



BIM based fast toolkit for  
Efficient rEnovation in Buildings

# D5.5 Technical report on testing and validation results



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### **D5.5 Technical report on testing and validation results**

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## EXECUTIVE SUMMARY

### Technical report on testing and validation results

In a renovation process it helps a lot to visualize and create 3-dimensional models of the existing buildings, especially for specialists and stakeholders involved in the design stage. By scanning walls, floors and ceilings with laser-scanning equipment together with a sensor stick, it will be possible to detect and visualize the walls digitally, as well as the hidden installations inside the walls with help of a HoloLens2. This procedure and tools are called Fast Mapping Toolkit, and are a part of the BIM-based fast toolkit for efficient building renovation.

The aim with the tool is; create 3-dimensional models based on building scans that include information about the construction's profile. The models will be in IFC-format that can be used and read by several applications. In this project the main application is the BIM-based fast toolkit for efficient building renovation.

This report, D5.5, contains the testing and validation of the toolkit, Fast Mapping based on the work made in the Work package, WP 5 Digital tools for fast mapping of buildings (geometrical data and materials).

The testing and validation include:

1. Demonstrating and testing the Fast Mapping Toolkit (scanning, sensor stick, HoloLens2 and Companion App) at a CGIs office
2. Demonstrating and testing at RISE offices (in different buildings)
3. Use at the demo sites (Italy, Finland, and Poland)

The most important results of the testing and validation are:

1. Creating simple IFC elements for the BIM is possible, however the tool needs development for generating of complete IFC model of a building.
2. The results from the testing of the Fast Mapping Toolkit show that it is possible to map a room of 25 m<sup>2</sup> in less than 1 hour.
3. The software and equipment are not yet user friendly. It works well for small rooms. However bigger spaces, the connection among these in a whole survey, as well as complicated wall surfaces, present complications in the general workflow. The training time to use the tool kit varies depending on the user's practice time in the use of AR-glasses.

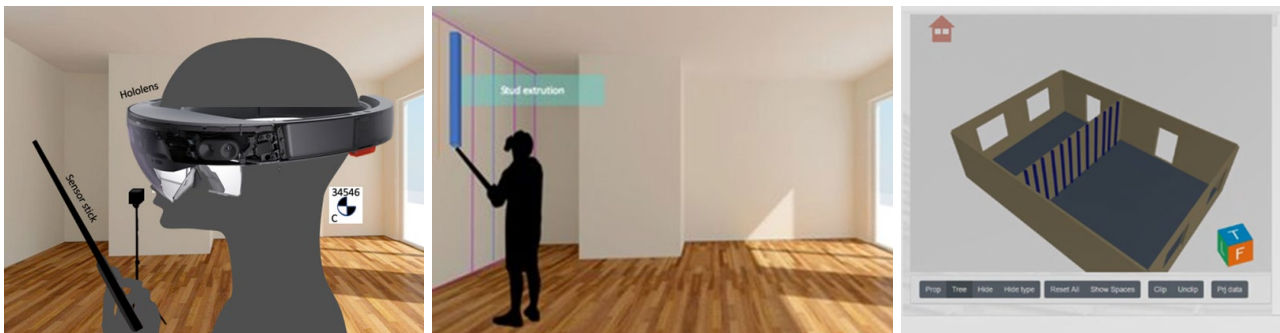
## PUBLISHING SUMMARY

### Technical report on testing and validation results

By scanning walls, floors and ceilings with laser-scanning equipment together with a sensor stick, it is possible to detect and visualize the walls digitally as well as the hidden installations inside the walls in a building with help of a HoloLens2.

A control room is scanned by using a laser scanner. The obtained cloud of points is loaded to a Companion App with connection to a HoloLens2. By using a sensor stick that measures capacitance, temperature, inductance and voltage, its possible to visualize the room with its hidden installations.

This report contains the results and evaluation of the used toolkit and procedure.



Equipment, mapping and result

## TABLE OF CONTENTS

1	Introduction.....	10
1.1	References to other activities and to the state of the art .....	10
1.2	Innovative results and progresses .....	10
2	Fast Mapping Toolkit .....	11
2.1	Laser scanning .....	11
2.2	Companion App .....	12
2.3	HoloLens2 .....	13
2.4	Sensor stick.....	13
2.4.1	Histogram and filtering .....	14
3	Testing and validation of Fast Mapping Toolkit .....	16
3.1	Overview .....	16
3.2	Testing at CGI office.....	16
3.2.1	Time result for mapping.....	16
3.3	Testing at Borås office.....	17
3.3.1	The Borås office .....	17
3.3.2	Evaluation of the set-up procedure.....	18
3.3.3	Evaluation of the sensor stick .....	18
3.3.4	Evaluation regarding semantics and ontology .....	19
4	Fast mapping at demo site in Italy .....	21
4.1	The demo site .....	21
4.2	Fast mapping .....	21
4.3	Result of the presented functionalities .....	22
5	Fast mapping at demo site in Finland .....	24
5.1	The demo site .....	24
5.2	Fast mapping demonstration .....	24
5.3	Result of the presented functionalities .....	26
6	Fast mapping at demo site in Poland .....	28
6.1	The demo site .....	28
6.2	Fast mapping .....	28
6.3	Result of the presented functionalities .....	31
7	Conclusions of results.....	32
7.1	Lesson learnt from the demonstration and testing's.....	32
7.2	Evaluation of KPI (Key Performance Indicators).....	33

7.3	Further improvements .....	33
8	Conclusions .....	34
9	References .....	35
10	Appendix .....	36
10.1	User Manual for Fast Mapping of Buildings AR-Toolkit, version 1 .....	36
10.1.1	Equipment needed .....	36
10.1.2	Instructions – How to scan and create point clouds .....	37
10.1.3	Instructions – Import point clouds into HoloLens .....	38
10.1.4	Instructions – Selecting and viewing point clouds .....	42
10.1.5	Instructions – Sensor Scanning .....	44
10.1.6	IFC-file transfer to BIMMS .....	46

## LIST OF FIGURES

Figure 1	Flow chart of the Fast Mapping Toolkit .....	11
Figure 2	Using an Imager 5010 to laser scan and create a point cloud .....	12
Figure 3	The point cloud of an apparatus room is previewed at the Companion App .....	12
Figure 4	HoloLens2 devise (left) with the home menu of the PoyTech app (right) .....	13
Figure 5	Live preview of values coming from the sensor stick .....	14
Figure 6	Histogram of values captured during a recording with the sensor stick. To the right, the recorded sensor cloud is selected and then the desired design part is selected, in this case beams .....	15
Figure 7	Beams are generated vertical, based on the sensor cloud (the point cloud with recorded value from the sensor stick). The beams are not in line with the point cloud and therefore need to be adjusted .....	15
Figure 8	The conference room at RISE, shown as a point cloud in the Companion App .....	18
Figure 9	Once the number of interactions and centroids are stated (above) its possibly to generate beams (below) .....	20
Figure 10	Italian demonstration site, before (left) and after renovation (right) .....	21
Figure 11	Demonstration at Italian demo site .....	22
Figure 12	The point cloud from the empty apartment visibly in the Companion App. Two beams were created in the HoloLens2, which are seen in the right Figure .....	23
Figure 13	Finland demonstration site in Espoo .....	24
Figure 14	Demonstration at Finland demo site. An equipment room .....	25
Figure 15	The downloaded point cloud in the Companion App .....	26
Figure 16	A IFC-file of a wall are created on the completely wrong position in the boiler room .....	27
Figure 17	Poland demonstration site in Chorzow .....	28
Figure 18	The point cloud of the living room downloaded to the Companion App at the laptop .....	29
Figure 19	A part of a wall is created behind the bench in the HoloLens2 (left). As long as the object has the orange colour, it's not committed to the Companion App and its possibly to change size and position on it. Use of the sensor stick on a wall (right) .....	30

Figure 20 A part of a wall is created and committed to the Companion App. The left Figure show a screen shot of what is seen in the HoloLens2. The grey colour indicates that it is committed and has become a IFC-files. The IFC-file (part of the wall) is visibly in the Companion App, right Figure ..... 30

Figure 21 The created IFC-wall opened in a commercial software (Xbim) without the point cloud ..... 31



## LIST OF TABLES

Table 1 Time to use the Fast Mapping Toolkit at CGI office.....	17
Table 2 Result of sensor stick evaluation.....	19

## 1 Introduction

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When a renovation process begins, it is important to thoroughly assess the existing property, its geometry, construction, or, for example, where to find pipes or studs. The Augmented Reality (AR) tool herein presented visualizes the existing building and generates information that might be used on drawings or 3D models. The toolkit produces an IFC-file as visualized information along with the point cloud and sensor cloud that can be opened and shared. The visualized information will be used by the owner of the building together with the advisors, designers or other consultants. It will help them with decision-making processes as well as optimizing the design of the renovation.

This report, D5.5 explains the evaluation of the Fast Mapping Toolkit.

The evaluation and tests were first performed in different types of buildings in Sweden and thereafter in the demo sites in Italy, Finland and Poland. The evaluation also includes a discussion about semantics and ontology.

This document describes the Fast Mapping Toolkit, how it works, and how it might be used in the different demo sites.

### 1.1 References to other activities and to the state of the art

The BIM4EEB project aims to develop an attractive and powerful BIM-based toolset able to support designers in the design and planning phase and construction companies to efficiently carry out the work and service companies to provide attractive solutions for building retrofitting. The Fast Mapping toolkit is one of six toolsets that together become the total toolset of BIM4EEB.

The renovation process and its different stakeholders are represented in D2.2 List of designers' needs and requirements for BIM-based renovation processes [1], D2.3 List of construction companies' needs and requirements for BIM-based renovation processes [2] and D2.4 List of service companies' needs and requirements for BIM-based renovation processes [3]. This deliverable describes the evaluation of the Fast Mapping Toolkit that are developed in WP 5, Digital tools for fast mapping of buildings. The development are based on the benchmarking of existing tools reported in D5.1 Report of existing techniques and recommendation of mapping technique [4]. It is also an application of the defined digital format reported in D5.2 Report of output from metering devices and their translation in BIM models [5]. Further on the Fast Mapping Tool will be used in the demonstration activities as part of, especially WP8 [6, 7] but also in WP4 Development of BIM management system [8].

### 1.2 Innovative results and progresses

The result of the development of an AR tool to effectiveness use of fast mapping a building with a HoloLens2 device, combined with a laser scanner and a sensor stick shows a handy modern tool. With this equipment the user also can get an impression what inside the walls when creating the drawings and prepare for renovations. Due to better knowledge of the construction it's easier for the designers and advisors to choose an appropriate scenario of renovation activities.

The novelty compared to commercially available products lies in combining the results with the AR and with the other tools in the BIM4EEB toolkit.

The testing of the AR tool shows that it is possible to scan and map a room of 25 m<sup>2</sup> in around 1 hour.

## 2 Fast Mapping Toolkit

The Fast Mapping Toolkit consist of:

1. Laser scanning with a commercial device
2. Companion App installed at a laptop computer
3. HoloLens2, an augmented reality helmet with a PolyTech app installed
4. Sensor stick created in the project

Figure 1 show the flow chart of the Fast Mapping Toolkit.

