 0.6 mm at 10 m range) [15]. This makes laser scanning accuracy unparalleled by manual measurement and traditional field surveying techniques [16]. The laser scanning method can rapidly measure angles and distances automatically, as well as capture complex geometry and detect small details [5]. It can analyse several units in a reasonable amount of time. Other techniques are much more complicated and consume more time, such as photogrammetry which is impractical on a large scale [9]. Despite that manual 3D generation is time

consuming a prone to errors [17]. Laser scanning collects geometric information in the form of point clouds, allowing the use of semi-automatic tools that can process the cloud points into simple geometries avoiding errors [18]. Another benefit is that the geometric and thermal inspections can be performed simultaneously, since they are independent, speeding up the process and reducing labor [15]. Lastly, by creating a BIM model, this can be exported directly to the simulation software greatly reducing the energy assessment process, especially considering that in a traditional method, up to 80% of the effort in input preparation may be spent on the defining building geometry [19].

Laser scanning technology has improved, and its popularity has increased in the past years. Nevertheless, there are many considerations which must be made when utilizing laser scanning, with cost and required expertise being two of the most important [16, 20]. When laser scanning technology first became commercially available it was cost prohibitive for most companies [16]. The laser scanning approach also has limitations due to expensive and fragile equipment, lack of portability, and a need for trained operators [5]. However over the past decade the technology has become more and more accessible, now even sub-contractors perform this work [16]. Due to the variety of laser scanner options available today, it is important to identify which can be used without the need of high-level expertise and technical knowledge while still delivering accurate results.

This study attempts to provide relevant information on how to improve the energy inspection in existing residential buildings. This has been done by exploring relevant technologies to build a BIM model that can be used under the EPC certification scheme. Specifically, the study compares three different measurement techniques; the traditional (manual) method and two type of laser scanners, to obtain an accurate geometrical model from an existing building that can be used for in-depth retrofit analysis.

## 2. Method

In order to select appropriate tools that can effectively improve the field inspection by reducing time and delivering accurate geometric measurements of residential buildings, three techniques for developing a geometric model have been analysed. The tools chosen were point laser, a Geoslam handheld laser scanner and a Microsoft Hololens. The assessment for each tool considered three aspects that are crucial to determinate their usefulness in field inspection, being accuracy, time and cost. Finally, recommendations are given on how to use these tools and which users would benefit if they incorporated these technologies in their professional practices.

- Accuracy: To analyse the accuracy of each tool, the model produced was evaluated in its raw, geometric form, in order to determinate the amount of information they were able to collect. A description of how well the provided data can assist to develop a BIM model is provided, as well as the impact of their geometric differences in an energy labelling and building performance simulation, using SIMIEN and IDA-ICE.
- Time: To assess the time that each tool required to gather the data, the time used in the learning process, field inspection, post processing of the data, and the production of the BIM and simulation model was considered.
- Costs: The assessment of the cost technique was based on the acquisition costs along with the complementary material that each technique required, as well as the support from the manufacture company, lifespan and component replacement.

### 2.1. Case study

The study was performed in a 54m<sup>2</sup> apartment built in 1933, in the middle of a long 5-storey brick apartment block typical of pre-war Oslo. As can be seen in Figure 1, the original drawings gathered from the municipality archives do not preserve an adequate level of detail other than the date of their production, their measurements practically illegible.

