BIM4EEB

BIM based fast toolkit for
Efficient rEnovation in Buildings

D8.4 Report on demonstration in Finland

This project has received funding from European Union's H2020 research and innovation programme under grant agreement N. 820660

Programmes	H2020
Call for Proposal	LC-EEB-02-2018 Building information modelling adapted to efficient renovation
Project Title	BIM based fast toolkit for Efficient rEnovation in Buildings
Acronym	BIM4EEB
Project Grant Agreement	820660

D8.4 Report on demonstration in Finland

Work Package	WP8
Lead Partner	VTT
Contributing Partner(s)	Caverion
Dissemination Level	Public
Type	R: Document, report (excluding the periodic and final reports)
Due date	31/05/2022
Date	31/05/2022
Version	1.0

DOCUMENT HISTORY

Version	Date	Comments	Main Authors
0.1	23.3.2021	First draft for comments	Teemu Vesanen (VTT)
0.2	2.2.2022	Updated structure after real situation in the pilot site and discussion with the other pilot task leaders	Teemu Vesanen (VTT)
0.3	3.3.2022	BIMMS and BIMeaser content added	Davide Madeddu (Oneteam), Teemu Vesanen (VTT)
0.4	11.3.2022	BIMPlanner content added	Markku Kiviniemi (VTT)
0.5	25.3.2022	Additions to energy simulation information and pilot description	Mika Oikarinen (Caverion)
0.6	30.3.2022	Finalising for the internal review	Teemu Vesanen (VTT)
0.65	11.04.2022	Internal review, comments and remarks	Larissa De Rosso (ACE), Olli Nummelin (Caverion)
0.7	15.04.2022	Revised version	Teemu Vesanen, Markku Kiviniemi (VTT), Mika Oikarinen (Caverion)
0.75	21.04.2022	WP leader review, comments and remarks. WP leader's approval	Aleksander Bartoszewski (Prochem)
0.8	4.05.2022	Revised version	Teemu Vesanen, Markku Kiviniemi (VTT), Mika Oikarinen (Caverion)
0.81	12.05.2022	Language check by a native English speaker	Karen Mould (IERC)
0.82	12.05.2022	Revised version	Teemu Vesanen (VTT)
0.9	23.04.2022	Coordinator review, plagiarism check	Bruno Daniotti, Martina Signorini (PoliMi)
1.0 FINAL	24.04.2022	Final version for submitting	Teemu Vesanen, Markku Kiviniemi (VTT), Mika Oikarinen (Caverion)
1.0 FINAL	31.05.2022	Final and formal review, submission	Bruno Daniotti (PoliMi), Gabriele Canzi (FPM/POLIMI)

BIM4EEB action has received funding from the European Union under grant agreement number 820660.

EXECUTIVE SUMMARY

The Finnish pilot building is a five-floor apartment building located in Espoo, in the capital region of Finland. The building has district heating and mechanical exhaust ventilation system. The building is built in 1992 and represents a typical technology which has also been used in many other apartment buildings, constructed in 1970's and 1980's.

Installing an exhaust air heat pump (EAHP) was found to be the most suitable measure to improve the energy-efficiency of the building. The recovered heat will be used for both space heating and domestic hot water heating, thus reducing district heating consumption significantly.

Four of the BIM4EEB toolkit tools were demonstrated on the pilot. BIM Management System (BIMMS) was used as a common data environment to store the BIM model of the pilot building, documentation, sensors streaming, activities and alerts. Fast Mapping Toolkit demonstrated visualizing and modelling features and BIM Early Stage Energy Scenario tool (BIMeaser) collected the available data for semi-automatic energy modelling. Construction production management tool (BIMPlanner) demonstrated how the renovation project activities can be monitored using BIM based location breakdown structure.

All the demonstrations were successful in a way that the stakeholders could see the benefit of the tools to the renovation business. BIMMS is closest to be exploited in real-life, while other tools would still require development and maybe partnering with some existing tools to enter the real-life market.

The use of the tools still required manual work and expert work to prepare the setup. The experts opinion is that the tools help make better choices in the design and result in better functioning building. However, in the limited demonstration, it was not possible to prove that the designers couldn't have found the same choices manually without our BIM4EEB tools. The monitored and simulated results in energy efficiency improvement and expert estimates for other indicators are very promising. The renovation works enhanced the energy efficiency during the measurement period by 33% of the total facility energy compared to the baseline consumption. According to the simulations the yearly savings in facility energy consumption could be 35%. Analyses of the energy renovation time revealed that a potential time saving in similar projects would be up to 33%.

PUBLISHING SUMMARY

The Finnish pilot building is a five-floor apartment building built in 1992 and located in Espoo, Finland and represents a typical technology which has also been used in many other apartment buildings, constructed in 1970's and 1980's. Installing an exhaust air heat pump (EAHP) was found to be the most suitable measure to improve the energy-efficiency of the building.