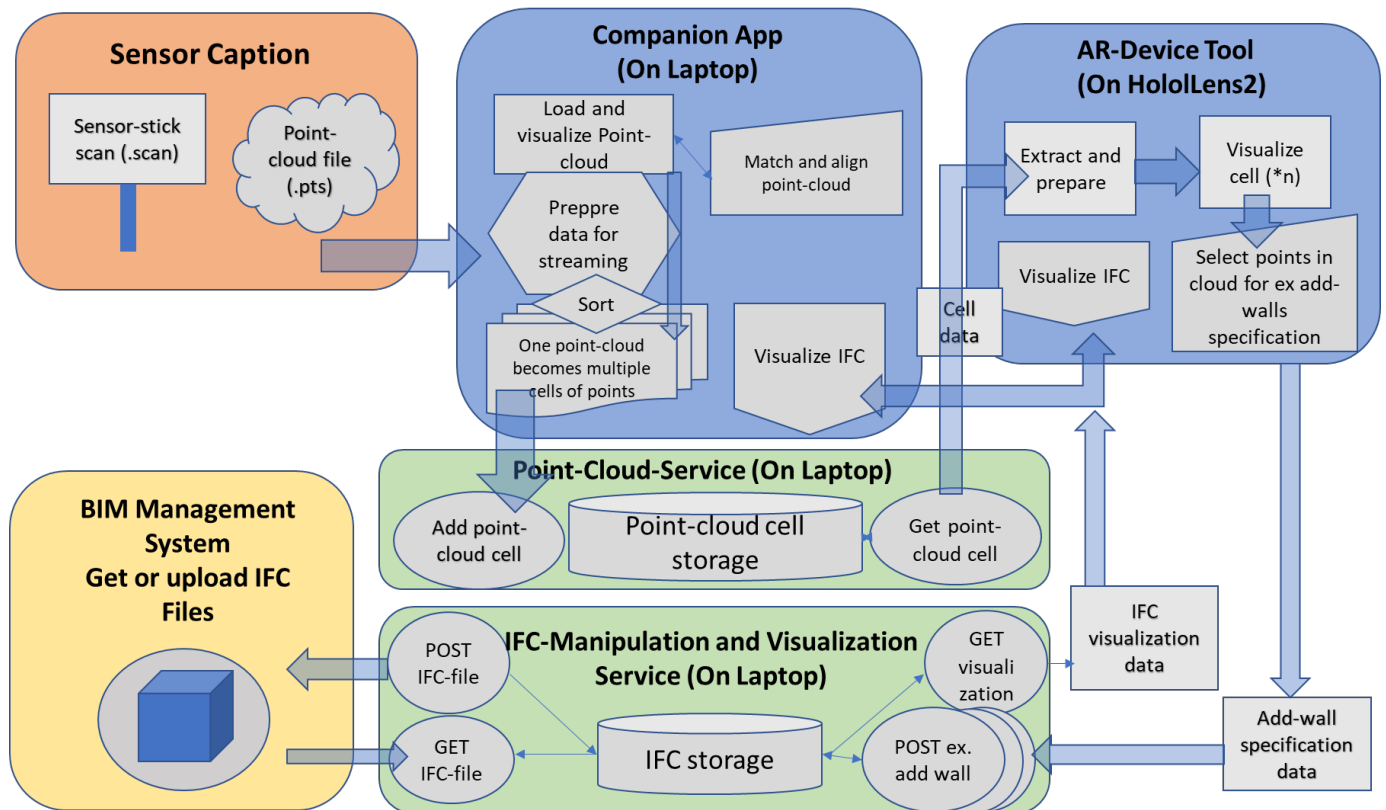
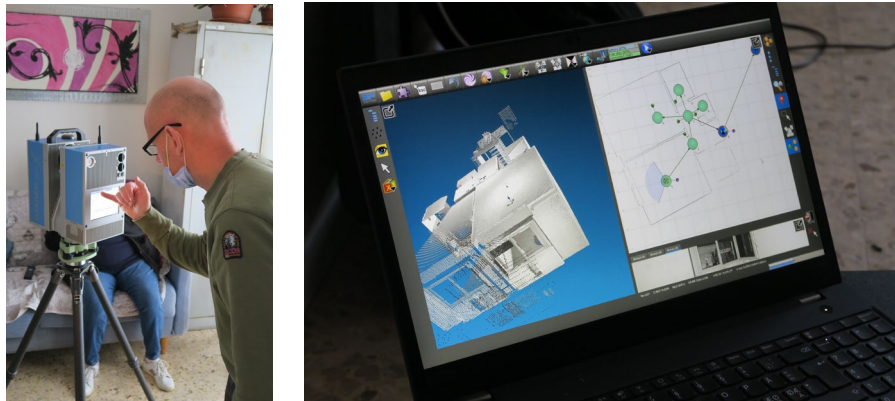


Figure 1 Flow chart of the Fast Mapping Toolkit

### 2.1 Laser scanning

The laser scanning can be performed by an expert before the actual Fast Mapping process begins. The purpose with the laser scanning is to create a 3D point cloud of the actual room. At the demonstrations, an Imager 5010 was used. The scanning took place from a number of different positions to give a good overview of the entire room.

One important thing is to reduce the number of points in the point cloud so that the file doesn't become too big. If the scan fil (.pts) are bigger than 0.5 MB than its difficult for the HoloLens2 to stream it from the Companion App.



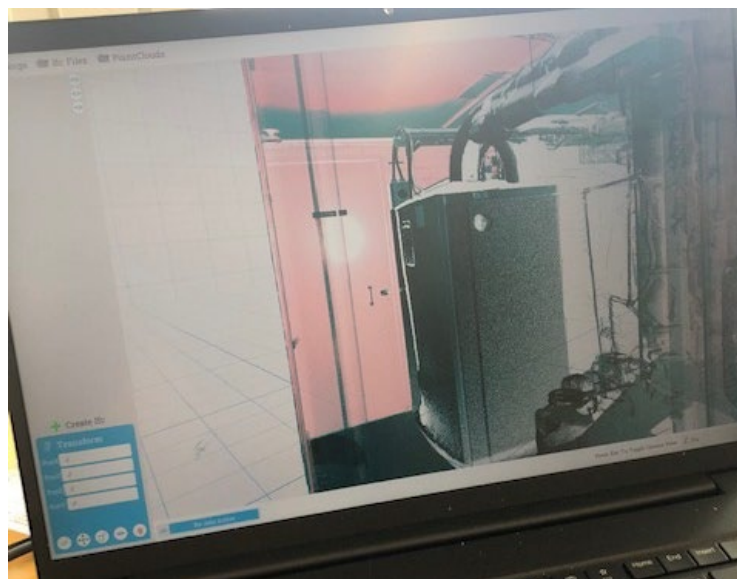
**Figure 2 Using an Imager 5010 to laser scan and create a point cloud**

## 2.2 Companion App

The Companion App acts as a central hub for all parts such as point cloud, data from HoloLens2 and sensor stick. The Companion App is created in the gaming and virtual reality development platform, Unity. From here, it is possible to import point-clouds from the laser scanner, create rough matches of point clouds and see the result from the mapping. You are also able to preview point clouds and see a representation of the IFC-file in 3D.

The HoloLens2 has a limited computer resource, therefore are the calculation parts of the program installed in the Companion App instead. This has resulted in a big stream of data between the two devices and hence a standalone Wifi must be used to connect the two devices.

The Companion App has three tabs in the menu; settings, IFC-files and Point-Clouds. Under settings, you set the IP addresses and ports for the HoloLens2 and sensor stick. You also name where (in which folder) point cloud will be picked up and where IFC-files will be stored. The below Figure shows the Companion App when the point cloud at a boiler room is visibly.



**Figure 3 The point cloud of an apparatus room is previewed at the Companion App**

## 2.3 HoloLens2

The HoloLens2 is an Augmented Reality headset developed by Microsoft. The HoloLens2 offers full hand tracking and interaction with the environment in 3D space.

In the Fast Mapping Toolkit the HoloLens2 are used to visualise the reality, the point cloud and the result from the sensor stick. This is made in the developed app called PolyTech. The programming is made in Unity. To handle big point cloud in a small device like a HoloLens2, an algorithm was created. The algorithm shows the position of the HoloLens2 and its direction which is viewed into the Companion App. The algorithm then streams the part of the point cloud that's the HoloLens2 devices just needs. By this algorithm its possibly to use big high density point clouds of a building.

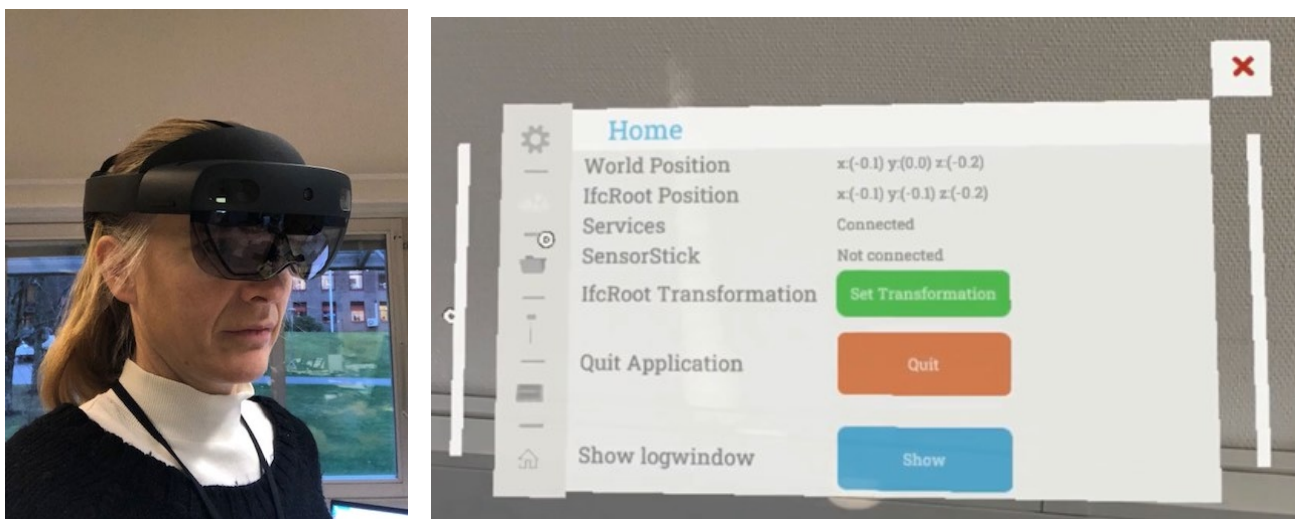


Figure 4 HoloLens2 device (left) with the home menu of the PoyTech app (right)

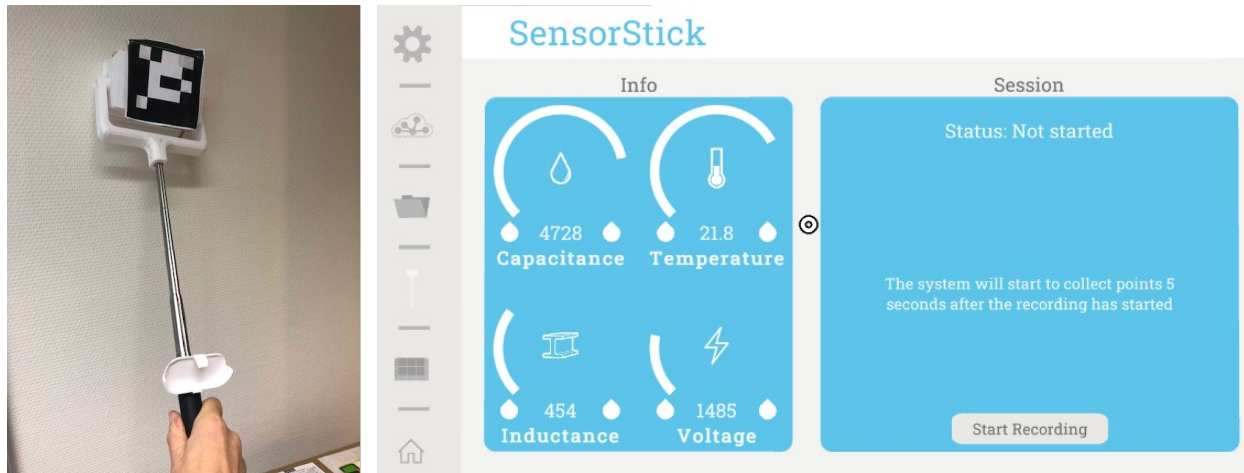
## 2.4 Sensor stick

The Sensor stick consists of several separate sensors that can measure different characteristics such as temperature, inductance, conductance and voltage. The temperature is measured by an infrared (IR) temperature sensor. By measuring inductance, we get information about the magnetic permeability of a material which can help us find metal pipes in the construction. Conductance can be described as a materials electrical conductivity and give us information about its permittivity. In general, permittivity is not a constant, as it can vary with the position in the medium, the frequency of the field applied, humidity, temperature, and other parameters. But since all materials have different permittivity, we can measure when something changes inside the wall as we drag the sensor across it. The voltage is measured by a radar that detect radio signals at 50 or 60 Hz. The same signal as most electric grids are running at.

When measuring all characteristics at the same time it's easier to understand what's behind the wall, it might be a stud, electrical cable, moist, water pipe or ventilation duct. As an example, the values we get for permittivity or magnetic permeability will be determined by the combination of materials that surrounds our measurement device and the closeness of the materials to the measuring device. We will therefore not be able to distinguish the individual materials. But since the permittivity or magnetic permeability is different at different frequencies in different materials, we can measure the two properties at different frequencies and even single out specific materials or the level of moisture in the walls.

The values from the sensor stick are shown as they are captured. As long as the HoloLens2 is connected to the sensor stick, you are able to preview what would be captured if you were recording. To record the

measurement from the sensor stick, the network that combine the different devices must be connected to internet. This is required because the sensor stick need to pick up and register the correct time.