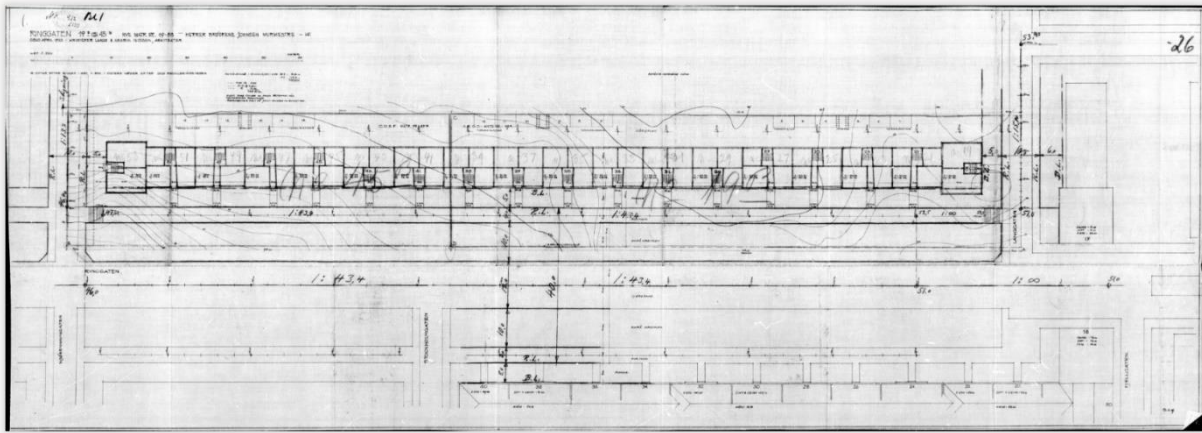


Figure 1. Original drawing of the building

## 2.2. Measurement equipment

Many instruments and techniques can be found to model the interior of a building. However, most of them are focused on complex geometries or on specific tasks, for instance cracks in the facade. This investigation will focus on finding a tool that can give reliable data and that can be used as complementary equipment during a field inspection. The instruments listed in table 1 were selected for this purpose. Table 1 also lists a summary of their characteristics and the amount of tasks that each tool require on the way their respective BPS.

Table 1. Summary of each tool features

Name	Technical features	Data gathering	Model development	simulations
<b>Pointlaser</b>	Laser ToF distance measurement	Preparation, measurement.	Organise measurements in Excel. Manually punching geometric data	SIMIEN
<b>Geoslam Revo</b>	Laser scanner, hand held	Preparation, calibration, scanning	Export pointcloud, cleanup, modelling	IDA ICE
<b>Hololens</b>	AR device with ToF depth camera	Preparation, scanning	Export pointcloud, cleanup, modelling	IDA ICE

### 2.2.1. Pointlaser

The laser distance measurer is a popular tool that is used in several fields, including building construction. Basically, it produces a laser beam toward a target and times the reflection to determine the distance to said target. However, it does not record each measurement and it does not provide a geometrical model, just the distance of two points. Despite this, it does not require technical skills or knowledge, it can be used by a single person and it might be the most probable tool use today by certifiers and energy auditors.

### 2.2.2. Geoslam Revo

Laser scanners have become more prolific the last 20 years, but these have always been cumbersome, tripod-based machines that require experience and time to operate. The Geoslam Revo has taken this technology and made it mobile, using a system of gyros to orientate itself from a starting point. The measurement principle is the same as with a pointlaser, but it uses a rotating head and optics to get

43000 measurements, of direction and distance, per second. It organizes these points into a cloud of dots, a point cloud, and when exported from the program Geoslam Hub, into Autodesk Recap, one gets a 3D-image of the room that has been scanned. The operation of the Geoslam is fairly simple; begin in the middle of the apartment and walk slowly and steadily around the rooms, eliminating any “shadows”, and come back to the start point several times so that the scanner recognizes it and “centers” itself for each room you scan. It is easily operated by one person, but as it is a new and technically groundbreaking piece of technology, it is still quite expensive.