Four of the BIM4EEB toolkit tools were demonstrated on the pilot. BIM Management System (BIMMS) was used as a common data environment to store the building's BIM model, documentation, sensors streaming, activities and alerts. Fast Mapping Toolkit demonstrated visualizing and modelling features and BIM Early-Stage Energy Scenario tool (BIMeaser) collected the available data for semi-automatic energy modelling. Construction production management tool (BIMPlanner) demonstrated how the renovation project activities can be monitored using BIM based location breakdown structure.

The monitored and simulated results in energy efficiency improvement and expert estimates for other indicators are very promising. The renovation works enhanced the energy efficiency during the measurement period by 33% of the total facility energy compared to the baseline consumption. According to the simulations the yearly savings in facility energy consumption could be 35%. Analyses of the energy renovation time revealed that a potential time saving in similar projects would be up to 33%.

Figure 1 Finnish pilot

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

The report describes the demonstration of BIM4EEB tools and methods in the Finnish pilot site. The scope of the renovation was to install an exhaust air heat pump into a residential building. The benefit of the heat pump was analysed with the BIMeaser BIM-assisted Energy refurbishment assessment tool, installation space was scanned with a Fast-Mapping Toolkit and the installation project was monitored with the BIMPlanner construction production management tool and the data were collected into BIM Management System, which acts as a Common Data Environment for the BIM4EEB Toolkit.

The benefit of the tools was evaluated using key performance indicators from the renovation process, social, energy, economic and environmental point of views.

Chapter 2 in the report presents the pilot site in general and chapter 3 elaborates on how each tool was used in the pilot. Chapter 4 and 5 present the qualitative assessment of the primary and secondary indicators for evaluation. Chapter 6 presents the quantitative results of the indicators that could be measured. Finally, chapter 7 presents the conclusions and reports best practices learned in the demonstration.

1.1 Relation to other work in BIM4EEB

The demonstration presented in the report is related to practically everything that has been done in the project so far. The list below highlights some of the most important preparatory work for this demonstration.

- BIM Management System:
  - D4.9 Tested version of the platform, public report
  - D4.10 Testing and validation results on demonstration sites, public report
- Fast Mapping Toolkit:
  - D5.5 Technical report on testing and validation results, public report
- BIMeaser:
  - D6.6 Decision-support tool, confidential report describing the tool
  - D6.9 Report on adoption of BIM-assisted Energy refurbishment assessment tool
- BIMPlanner
  - D7.1 Server software to manage interlinked BIM-workflow data for construction production management, confidential report describing the software
- Demonstration preparation and key performance indicators
  - D8.1 Report on management of real Best Practice Examples, public report

There were three pilots in the project in total. The pilots were not exactly similar but had some differences in the demonstrated tools and assessed KPIs. Two other pilots have been described in the public reports D8.2: Report on demonstration in Italy and D8.3: Report on demonstration in Poland. All the three reports refer to each other in some places to avoid repetition in chapters describing the common elements.

The public reports can be found in the project website[1] when the reports have been accepted. The confidential reports are not publicly available. Please contact the authors of this document or BIM4EEB coordinator for more information. The contact details can be found in the project website.

[1] https://www.bim4eeb-project.eu/

1.2 Changes in the project

Pilot building in Finland was changed during the project. BIMeaser testing that is described in D6.9 is done in the previous site while other tools are tested in the new site.

The reason for having to change the Finnish pilot building was that the renovation was found to be unfeasible in the original building in Tampere. The new building and related renovation project in Espoo are very similar to the previous ones, as can be seen in the comparison in Table 1, where the new building is on the right. The renovation scope is basically the same; an exhaust air heat pump will be installed. A difference to the earlier pilot building is that, there will be no new sensors installed in the new pilot since the new pilot has an existing wireless sensor set up in the apartments. The new pilot building is also connected to a 24/7 monitoring system. The renovation's impacts, execution schedule and targets are similar in both cases.

Table 1 summarizes the similarities and differences between old and new pilot building.

Table 1 Original Finnish pilot building in the left, the new one in the right.

	Originally planned pilot building	New pilot building
Photo		
Location	Tapettikatu 13, Tampere	Reviisorinkatu 3, Espoo
Use category	Residential	Residential
Building type	One group, multi-apartment block	Apartment building, commercial spaces in the first floor
Client	YH Kodit	KEVA
Flat ownership	Buildings owned by YH Kodit, a private company owned by local municipalities (Tampere, Turku, etc.)	Apartments owned by Keva and rented further. Keva is the largest pension fund in Finland.
Construction year	1998	1992
Number of floors	5	5
Number of apartments	52	43
Total area (m^2)	4200	4487
Total volume (m^3)	12 700	14 189
EPC class	D	D
Heating type	District heating	District heating
Elevators	yes	yes

2 Description of the Finnish pilot

The Finnish pilot building is an apartment building located in Espoo, capital region of Finland. It has five floors in total, of which the ground floor has mostly commercial spaces. The building has district heating as its heating method and the heat distribution center has been renewed in 2010. All the 43 apartments already have wireless meters measuring temperature and relative humidity. The building is a good representation of most apartment buildings in Finland.