**Figure 5 Live preview of values coming from the sensor stick**

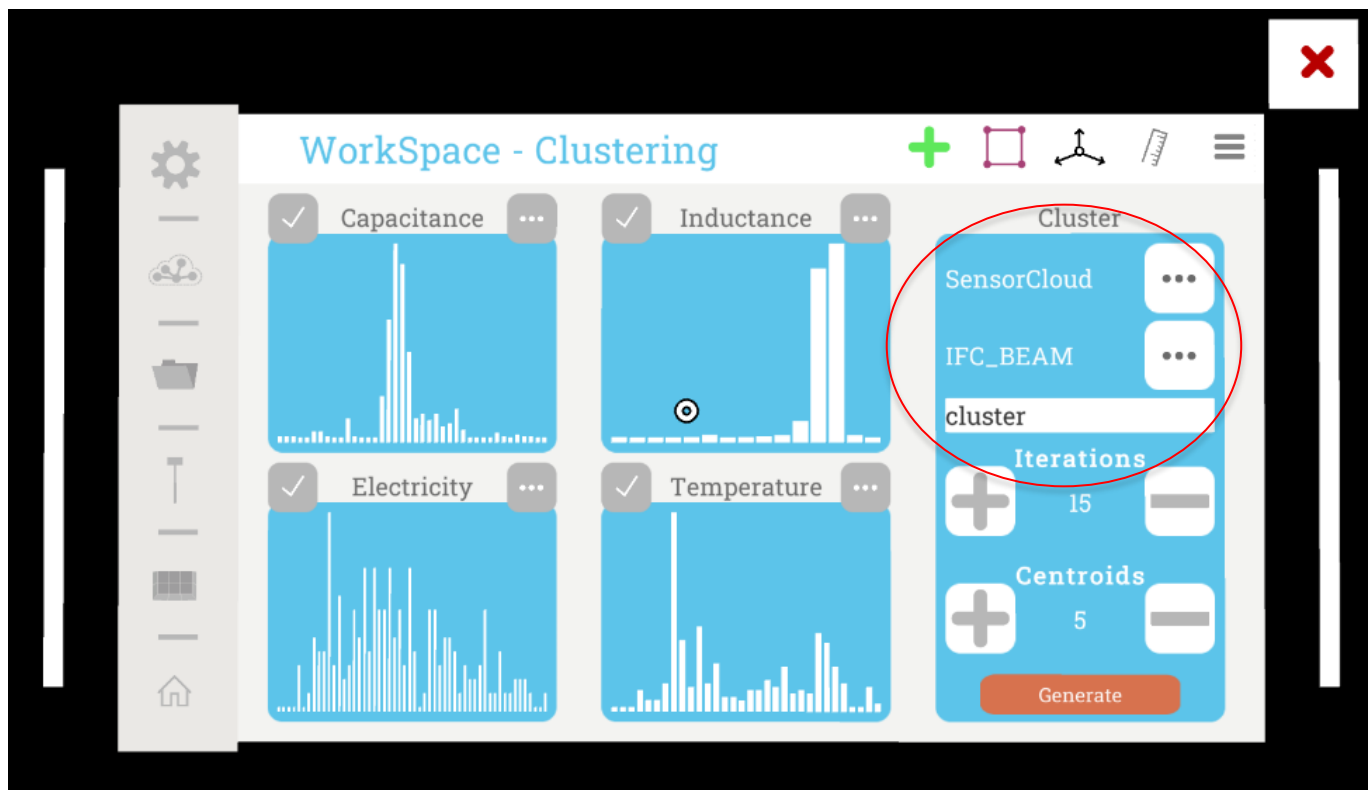
### 2.4.1 Histogram and filtering

The recorded data from the sensor stick is shown both as different colored dots and as four different histograms, one for capacitance, one for inductance, one for electricity and one for temperature. By default, all histograms are visualized, but individual categories can be turned off and on, it is also possible to skip or rather filter values that are too high or too low. The filtered values then serve as a base for example generating beams.

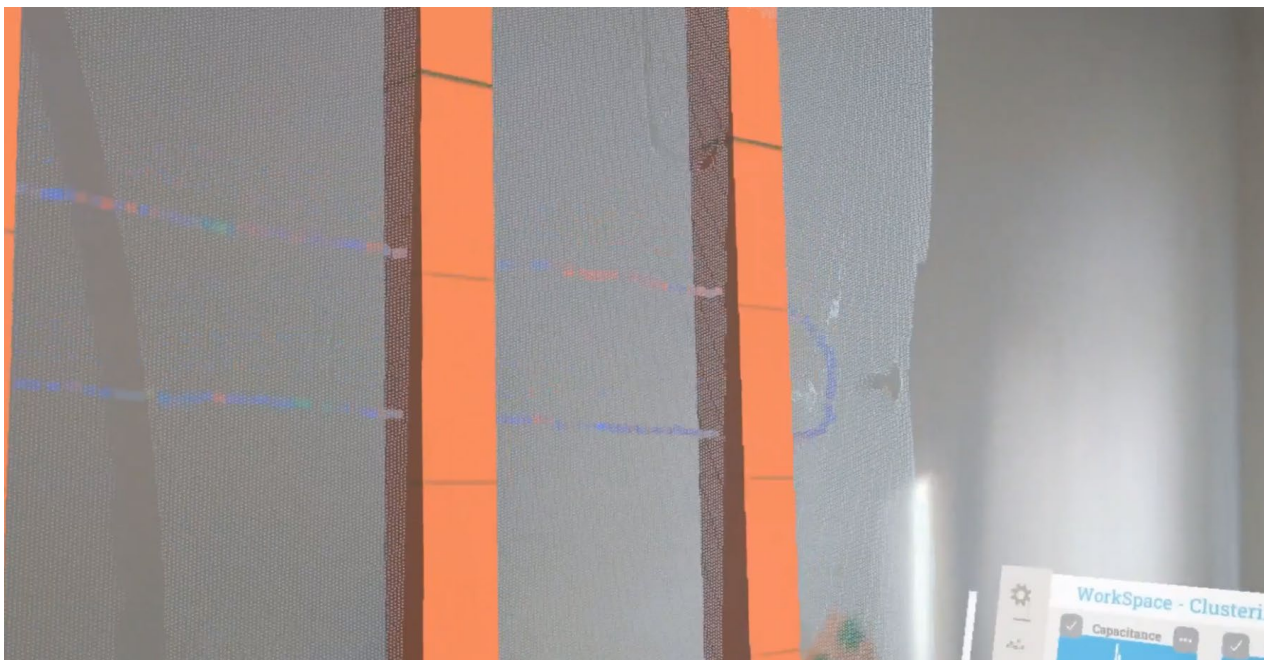
The generation of beams is done by using the menu in the HoloLens2. Figure 6 shows how it looks like in the HoloLens2. To the right, the recorded sensor cloud is selected and then the desired design part is selected, in this case beams. This can be done for vertical beams, but it is also possible to generate them if the values were captured on a ceiling.

The beams are therefore placed in such a manner where they are tilted as the sensor-cloud is tilted. Figure 7 shows when beams are generated vertical, based on the sensor cloud (the point cloud with recorded value from the sensor stick). The beams are not in line with the point cloud and therefore need to be adjusted.





**Figure 6** Histogram of values captured during a recording with the sensor stick. To the right, the recorded sensor cloud is selected and then the desired design part is selected, in this case beams



**Figure 7** Beams are generated vertical, based on the sensor cloud (the point cloud with recorded value from the sensor stick). The beams are not in line with the point cloud and therefore need to be adjusted

## 3 Testing and validation of Fast Mapping Toolkit

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### 3.1 Overview

Every time the toolkit is tested at a new place, following things need to be done:

1. Scan rooms with a laser scanner.
2. Use the Companion App to import the scans and prepare them for streaming to the HoloLens2.
3. Stream the point clouds to the HoloLens2
4. Within the HoloLens2, adjust the point cloud with the reality. Use the sensor stick to scan walls and surfaces in the room. Geometries such as beams, walls etc are created by using the toolbar in the HoloLens2. The geometries are adjusted to fit the reality, also by the toolbar in the HoloLens2.
5. Create .IFC-files.

The testing and validation were made both by well-trained persons from the CGI office and more untrained persons from the RISE office. This was done in order to capture both the full potential of the toolkit but also catch difficulties that might be hard for an experienced person to see.

When validating the tool by the well-trained persons, the time was taken for the different steps in order to have something to measure and compare against traditional ways of mapping buildings. This is only done for the CGI office.

There are different use-cases for using the toolkit. There are scenarios when only the visual geometry is needed, and the sensor stick is not needed. There are also scenarios where it's important to detect for example electrical cables which means that the result from the sensor stick is more important. The testing and validations contain both kind of scenarios.

The approach for testing the toolkit is to do everything at the same time, that is; one person starts the laser scanning, and once you have enough scanned environment, a second person can start to map it with the HoloLens2 and the sensor stick. This way, we are working seamlessly, not having to rely on waiting for more than one room on the other person.

### 3.2 Testing at CGI office

The testing of the toolkit was first performed at CGI office in Umeå, Sweden. A laser scanning of the office was made. The Scan result were transferred to the Companion App and then streamed to the HoloLens2. Once in the HoloLens2 a map structure was created for storing the IFC-files. The point cloud was downloaded and aligned with the reality. The sensor stick was used to scan a wall and the results were recorded and saved to the Companion App. The sensor scan result was then opened in the HoloLens2 and visualised by histograms at the template and as different colours in the point cloud. By having the sensor scans results as a background, IFC objects such as beams walls etc were created. The results were shown in the Companion App and may also be transferred to the BIMMS platform.

The testing at CGIs office were recorded and a movie was created that can be watched at [www.bim4eeb.eu](http://www.bim4eeb.eu)

#### 3.2.1 Time result for mapping

A laser scan with pretty good density and accuracy creates a scan in about 10 minutes, and to set it up takes about 2 minutes added to that. Depending on how many objects are obstructing the view of the laser scanner, you may need more scans. An empty room rarely requires more than one scan, but at the CGI office with that environment, an average of 2.5 scans per room were needed.



That is roughly 35 minutes of setting up the scanner and run the scanner 3 times.

Importing a single scan to the Toolkit took about 2 minutes, and as soon as the first three scans are available, we are able to map geometries with the HoloLens2.

Mapping 1 room that is roughly 25m<sup>2</sup> took us about 30 minutes, but this also depends on how many of the walls need to be mapped with the sensor stick, and what level of detail we expect, how many doors and windows there are. The same room without the sensor stick and without worrying about where the beams are, or where electrical cords are taking us about 13 minutes.

One thing to mention here though is that if two persons are working together, one person scanning and then imports the scans to the toolkit, and another person mapping the environment; is that there are not that many hold ups. We don't need to scan everything to be able to map it. Working with the toolkit can be very seamless.

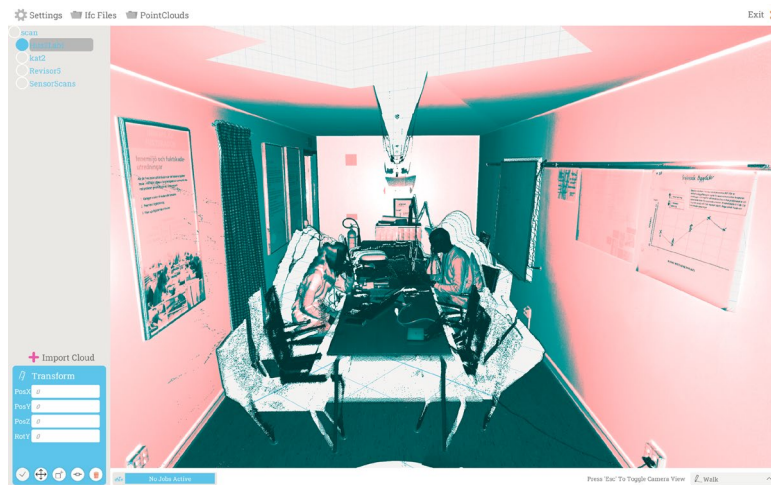
**Table 1 Time to use the Fast Mapping Toolkit at CGI office.**

Activity	Time to do	Comments
Laser scan of an empty room including set up	12 minutes	One laser scan
Laser scan of an almost empty room including set up	35 minutes	Three laser scans
Mapping a 25m <sup>2</sup> room with the sensor stick	30 minutes	
Mapping a 25m <sup>2</sup> room without the sensor stick	13 minutes	

### 3.3 Testing at Borås office

#### 3.3.1 The Borås office

The Fast Mapping Toolkit where tested at a conference room in RISE office at Borås. The room consists of a steel frame construction with painted gypsum board on the inside, plastic mat, and a ceiling. The toolkit was also tested in a wood framed villa with floor heating on the ground concrete slab.