### 2.2.3. Hololens

AR technology is making leaps and strides with the practical use of the Microsoft Hololens, a technology with the potential of ridding the developed world of its dependency on screens. In Hololens, Microsoft has achieved the creation of a computer worn on your head that scans the geometry around you and places interactionable objects, in the form holograms, through the view glasses, in your field of view. The ToF depth camera mounted in the front captures the IR laser scan cast out by four “flooders” on the Hololens, using the same principle as the two previous tools to calculate distance. Through new apps specifically designed for the Hololens, this investigation examined the possibility of creating a geometric scan of the apartment and examined the accuracy of said scan. The Hololens can only be operated by one person. The scanning frequency is quite a lot slower than the laser scanner, so the scan must be performed at a very slow pace. It is worth noting that as the awareness of the Hololens has grown, Microsoft has not been able to meet market demand. Hence, the technology has become more valuable after their acquisition. This might be remedied by their introduction of the Hololens2, in the spring of 2019.

## 3. Results

The following measurements results were performed several times by an unexperienced user with this equipment. As mentioned earlier, the measurements were done after a learning period of at least one run-through, to familiarize the user with the handling and operation of each tool.

### 3.1 Accuracy-Geometry

As can be seen in figures 2 through 4 the image quality obtained directly from the devices show large differences, which should influence the results in the modelling tasks. Despite the visual differences, all the techniques were good enough to be used as a base for modeling the BIM. Even if the Geoslam generated a much denser point cloud to model from, for the purpose of geometry generation the denser cloud had little impact on the post processing in BIM.

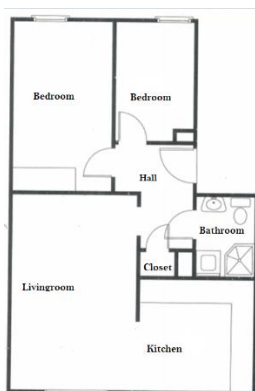


Figure 2. Measurement notes taking with the laser point over a sketch of the apartment

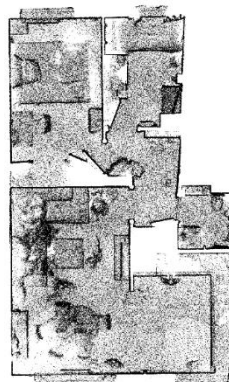


Figure 3. Images generate by Geoslam



Figure 4. Images generate by Hololens

As shown in table 2, the geometry output of the three methods initially revealed very small differences, and the total floor area calculations were all within less than 1% of each other. There were discrepancies from room to room, especially the bathroom was scanned to be 17% or 23% smaller using the Geoslam and the Hololens respectively, as can be seen in Table 2. The small discrepancies in area were mirrored by the volume calculations, with a maximum of 1,5% difference between the conventional method and the modern method using the Hololens.

Table 2. Results from the geometry measurement

Space	Floor Area [m <sup>2</sup> ]			Volume [m <sup>3</sup> ]		
	Laser-point	Geoslam	Hololens	Laser-point	Geoslam	Hololens
<b>Bathroom</b>	3	2.48	2.32	6.8	6,45	6,03
<b>Bedroom</b>	6	6.17	6.35	15.8	16.05	16.52
<b>Entrance hall</b>	4	3.98	3.96	10.5	10.35	10.30
<b>Livingroom/Kitchen</b>	26	25.86	25.52	68.6	67.24	66.34
<b>Master bedroom</b>	11	11.22	11.35	29	29.17	29.52
<b>Total</b>	50	49.71	49.5	130.7	6576.81	6160.68

The measurements of the exposed areas (façades), seen in Table 3, present larger differences that might be critical for the usefulness of the model. These had a maximum difference of up to 11,5% between the pointlaser method and the scanners. The brunt of the difference was tied to the size of the windows, and it is likely that they were caused by the problems yielded by reflective surfaces in scanners. These differences were of major concern, as their impact would affect the energy simulation adversely.