**Figure 8 The conference room at RISE, shown as a point cloud in the Companion App**

### 3.3.2 Evaluation of the set-up procedure

The sensor stick and the software to run the Companion App and the Hololens2 were sent from CGI to RISE. Laptop, Hololens2 and a router were bought by RISE and not the same as CGI had used at previous testing.

It turned out to be more difficult than expected to transfer the software to a new computer and get it to communicate with both the sensor stick and the Hololens2. One thing that has not been noticed before was that the Companion App needs to read its own computer's IP address before it can communicate with the other devices via the router.

During the set-up evaluation, a few things were noticed that need to be improved in the future.

- Simplify the start-up procedure. Today all apps need to be started in a certain order to work.
- Downloading laser scanned point clouds to the Companion App. The downloaded point cloud does not appear in the Companion App automatically, the files need to be manually moved to a certain folder. This is done in the laptops file manager.
- Save the point cloud in a simpler way, if possible. Today the downloaded point cloud is divided into countless many files, which means that you can only store small point cloud such as for a room or an apartment. A whole building is not possible to work with.

### 3.3.3 Evaluation of the sensor stick

The function of the sensor stick was tested by using it in the well-known conference room in RISE office at Borås, Sweden and at the villas. Following things were tested:

Finding things behind a gypsum and wood board:

- Finding studs or beams
- Finding water pipes
- Finding electrical cables
- Finding ventilation ducts

Finding things behind or in concrete:

- Finding water pipes

- Finding floor heating
- Finding electrical cables

The sensor stick measure and show, inductance, conductance, temperature and electricity at the same time. In the program code of the sensor stick its possibly to change the sensitivity of the different sensors. The Table below show the result of the evaluation.

**Table 2 Result of sensor stick evaluation**

Finding component	Result	Sensor in use
<b>Finding studs or beams behind wood or gypsum board</b>	When the studs consist of metal the inductance sensor give high values which make them easy to find. The studs were much more difficult to find when the consists of wood	Manly, inductance but also little capacitance
<b>Finding water pipes behind wood or gypsum board</b>	Depending on how far in the wall the pipes were placed they was possibly to find. It was easier to find the pips when the water was warm in them because then the temperature sensor also gave results	Capacitance and temperature
<b>Finding electrical cables behind wood or gypsum board</b>	If the electricity was on, the cable was easy to find	Electricity
<b>Finding ventilation ducts behind wood or gypsum board</b>	No ventilation duct was found	Manly, inductance but also little capacitance
<b>Finding water pipes and floor heating inside concrete slab</b>	Depending on how far in slab the pipes were placed they was possibly to find. It was easier to find the pips when the water was warm in them because then the temperature sensor also gave results	Capacitance and temperature
<b>Finding electrical cables behind wood or gypsum board</b>	If the electricity was on, the cable was possibly to find even if the indication was smaller than in the gypsum/wood case.	Electricity

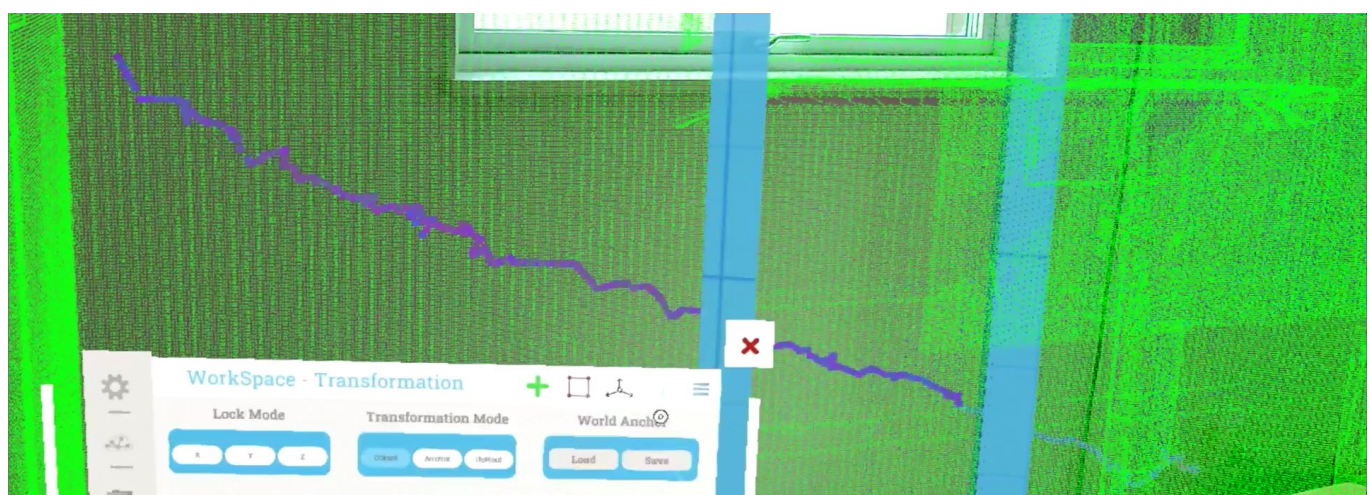
### 3.3.4 Evaluation regarding semantics and ontology

Semantic technology helps computer systems more accurately to interpret what we mean, and the ontology defines all elements involved in the system.

The procedure for fast mapping is to use a point cloud in the file format .pts and manually, by the help of a HoloLens2 define and create IFC-files for wall, floor, ceiling, window etc. To this, its possibly to add the result from the sensor stick. The sensor stick show the temperature, inductance conductance and voltage

at the considered surface. Out of the result from the sensor stick its possibly for the software to suggest where beams are located behind the wall. The program needs some guidance by stating the number of interactions and centroids. Once this is made, beams are generated automatically by pushing “Generate”, Se Figure 9 below.

So far, its only beams that can be generated. For other objects, like pipes, electrical cables, moist etc the user himself has to interpret these properties and define them in the HoloLens2 and finally create IFC-files of them. By using semantic and artificial intelligence (AI) it would be possibly for the sensor stick itself to suggest what is inside the construction. Instead of just measuring inductance and conductance you can get an indication about that it likely is a water pipe behind the wall.



**Figure 9** Once the number of interactions and centroids are stated (above) its possibly to generate beams (below)



## 4 Fast mapping at demo site in Italy

The activities took place on November 2nd and 4th 2021. Morning and afternoon at Via della Birona, 47 in Italy. The purpose with the demo site demonstration was to present and show the different functionalities of the Fast Mapping Toolkit.

### 4.1 The demo site

The Italian demonstration site was built in 1981. External facades are plastered, while the two stairwells and fronts balconies are fair-faced concrete. This building represents a typical example of social residential building of the '60s, '70s and '80s, period in which most of the built environment was developed in Italy. A more detailed description of the demo site will be found in D8.2 Report on demonstration in Italy [7].

One empty and one occupied apartment was mapped with the Fast Mapping Toolkit.



**Figure 10 Italian demonstration site, before (left) and after renovation (right)**

### 4.2 Fast mapping

The first day of demonstration activity of the Fast Mapping Tool consisted of the survey of an empty not inhabited apartment

1. Survey of the whole apartment with the laser scanner (Imager 5010).
  - a. Set up the laser scanner (definition of Mpt and quality). The survey was carried out with a medium coverage set up because it is a quite easy apartment
  - b. Reproduction of point cloud within the software (software released by the laser scanner producer) related to each surveyed room.
  - c. 18 scans in total. Merge together the different developed points cloud
2. Import and download the point cloud in the Companion App at the laptop
  - a. HoloLens2 based activity and import of the point cloud in 3D unity
  - b. Within the HoloLens2 it was possible to see the point clouds
  - c. An IFC object was designed using the HoloLens2 (one plane representative of a window

system)

3. Survey test with sensor stick to detect electric wires, plumbing, etc. the test was focused on a single room.

Note: The activity in the afternoon was performed as a workshop session with the presence of: ALER, POLIMI and REGIONE LOMBARDIA. Each participant had the possibility to put the HoloLens2 on and get a feeling of its interface.



**Figure 11 Demonstration at Italian demo site**

The second day of demonstration activity of the Fast Mapping Tool consisted of the survey of an inhabited apartment.

1. Survey of the whole apartment with the laser scanner.
2. Mapping test with HoloLens2 and stick with the purpose of time monitoring of the activities.
3. In the afternoon, the sensors stick survey was carried out again in the empty apartment of the first day. In particular, same rooms than the occupied apartment were chosen for a comparison purpose.

### 4.3 Result of the presented functionalities

The idea of the stick and its functionalities were presented. It was possible to appreciate the sensitivity of the sensors in detecting wires and plumbing, but it was not possible to see real time mapping through the HoloLens2. Some communication issues between stick and HoloLens2 were present.

Due to the not working connection between the stick and the HoloLens2, all the mapping test activities are considered as indicative to have an idea of the time needed for mapping each building surface.

It turned out that the stick can better detect the electric wires if there is some power present in the apartment. In this first case the presence of the wire is detected through the Voltage sensor. If the electricity is switched off or very low, the stick can detect the electric wires through the Capacitance sensor. This only works in non-reinforcement constructions because the Capacitance sensor have difficulty to separating the non-live electric wires from the reinforcement.

Some difficulties in the alignment of the point cloud with the scanned room through the HoloLens2. This activity was repeated several times to get a perfect alignment, but there were issues during the process, and it took time.

There were several persons inside the room. The more the person were present the more the alignment

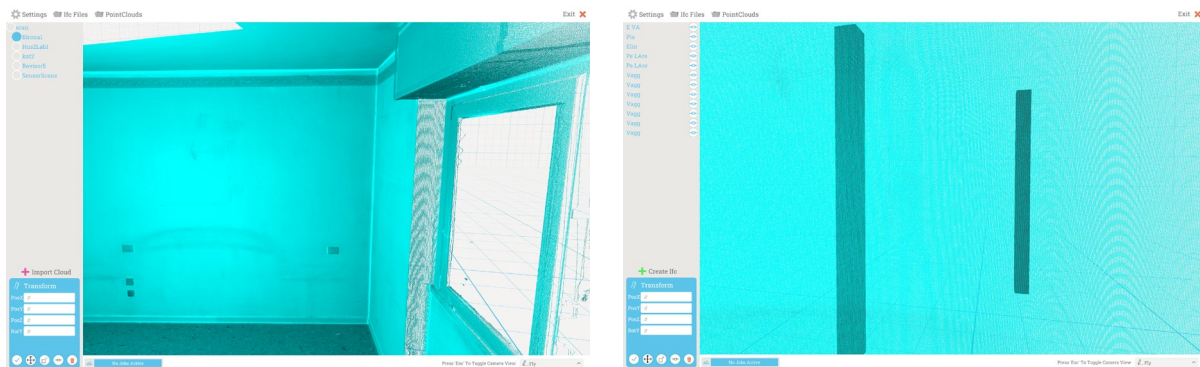
of the point cloud was difficult. An empty space is required to speed up the process.

It also appeared that Wi-fi and cell phones interferes with the data stream between the Companion App, the sensor stick and HoloLens2. Additional wi.fi devices present in the space should be switched off.

While in use it is a problem to change the HoloLens2 user. Every time a re-alignment of the space should be needed such as an on-off switch of the device.

Dust in the empty apartment was an issue. While moving over the floor/ceiling/wall surfaces of the empty apartment the sensor could collect dust. There is the possibility that dust could interfere with the reading capabilities of the sensor included in the prototype. At the end of the second day the capacitance sensor went out of scale and had difficulties in proposing the right bottom scale value.

Figure 12 show the point cloud from the empty apartment, when loaded to the companion App. On site a IFC object similar to a window were created. Later, and out of the demonstration, two beams were created, these are seen as IFC objects to the right in Figure 12.



**Figure 12 The point cloud from the empty apartment visibly in the Companion App. Two beams were created in the HoloLens2, which are seen in the right Figure**



## 5 Fast mapping at demo site in Finland

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### 5.1 The demo site

The Finish demonstration site was built in 1992. The apartment building is owned by Keva. The building is heated with district heating. This building represents a typical example of social residential building of the '70s, '80s and '90s, period in which most of the built environment was developed in Finland. A more detailed description of the demo site will be found in D8.4 Report on demonstration in Finland [7].

The purpose with the demo site demonstration was to present and show the different functionalities of the Fast Mapping Toolkit.



Figure 13 Finland demonstration site in Espoo

### 5.2 Fast mapping demonstration

The activities took place on January 25, 2022. A boiler room on the ground floor and part of a staircase were selected for the demonstration. The reason for this was to define whether the new heat pump fits



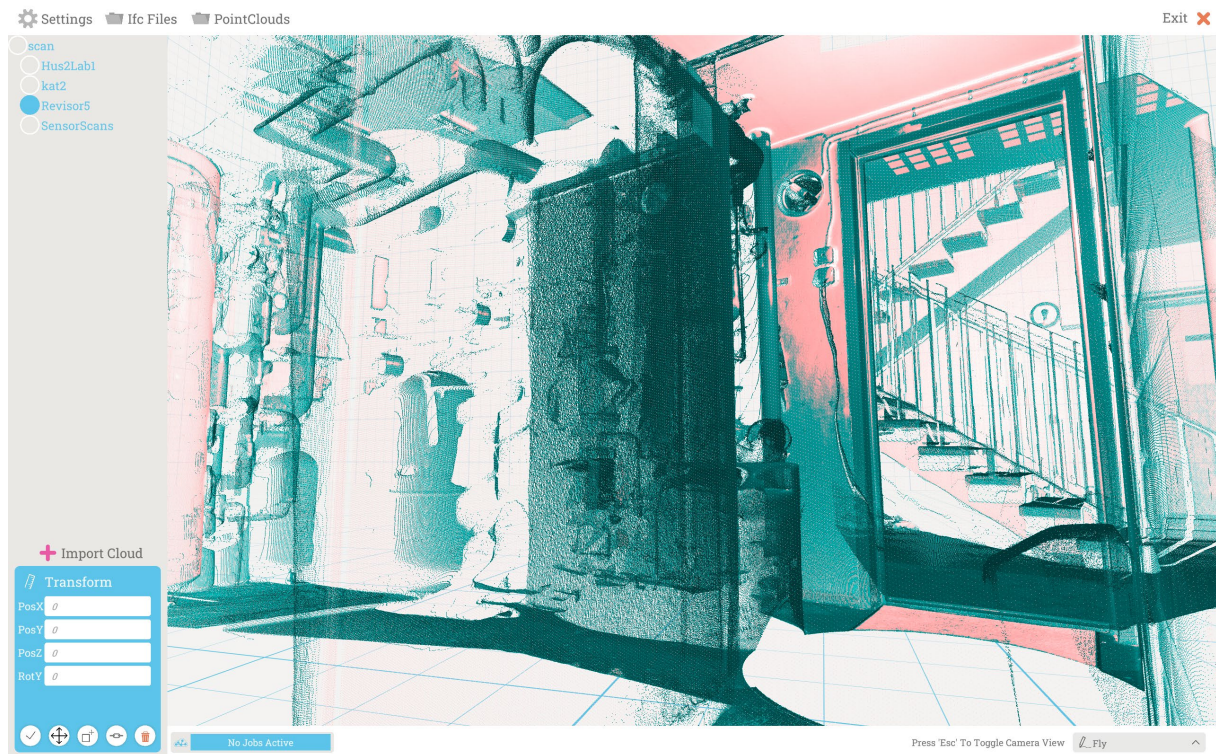
and can be transported there without breaking the walls or moving other equipment. Due to the corona restrictions of not traveling and the issues with not get the Fast Mapping Toolkit to work properly the demonstration was delayed. Which resulted in that the new heat pump already was installed at the visit.

The demonstrations contained following:

1. Survey of the whole room and stairwell outside with the laser scanner (Imager 5010).
  - a. Set up the laser scanner (definition of Mpt and quality). The survey was carried out with a medium coverage set up because it is easier to handle.
  - b. Reproduction of point cloud within the software (software released by the laser scanner producer) related to each surveyed room.
  - c. 5 scans in total for the equipment room and another 3 for the stairwell. Merge together the different developed points cloud
2. Import and download the point cloud in the Companion App at the laptop
  - a. HoloLens2 based activity and import of the point cloud in 3D unity
  - b. Within the HoloLens2 it was possible to see the point clouds
  - c. An IFC object was designed using the HoloLens2 (one plane wall and a pipe)
3. Survey test with sensor stick to detect electric wires, plumbing, etc. the test was focused on the equipment room. Due to the small surfaces in the room, the floor and ceiling was used for the sensor stick mapping.



**Figure 14 Demonstration at Finland demo site. An equipment room**



**Figure 15 The downloaded point cloud in the Companion App**

### 5.3 Result of the presented functionalities

The function of the HoloLens2 in combination with the Companion App and sensor stick were demonstrated. It was possible to detect electrical cables inside the wall and identify inhomogeneous part of the construction (changes in inductance and capacitance measurements). It was also possible to see real time mapping through the HoloLens2, but not recording the results.

The stick had some difficulties to detect all electrical cables, which probably depend on their location in the wall. The deeper in, the harder it is to discover. This was typical for one wall in the Stairwell outside the equipment room.

It turned out that it was quite difficult to align the point cloud with the scanned room through the HoloLens2. All the equipment and small room made it more difficult than at the Italian demo. This activity was repeated several times to get a perfect alignment, but where only obtained once.

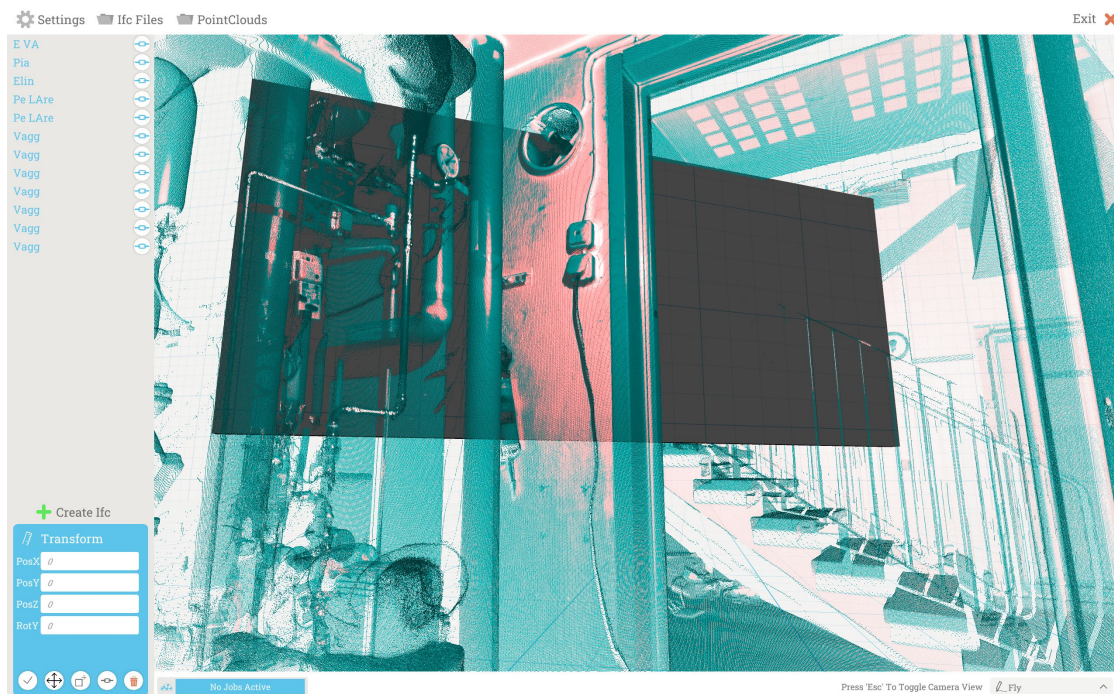
While in use it is a problem to change the HoloLens2 user. Every time a re-alignment of the space should be needed such as an on-off switch of the device.

A wall was created as an IFC-file in the HoloLens2 by snapping to the loaded point cloud. Since the boiler room was fully equipped it was hard to find the correct point to snap against which resulted in that the wall appears in a completely wrong place, see Figure 15. This is possibly to correct in HoloLens2 by move and rotate the object before its committed to the Companion App. Once it's committed, a IFC-file is created and the object become grey in the HoloLens2 and is visibly in the Companion App.

Modifying committed objects are little tedious to do, but it is possible. Removing content from an existing IFC-file was the most troublesome because there are many links between entities that must be accounted for, they needed to be deleted in such a manner where we don't produce empty references. Adding content however are easier, it has no impact whatsoever, for example, creating an opening in an existing wall or



adding a pipe.



**Figure 16 A IFC-file of a wall are created on the completely wrong position in the boiler room**

## 6 Fast mapping at demo site in Poland

### 6.1 The demo site

The Polish demonstration site was built in 1902. It is a residential building located in Chorzow, near Katowice. The building has five floors with 12 apartments and some commercial areas. A more detailed description of the demo site will be found in D8.3 Report on demonstration in Poland [7].

An apartment on the top floor with usable area of 90 m<sup>2</sup> on the top floor was chosen for the Fast Mapping Tool demonstration. The purpose with the demo site demonstration was to present and show the different functionalities of the Fast Mapping Toolkit.



Figure 17 Poland demonstration site in Chorzow

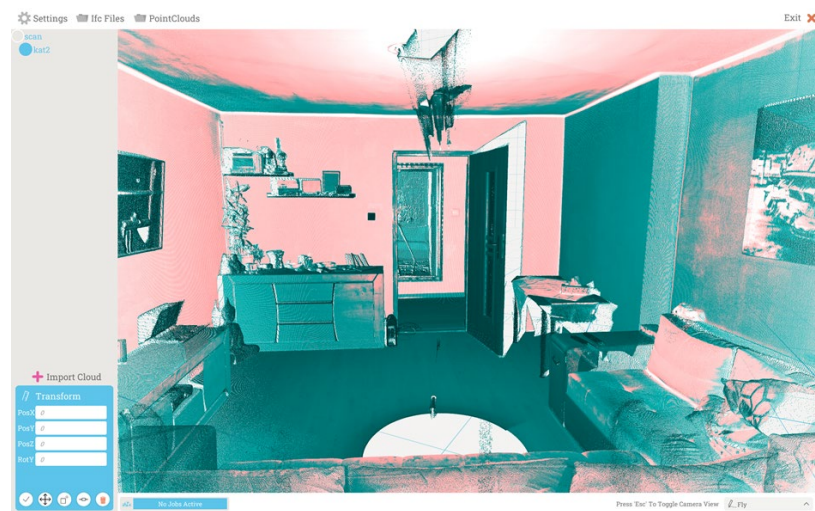
### 6.2 Fast mapping

The demonstration activity of the Fast Mapping Tool, took place during two half days in beginning of February 2022. The living room in the apartment were chosen for the demonstration.

The demonstrations contained following:

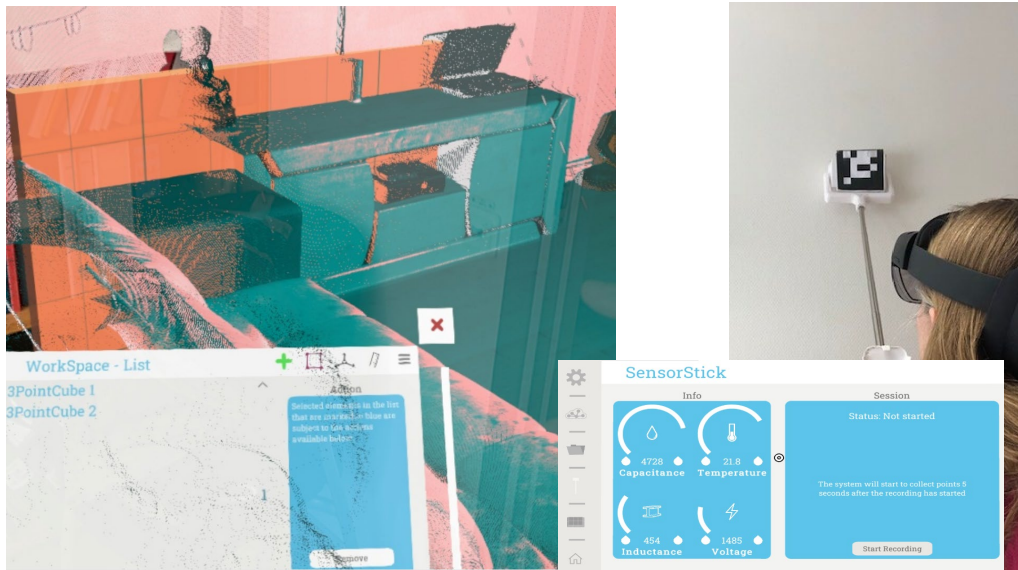
1. Survey of the living room, hall, part of the kitchen and one bead room with the laser scanner (Imager 5010).