Table 3. Results from the measurement of the façade

Element	Façade [m <sup>2</sup> ]		
	Laser-point	Geoslam	Hololens
<b>Ext.wall, living room</b>	10.53	12.09	12.08
<b>Window, living room</b>	4.77	4.01	4.14
<b>Ext.wall, bedrooms</b>	8.86	9.36	9.55
<b>Window, bedroom</b>	1.91	1.65	1.72
<b>Window, master bedroom</b>	1.73	1.79	1.97
<b>Total area, windows</b>	8.41	7.44	7.82
<b>Total area, walls</b>	19.39	21.45	21.63
<b>Total exposed area</b>	27.8	28.89	29.44

### 3.2 Accuracy-Simulation

The geometric models from the measurements done with Geoslam and Hololens were obtained from Revit and exported as IFC file to IDA-ICE. This process was successful since very few adjustments were required by IDA-ICE, basically just creating zones in the different rooms. While for the laser point measurements, the geometric measurements had to be punched manually into Simien, as a regular certifier would do. In order to determinate the impact of the differences in measurements, the simulation was carried out with the same inputs, loads and weather files. As can be seen in Table 4, significant differences were observed. This can be explained by the windows measurements, since they represent the main deviation between the models. Despite the differences in the windows



measurements of around 10%, the small size of the apartment makes it sensitive to these variations, due to the influence of the solar radiation gains during daytime (the sun is quite low in the winter in Norway) and the thermal losses during the night. As expected, the larger windows measured by the point-laser produced a higher energy demand for the apartment in the simulation.

Table 4. Results from the energy simulation

Energy demand	Point-laser	Geoslam	Hololens
kWh	7856	6995	7378
kWh/m <sup>2</sup>	157,12	139,90	147,56

### 3.3 Time

The amount of time taken to perform all three phases illuminated the chasm between the single point laser measurement and laser scanning. The difference in time taken for preparation and measurement of the geometry was, as expected, large; in the conventional approach, the manual measuring of the spaces in the apartment took 102 minutes using a laser distance measurer, while the point cloud generation using the Geoslam and the Hololens took 15 and 33 minutes respectively. The conventional approach caught up a bit during model development, as organising data in Excel was relatively easy compared to converting files, editing pointclouds and creating BIM models. But this inconvenience was eclipsed in the simulation part, as entering the geometric data, creating zones and performing the simulation in SIMIEN took 300 minutes, while importing the IFC file, creating zones and simulating only took 15 minutes in IDA ICE. A comparative piechart, the size illustrating the total time used, can be seen in Figure 5.

The results are not surprising, as BIM modelling is the task that requires the most time to complete and “get right”, in order to yield rewards like accurate simulations and time saving further down the process line. Also, the creation of the BIM has value in itself, as its versatility makes it an asset worth preserving. An overhaul of the building would save a lot of time in the planning stage if there existed an as-built digital twin. In fact, one of the findings during this investigation was that the original drawings from 1933 preserved in the municipal building archives were not accurate, as the wall of the smallest bedroom was found to be slightly angled, as illustrated in Figure 6, below.

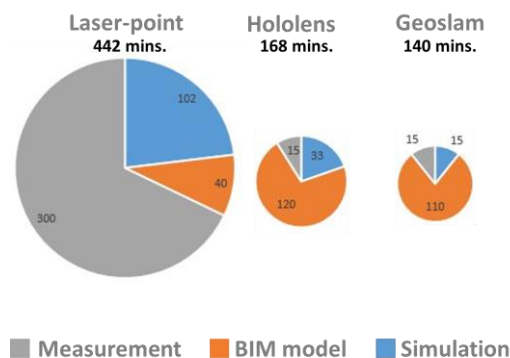


Figure 5. Shows the time consumption in each task

Figure 6. Shows the area difference between single laser point and laser scanning

### 3.4 Costs

The cost considered for the assessment include the acquisition price of the equipment. Also, the software that can process the outcome data has costs and should be added to the sum. In Figure 7, we can see an overview of the total cost for each method. It is quite clear that the costs of using the



Geoslam are far higher than the other methods. This is a result of the price and of the instrument itself. Even so, the Geoslam was the most accurate piece of equipment, was easy to use, easy to model after, and gave the most cloudpoints per kroner when compared to the HoloLens (4,65kr vs 4,81kr). It is important to note that the numbers below only represent the amount required for the acquisition of the technology. In reality, the costs would be spread over several contracts, with the impact of speed and accuracy leveling the difference somewhat.