- a. Set up the laser scanner (definition of Mpt and quality). The survey was carried out with a medium coverage set up because it is easier to handle.
  - b. Reproduction of point cloud within the software (software released by the laser scanner producer) related to each surveyed room.
  - c. 4 scans in total for the living room and another 10 for the hall, kitchen and bead room. Merge together the different developed points cloud
2. Import and download the point cloud in the Companion App at the laptop
    - a. HoloLens2 based activity and import of the point cloud in 3D unity
    - b. Within the HoloLens2 it was possible to see the point clouds
    - c. Some IFC object was designed using the HoloLens2 (one plane wall, studs and part of a pipe). Only the plane wall was committed and transferred to the Companion App.
  3. Survey test with sensor stick to detect electric wires, surface temperature and differences in inductance and capacitance within the walls. The mapping with the sensor stick were only done in the living room. Two recording from the sensor stick was saved within the HoloLens2 but not saved in a correct way.

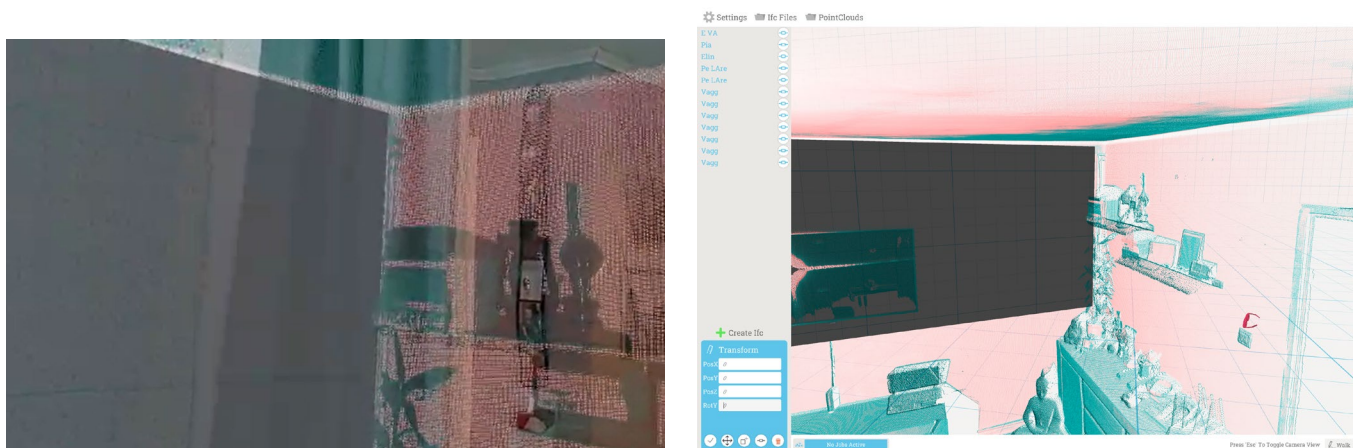


**Figure 18 The point cloud of the living room downloaded to the Companion App at the laptop**

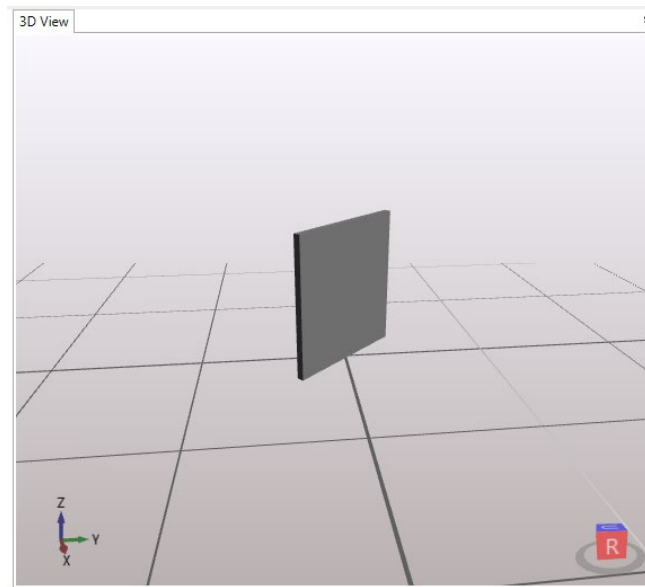




**Figure 19** A part of a wall is created behind the bench in the HoloLens2 (left). As long as the object has the orange colour, it's not committed to the Companion App and its possible to change size and position on it. Use of the sensor stick on a wall (right)



**Figure 20** A part of a wall is created and committed to the Companion App. The left Figure show a screen shot of what is seen in the HoloLens2. The grey colour indicates that it is committed and has become a IFC-files. The IFC-file (part of the wall) is visibly in the Companion App, right Figure



**Figure 21 The created IFC-wall opened in a commercial software (Xbim) without the point cloud**

### 6.3 Result of the presented functionalities

The function of the HoloLens2 in combination with the Companion App and sensor stick were demonstrated in an apartment. It was possible to detect electrical cables inside the wall and identify inhomogeneous part of the construction (changes in inductance and capacitance measurements) even if these were much smaller than in previous demonstrations in Finland and Italy. It was also possible to see real time mapping through the HoloLens2, but no recording was possible.

The result of the laser scanning is downloaded to the laptop before its downloaded to the Companion App. Surprisingly it was not possible to load it to the Companion App without connecting the computer to the local network between the HoloLens2, sensor stick and laptop.

The problem with the alignment between point cloud and reality continues even if it's become easier with more training. It was also quite time consuming to reach the keyboard within the HoloLens2 to be able to name the created IFC-object.

## 7 Conclusions of results

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### 7.1 Lesson learnt from the demonstration and testing's

The demonstrations are satisfied, but the toolkit still needs some improvements. It is difficult to use for an untrained person but with further improvements it's have high potential to become a commercial tool.

Creating simple IFC elements for the BIM is possible, but for generating of complete IFC model of the building, the tool will still need more development.

The sensor stick together with the live visualization is very handy as it is possibly to fast pinpoint deviations inside the structure and when decide where to cheerfully record with the sensor stick.

The feeling is like this really could be a suitable toolkit for the job of mapping buildings for renovation. Even though we are happy with the results, we could get even further with some of the mentioned improvements.

Different improvements were detected at the different demonstration sites:

1. The user need training in aligning the point cloud with the reality within the HoloLens2. This is done by first snap at the point cloud and then snap at a point where the first snap should move to. The difficulty is that you do not get any indication that the first point has been registered when you choose the second one.
2. It would help if it were possible to save the alignment at the Companion App once it is made.
3. Mobile phones and other data transfers might disturb the connection between HoloLens2, Companion App and the sensor stick.
4. It is easier for the sensor stick to detect electrical cables if the power is on.
5. The user need training in handle the HoloLens2 and in particular found the special finger snap to be able to reach the keyboard and other important bottoms in the PolyTech app within the HoloLens2.
6. It is not possible to download the point cloud to the companion app without connection the computer to the local network, even if the point cloud is at the computer's hardware.

Different improvements that were detected at the Boras office:

1. The start-up procedure needs to be simplified. Today all apps ned to be started in a certain order to work.
2. Easier downloading laser scanned point clouds to the Companion App. The downloaded point cloud does not appear in the Companion App automatically, the files ned to be manually moved to a certain folder. This must be done at the laptops file manager.
3. Saving the point cloud in a simpler way, if possibly. Today the downloaded point cloud is divided into countless many files which means that you can only store small point cloud such as for a room or an apartment. A whole building is not possibly to work with.
4. Getting the software to work on more kind of laptops. It turned out that the software only works on certain computers and it's not clear how and why it's in this way

There was a big difference between who carried out the demonstration in terms of time and functionality. When the demonstration is made by a well-trained person, all functions work, and the time for mapping a building can be roughly estimated in minutes as the number of square meters multiplied by 1.25.



## 7.2 Evaluation of KPI (Key Performance Indicators)

The purpose with the Fast Mapping Toolkit is to create IFC-files in a faster and more illustrative way, not only geometrical data but also be able to add information about the construction, with help of the sensor stick. One of the projects KPIs are to show the possibly time reduction. This is described in more detail in the deliverables connection to work package 8 (WP8) Demonstration in relevant environment. Mapping a building without access to a 3D scanning is very time consuming. It means that every single measure (corners, window position, door position, ceiling and floor area) must be added to drawings by hand craft. To this you need to add time for detection of studs and pipes.

By using the Fast Mapping Toolkit both the scanning and mapping become easier and much faster. It also gives benefits for the building owner when understanding the construction and discuss different renovation options with the different advisors and designers. The mapping might show where to not open or to open a wall due to electrical cables or other pipes inside it.

During this testing and demonstration, it was only relevant to take the time when mapping at CGIs office. The other demonstrations and testing where performed with more untrained persons which resulted in that it took a lot of time to communicate with the HoloLens2 in correct way with the correct finger snap.

The time for mapping a building can be roughly estimated in minutes as the numbers of square meters multiplied by 1.25

## 7.3 Further improvements

Based on the lesson learnt there are several of improvement that can be made:

1. Easier download the point clouds. Today the files need to be moved manually between different maps. Uther wise the Companion App can't find them.
2. Insert a sound or a colour to indicate when a snap (click) is registered in the HoloLens2. Especially when aligning the point cloud.
3. Simplify the start-up procedure. Today all apps need to be started in a certain order to work.
4. Save the point cloud in a simpler way. Today the downloaded point cloud is divided into countless many files which means that you can only store small point cloud such as for a room or an apartment. A whole building is not possibly to work with.
5. Clarify and add instructions in the HoloLens2 about where the record of the sensor stick is saved.
6. Get the software to work on more kind of laptops. It turned out that the software only works on certain computers and it's not clear how and why it's in this way.
7. Create templates with in the PolyTech app (in the HoloLens2) of doors, windows, openings that are placed often. '
8. Add templates to the spline tool, this way we can draw walls much quicker
9. By using semantic and artificial intelligence (AI) it would be possibly for the sensor stick itself to suggest what is inside the construction. Instead of just measuring inductance and conductance you can get an indication about that it likely is a water pipe behind the wall

## 8 Conclusions

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The Fast Mapping Toolkit have been tested and demonstrated in different kind of buildings and rooms.

- An office at CGI (light construction)
- A meeting room and a villa at RISE (light and heavy construction)
- Two different apartments at the Italian demo site, one empty and one occupied.
- A boiler room at the Finnish demo site.
- An occupied apartment at the Poland demo site.

The testing and demonstration at all places except the CGI office are performed by RISE who have not been involved in the programming of the software, the user have only had the manual and the movies to guide them through the handing of the toolkit. It has worked well, but it has not felt relevant to take the time of mapping the different room since there have been a lot of struggles with the equipment. The time it takes to scan and map a room are instead only measured at CGIs office where the person is well trained in the use.

During the project the toolkit have been continuously developed and updated. Here the newest interface of the HoloLens 2 and Companion App were demonstrated. The outcome should be a 3D visualisation of a room with its hidden studs, pipes and power cables shown, in this report, a wall is shown as an example. 3D information of a building's geometry, construction and hidden studs, pipes and power cables are important information for the building owner when to decide about renovation and other changes in the building. The designers (both architects and constructor) need to know existing size of the rooms within a building and its construction to be able to suggest the best solution for a renovation. The 3D visualisation also helps to understand how things look like when communicate to tenants and other stakeholders.

The testing at CGIs office showed that the tool kit worked well. It took around 1 hour to scan and map a 25 m<sup>2</sup> room. Half of the time was for scanning and half for the mapping. Despite the good results, some opportunities for improvement were identified, such as create templates of doors, windows, openings that are placed often and add templates to the spline tool to be able to draw walls much quicker.

The IFC-file created from the scanning and mapping is part of the total BIM.

## 9 References

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- [1] D2.2 List of designers' needs and requirements for BIM-based renovation processes. Public report (VTT)
- [2] D2.3 List of construction companies' needs and requirements for BIM-based renovation processes. Public report (PoliMi)
- [3] D2.4 List of service companies' needs and requirements for BIM-based renovation processes. Public report (PoliMi)
- [4] D5.1 Report of existing techniques and recommendation of mapping technique. Public report (RISE)
- [5] D5.2 Report of output from metering devices and their translation in BIM models. Public report (RISE)
- [6] D8.1 Report on management of real Best Practice Examples. Public report (PoliMi)
- [7] D8.2-8.4 Reports on demonstration in Italy (Mediterranean country), Poland (Continental country) and Finland (Scandinavian country). Public reports (PoliMi, PROCHEM and VTT)
- [8] D4.8 Guidelines for the integration of new tools in the BIM management system. Public report (OneTeam)

Figures and photos are taken or made by the following own creators:

Fig. Publishing summary: Anton Gustavsson, RISE and Anders Bratt CGI

Fig. 2: Andrea Giovanni Mainini, PoliMi

Fig. 6-7: Anders Bratt, CGI

Fig. 9: DoV 2018 and Eva-Lotta Kurkinen, RISE

Fig. 10: Andrea Giovanni Mainini, PoliMi

Fig. 11: Caverion and VTT

Fig. 15: Aleksander Bartoszewski, Prochem

All other Figs.: Eva-Lotta Kurkinen, RISE

## 10 Appendix

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### 10.1 User Manual for Fast Mapping of Buildings AR-Toolkit, version 1

The following document is an instruction manual for the use of the BIM4EEB, Fast mapping of Building AR-toolkit, version 1.

It covers the equipment of mapping buildings and instructions for work flow with required devices from a user perspective. It also describes how to create an IFC-file to transfer data to BIM Management System.

Detailed instructions and equipment are presented under Equipment needed. The following list is an overview of the entire process of acquisition to help you navigate the workflow:

- A laser scan is made of the studied room
- The laser scan is imported to a laptop
- The laptop is used to clean up the laser scan and make it reachable by the other devices
- A HoloLens 2 is connected to the laptop via Wifi
- The Sensor Stick is connected to the HoloLens 2 via Bluetooth
- The point cloud becomes visible in the HoloLens 2 and the point cloud is oriented to match the building that was scanned.
- The Sensor Stick and the HoloLens is used in tandem to perform scanning of walls, filter scan data, create polygonal geometry, create notes and place virtual objects
- All items added by the HoloLens 2 is committed to the laptop
- The updated version of the point cloud is converted to a BIM file format through xBIM.

#### 10.1.1 Equipment needed

##### Overview

You need:

- Scanning equipment
- HoloLens 2
- BIM4EEB Sensor Stick V2
- A powerful laptop computer
- Scanning software (installed on computer)
- The BIM4EEB Companion app (installed on computer)
- The BIM4EEB HoloLens app (installed on a HoloLens 2)
- Recommended: Access to on site Wifi

##### Scanning equipment

The BIM4EEB system uses point clouds to position and overlay information in all stages of the process. This means that the user needs a point cloud of the subject building to be able to output valuable results. The step by step instructions for laser scanning will not be outlined here as different scanning equipment all behave differently. Keep in mind that a PTS file format is needed and is to be transferred to the computer

running the BIM4EEB Companion app. A laser scanner should be of high quality although the point cloud density can be set to a medium setting as this also reduces the amount of data needed to project and transfer between the devices. We recommend an experienced surveyor with a high level type of laser scanner, TLS.

### **HoloLens 2**

The BIM4EEB system uses a HoloLens 2 for interaction with user interface and positioning of other scanning equipment in the subject structure.

### **The BIM4EEB Sensor Stick V.2**

The Sensor Stick is an array of sensors mounted on the end of a handheld telescopic stick. This array of sensors pick up shifts in temperature, density and radio wave frequency to determine position and material of hidden objects in the walls ceilings and floors.

### **Computer (Laptop)**

We recommend using a laptop that offers both mobility and power as this allows for sensor scanning and laser scanning can be acquired in parallel with high efficiency. With the correct set-up the user can move from room to room maintaining connectivity between all devices as well as performing process-intensive tasks in the building being scanned.

#### **Recommended specifications of laptop:**

- 32GB RAM
- Nvidia 1070 or higher
- 500 GB hard drive
- Intel i7 CPU

### **Software**

Installed on the laptop:

- The BIM4EEB Companion app
- Laser scanning registration software.

#### **Installed on the HoloLens 2:**

- The BIM4EEB HoloLens app

### **Wi-Fi**

It is recommended to gain access to the on-site Wi-Fi. Alternatively you could connect to other wireless alternatives that help the Sensor Stick, HoloLens 2 and laptop stay connected throughout the process. We recommend at least a 4G connection. Remember that the laptop can also host as a local network to connect devices within a small area if needed.

## **10.1.2 Instructions – How to scan and create point clouds**

Set-up of the laser scanner, laptop, HoloLens.

### **Laser scanning of geometries**

1. Start the scanner and begin to scan the selected areas in the room.
2. Place the scanner in the middle of the room and start with a survey scanning. You need to move

the scanner in the room to get different angles to cover the whole area in the room. All corners need to be included.

3. Finally, place the scanner in the door opening to scan outside the room. This is needed to connect the room together with other scanned rooms.
4. Make a brief registration to get all scanings in the same coordinate system. This is done directly after scanning to show if the scanned data can be visualized as expected results.
5. Adjust the results more in detail if needed so the made scanings work together.
6. Create a point cloud from the scanned data, transfer it to the laptop and import it into the Companion App in the laptop computer.

### 10.1.3 Instructions – Import point clouds into HoloLens

This instruction assumes the user has performed the following steps:

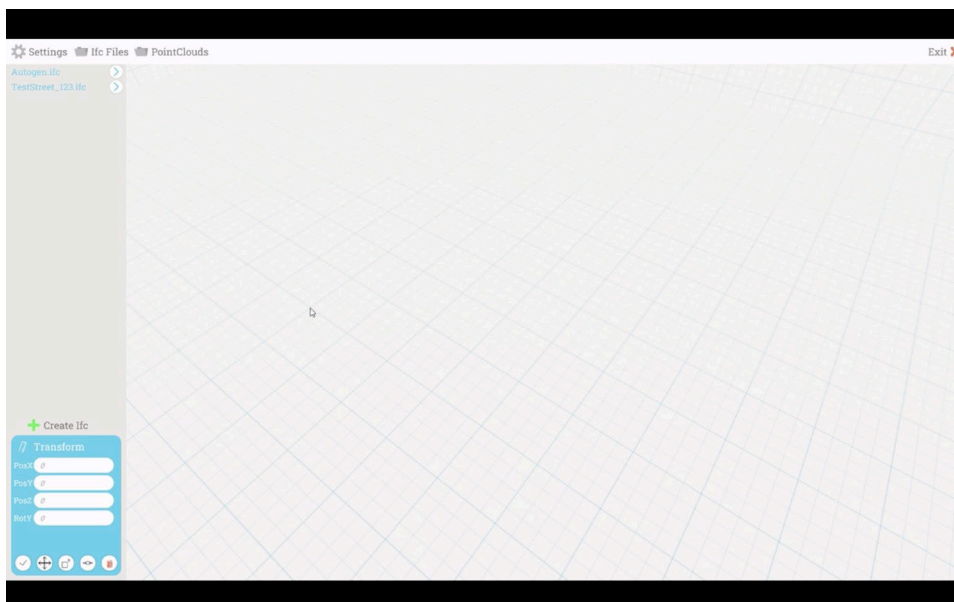
- Point cloud has been acquired through laser scanning.
- Point cloud has been cleaned up using appropriate point cloud related software and all files related to the point cloud are located on the laptop.

In this section we will learn how to:

- Import the point cloud to the BIM4EEB Companion app
- Transform the point cloud inside the BIM4EEB Companion app
- Prepare the point cloud for use in the HoloLens

#### Import of point cloud

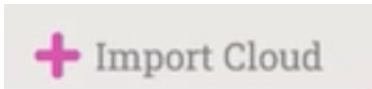
All of the following actions take place on the laptop running the BIM4EEB Companion app.



- Click Point clouds



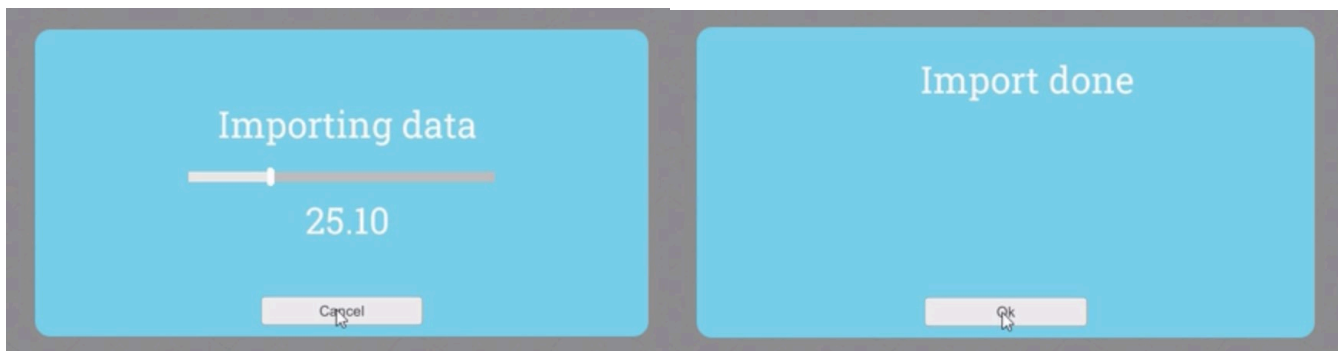
- Click import Cloud



- Locate a laser scan file ending in .pts and click import

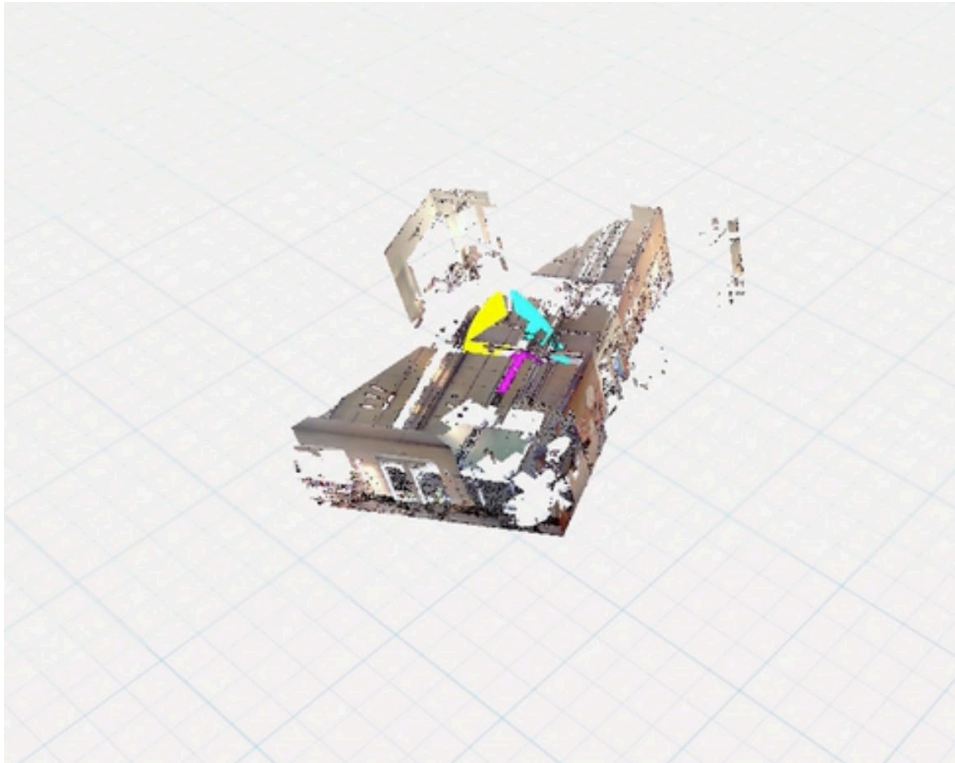


- Wait for the import to finish and click Ok

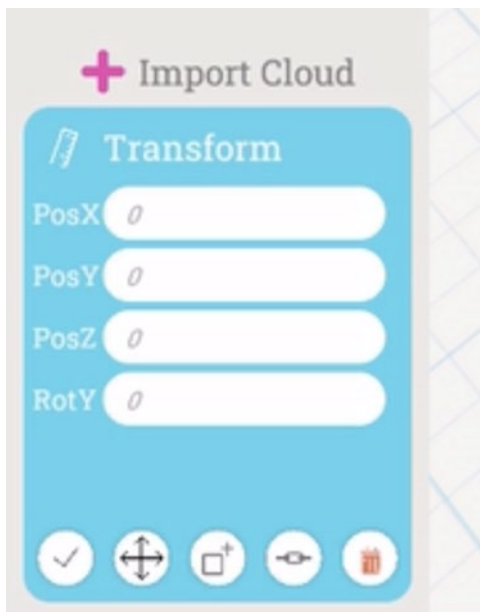


- Once the point cloud is imported you can transform its position and rotation by clicking different parts of the transformation tool in the 3D viewport.