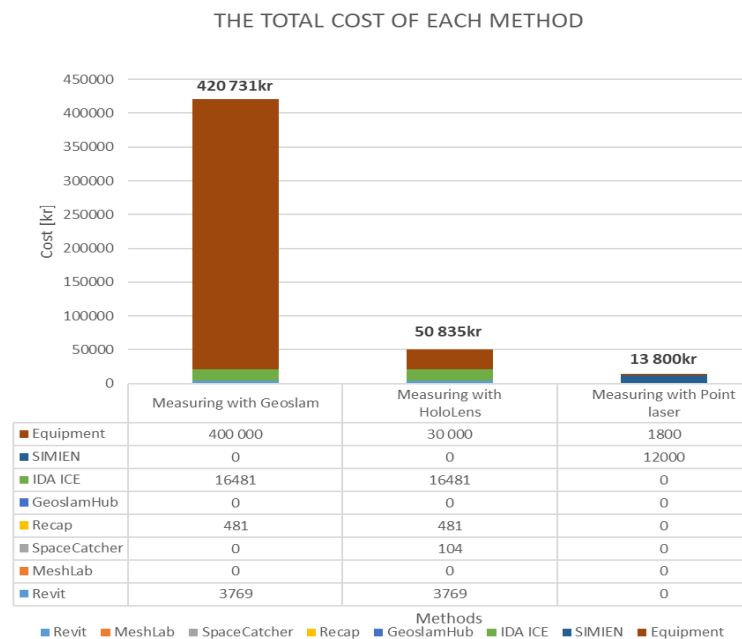


Figure 7. Shows the cost that involves each tool.

#### 4 Conclusion and Recommendations

This paper presents an assessment of different tools to obtain a building geometry that can be used during a field inspection by certifiers or energy auditors. The evaluation considered three main aspects that are crucial in consideration by the selected users: accuracy, time and costs. The results show that the laser scanning devices can largely reduce the time needed to measure an apartment unit, providing at the same time more accuracy than a single laser point measurer. The scanning devices should not demand especially high technical knowledge and it is expected that with repetition, an untrained user can improve both accuracy and time spent on this task. On the other hand, the costs of acquisition are much greater than conventional tools, as well as costs for software programs, maintenance and repair. Considering the pros and cons, the following recommendations are proposed:

The greatest advantage of a single-point laser is that it is easy to use, inexpensive and provides adequate results. The technology is expected to become cheaper and more accessible. Despite this, it will always represent a lost opportunity, since the exclusion of BIM is a step back. Not creating a database, storing measurements, collecting building models, this hampers energy experts from having an overview of the performance of the building sector. By creating a building model, future assessment of the same building can easily be done by simply updating modifications if there are any. Policymakers could also have a great source of information on the building stock.

The scanning devices present a large difference in terms of costs. It is hard to believe that an independent certifier will be able to afford a Geoslam, and even if the users choose such an investment, to be able to recover the initial costs it would have to move from dwellings into commercial or industrial buildings. On the other hand, if the initial costs are financed by an energy

program, a larger number of dwellings can be assessed in less time, without increasing the number of certifiers or energy auditors. An example of this can be seen in the US, under the energy program Home Energy Squad.

Hololens is in the price range that independent certifiers can afford, and despite that is not as accurate as the Geoslam it presents strong features that can be easily tailored for field inspection purposes if apps or specialised software are implemented. More research is needed in this area to capitalise on the uses of 3D scanning and BIM to improved energy performance of residential buildings, especially with the development of the Hololens2.

## 5 Acknowledgments

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