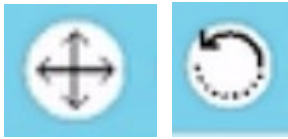


- Clicking the yellow, magenta and blue sides of the transformation tool will allow you to orient the pointcloud in two axes at the same time.
- You can also use the transformation window in the lower left to manually set transformation values.

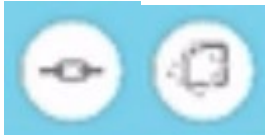


- The transformation window also holds a tray of tools to help position the pointcloud. Clicking the following icons will toggle between the move tool and the rotate tool





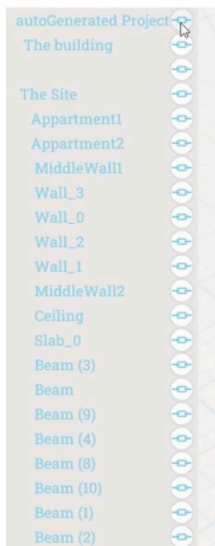
- Clicking the pivot icon will allow you to move the transform tool itself (editing the pivot point), making it easier to match different pointclouds with each other in 3D space. This is done by toggling between the following two icons



- To navigate to the library of ifc files press Ifc Files



- This will show all of the components of the opened Ifc file



- The following icon allows you to toggle visibility of any object in the Ifc-file



- To create a new Ifc file to be rendered in the HoloLens go to Ifc-files



- Click Create Ifc



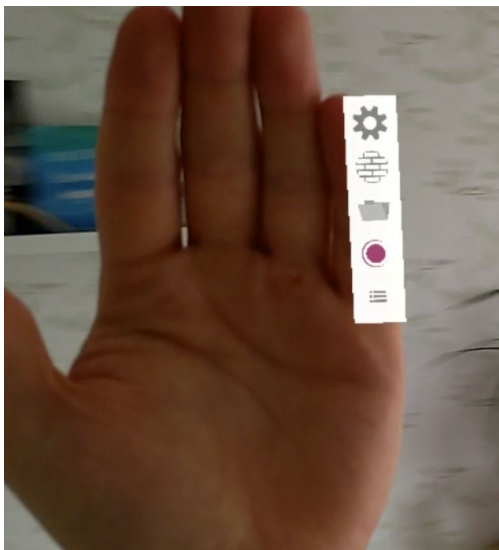
- Give the new Ifc-file a save directory and a name and click Create!



- The Ifc-file will be automatically selected when looking through the HoloLens

#### 10.1.4 Instructions – Selecting and viewing point clouds

##### Getting to know the Main Menu inside the HoloLens



When you raise your arm and show the palm of your hand to the hololens, a menu will appear with everything you need for using this application.

There are two ways of interacting with the menu, either by “touching” it with your finger tips, or by pointing at it with the opposite hand.

In descending order the options are as follows;



Options

This is where you can change the root position of the current project in relation to the physical world, and you can also change how far point clouds will be rendered.



PointClouds

This is where you select what point clouds should be visible from within the HoloLens.



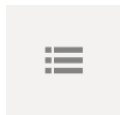
Ifc-Files

This is where you inspect, alter select and view your Ifc-file.



SensorRecording

This is where create sensor recordings.

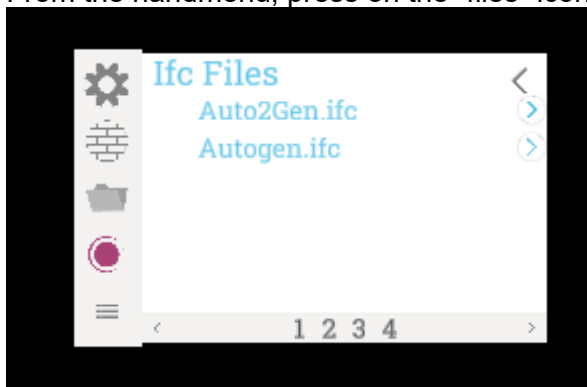


WorkSpace

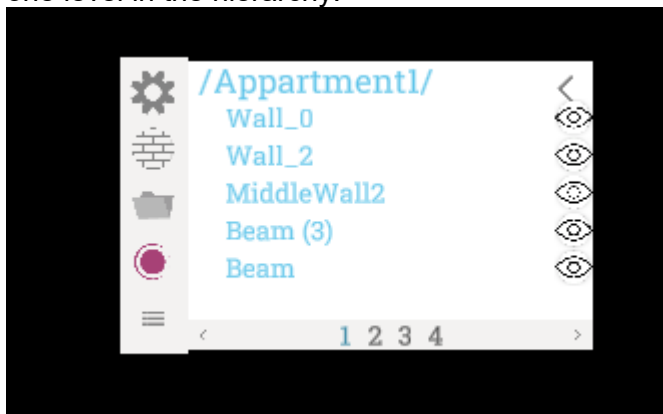
The workspace is where you create and manipulate 3D geometries and then push them to the Ifc-file.

### Selecting and Viewing IFC-Files

From the handmenu, press on the “files” icon and select an ifc-file that you want to work with.

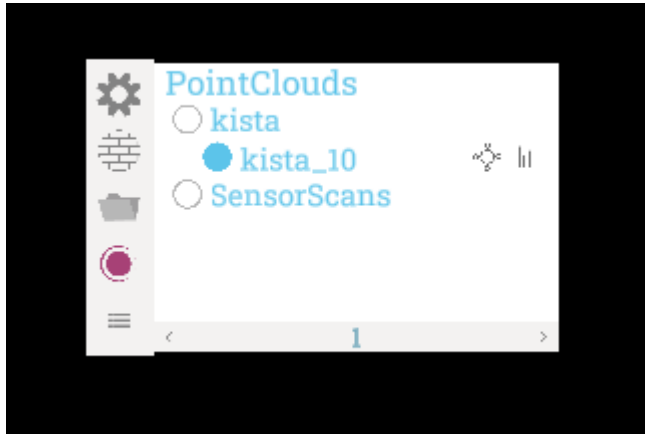


An hierarchy is displayed of the current ifc-file, and by pressing on the individual items you can go down one level in the hierarchy.



## Selecting And Viewing Point-Clouds

From the handmenu, press the Point-Clouds icon and select the point cloud that you want to visualize.



## 10.1.5 Instructions – Sensor Scanning

### Scanning with Sensor Stick

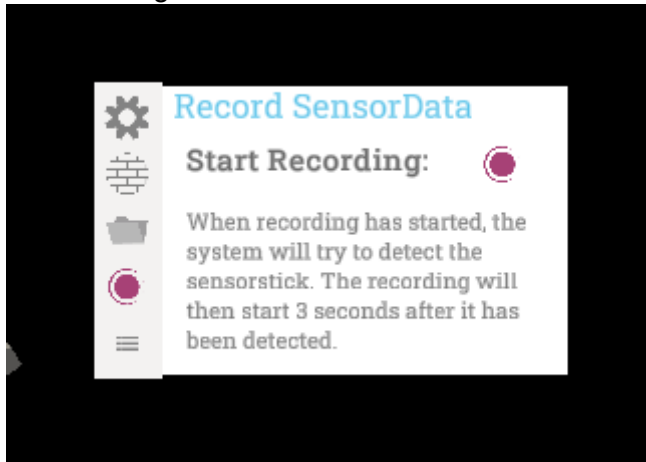
Before you start scanning, make a visual observation of the room to detect areas that need to be investigated and scanned in detail that may, for example, present moisture damages etc. If damages are visible, do more detailed scans to find moisture problems.

### Start Scanning

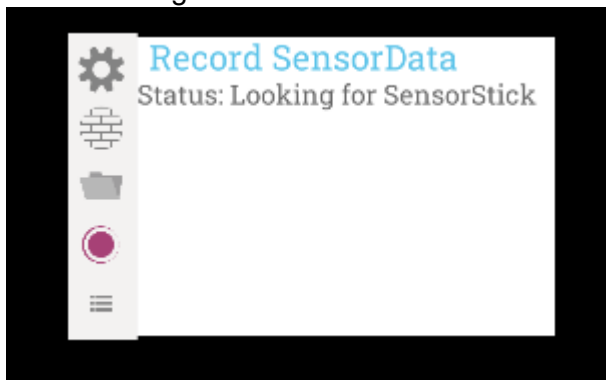


1. Start the Sensor Stick by connecting the cable to the power bank. Check that the Sensor Stick has started after about 20-30 seconds.

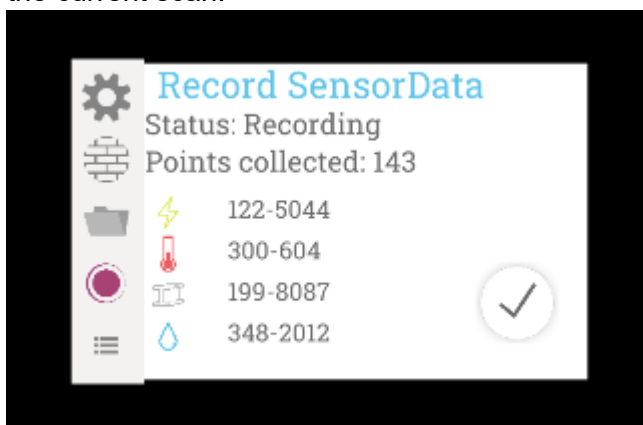
2. Choose an area on the wall to scan. It is recommended to sweep the sensor stick in a rectangle form from corner to corner around the room. After the corners are detected, the sensor stick shall be drawn diagonal as a cross model to cover all installations in the wall.
3. Get the palm menu up and navigate to the Recording view, then click on the button for starting the recording.



4. Make sure that the sensorstick is visible at all times for the HoloLens front-facing camera. The recording will start 3 seconds after it has been detected.

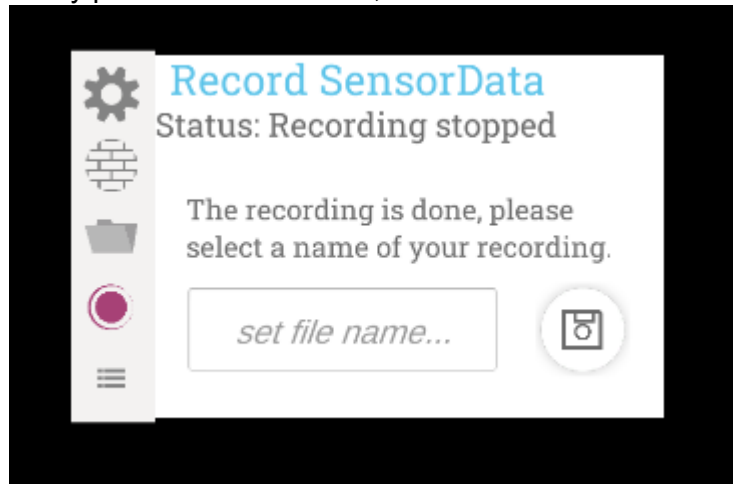


5. Define the geometry in the room by drawing the stick along the edges of the wall around the room and draw after that a cross in the middle of the room from corner to corner. This is needed to cover most of the installations as electricity, water pipes, chords etc.
6. Sweep with the stick across the area of interest. The hand menu will show you a brief status of the current scan.





7. When you are done, press the checkmark on the hand menu. Add a name to your scan and finally press the save button, and the scan will be saved on the Laptop.



### Adding and creating 3D Geometries from the WorkSpace

There are currently three ways for generating geometries;

1. Manual geometry generation  
By selecting the desired base geometry you can then manipulate it in to what you want it to become, for example a cube becomes a wall and a cylinder becomes a pipe. The geometry is then added to the “Workspace” and can be added in batch to the lfc-file.
2. Sensor-scan group filtering  
First select a sensor scan from the list of point clouds. Then select Cluster Grouping inside workspace menu. If the threshold values are altered, the result from the cluster grouping is also changed, resulting in, for instance, beams inside the walls based on the values.
3. Point-cloud filtering  
The third option is to start from a point cloud. Using this option you can use real measurements from the point cloud as a base for you geometries. As an example you can use Edge Geometry to select edges inside the point cloud, and then use these edges as a base for your geometry, for example four courses in the point cloud become a wall.

When you are satisfied with your geometries, you can select them as a group or individually and then add parents for them from the lfc-file. Property sets and Quantity sets are also added here.

#### 10.1.6 IFC-file transfer to BIMMS

Since the framework is constantly updating the lfc-file, it can at any time be transfered to the BIM Management System. Point clouds are not merged into the lfc-file, they are considered stand alone files. But the point clouds can of course also be uploaded to the BIM Management System.