Figure 2 Finnish pilot building.

2.1 Heat pump installation

During preliminary planning, installing an exhaust air heat pump (EAHP) was found to be the most suitable measure to improve the energy-efficiency of the building. Because the building has three staircases, three heat recovery units (HRU) were installed on the roof. The recovered heat is used for both space heating and domestic hot water heating, thus, reducing district heating consumption.

Originally the intention was to use CO2 based heat pump technology as described in the D7.4. It was however changed into more conventional exhaust air heat pump solution which uses ethanol-based brine as heat transfer liquid. This was due to extensive delivery time of the CO2 system. The decisions regarding both pilot sites had taken much longer time than expected due to difficulties in collaboration with external stakeholders during the Covid-19 pandemic. When the decision to change the pilot was made, it was decided to not take a risk of additional delay by selecting a product with an extensive and possibly uncertain delivery time. Therefore, a more conventional heat pump system was selected to be installed to the pilot site.

2.2 Sensor set-up

The original planning of installation of wireless Sigfox sensors in the pilot is described in D8.1. After the pilot site was changed, the new pilot building had a wireless sensor set-up provided and monitored by Ouman[2] and a plan to install more indoor condition sensors became unnecessary. The property has 39 apartments. Each apartment is equipped with 1 wireless sensor that measures the room temperature and relative humidity. Thus, there are a total of 39 measuring points at the site. The location of the sensor is in the living areas, i.e. the living room, and in such a way that the sensor is not exposed to direct thermal effects that distort the measurement (e.g. sunshine, bathroom, hot water surges, radiators, electrical equipment, etc.). The installation height of the sensor is 150 cm from the floor. The sensor sends the measurement data every 15 minutes to a base station in the heat distribution room, through which the data is forwarded over the Internet to the service company remote monitoring centre (Ounet[3]) for storage and surveillance.

Prior to the installation of the heat pump system, the average of the temperature data in the dwellings was used to optimize the heating (room compensation).

More detailed description of the Ouman wireless measuring system is shown in Figure 3.

[2] Ouman company website: https://ouman.fi/en/
[3] Ounet remote monitoring service: https://ouman.fi/en/product/ouman-ounet/

Base station WL-BASE	
Case	ABS plastic
Operating temperature	0...+50 °C
Protection class	IP20
Measurement interval in installation mode	10 seconds
Measurement interval in normal mode	can be adjusted (1–240 min).
Dimensions	90 x 70 x 59 mm
Installation	Mounted to DIN bar
Operating voltage	24 VAC / 5.5 VA or 20...30 VDC / 3W If the voltage is 10-20 VDC, then the AO output does not work properly.
Power consumption at full load	12 VDC 160 mA 24 VDC 85 mA 24 VAC 210 mA
Compatible OUMAN controllers	C203 S203 H23 EH-203 EH-201/L
Connection at fieldbus level substation level	Modbus RTU Modbus TCP

Temperature sensor:

- Built-in antenna
- Sensor coverage is not impaired when the battery is low.
- 869 MHz

WL-TEMP-RH Temperature sensor and humidity sensor	
Case	ABS plastic
Operating temperature	0°C...+50°C
Protection class	IP20
Temperature meas. accuracy +10...60°C Measurement area	± 0,3°C -30...+100°C
Humidity meas. accuracy 20...80%rh Measurement area	± 3 %rH 0...100%rH
Any of the following measurements can be implemented by using the AUX connection:	
• **AUX temperature measurem.** - Measurement area - Measurement accuracy (25 °C)	 -30°C...+50°C ± 0.3°C
• **AUX 0-10VDC transmitter** - Measurement area - Measurement accuracy	 scaleable 0.5% / 50mV
Power source operating as non-routing temperature sensor Power source operating as router	2 x AA batteries 5...9 VDC
Battery life (not included in delivery):	
Energizer L91 Ultimate Lithium 3100 mAh: 15 min measurement interval 60 min measurement interval	 9.5-15 years 12-20 years
External power source (operating as routing temperature sensor)	5 VDC
Dimensions	90 x 96 x 26 mm
Installation	Surface installation

Figure 3 Ouman wireless measuring system in the pilot building

2.3 Creation of BIM for pilot building

An IFC-model of the existing building was created for the demonstration. The original blueprints from 1990s and other needed documentation were obtained from the owner's digital document archives. In the Figure 4, there is an example of a floor blueprint in PDF-format that was utilized in 3D-modelling.

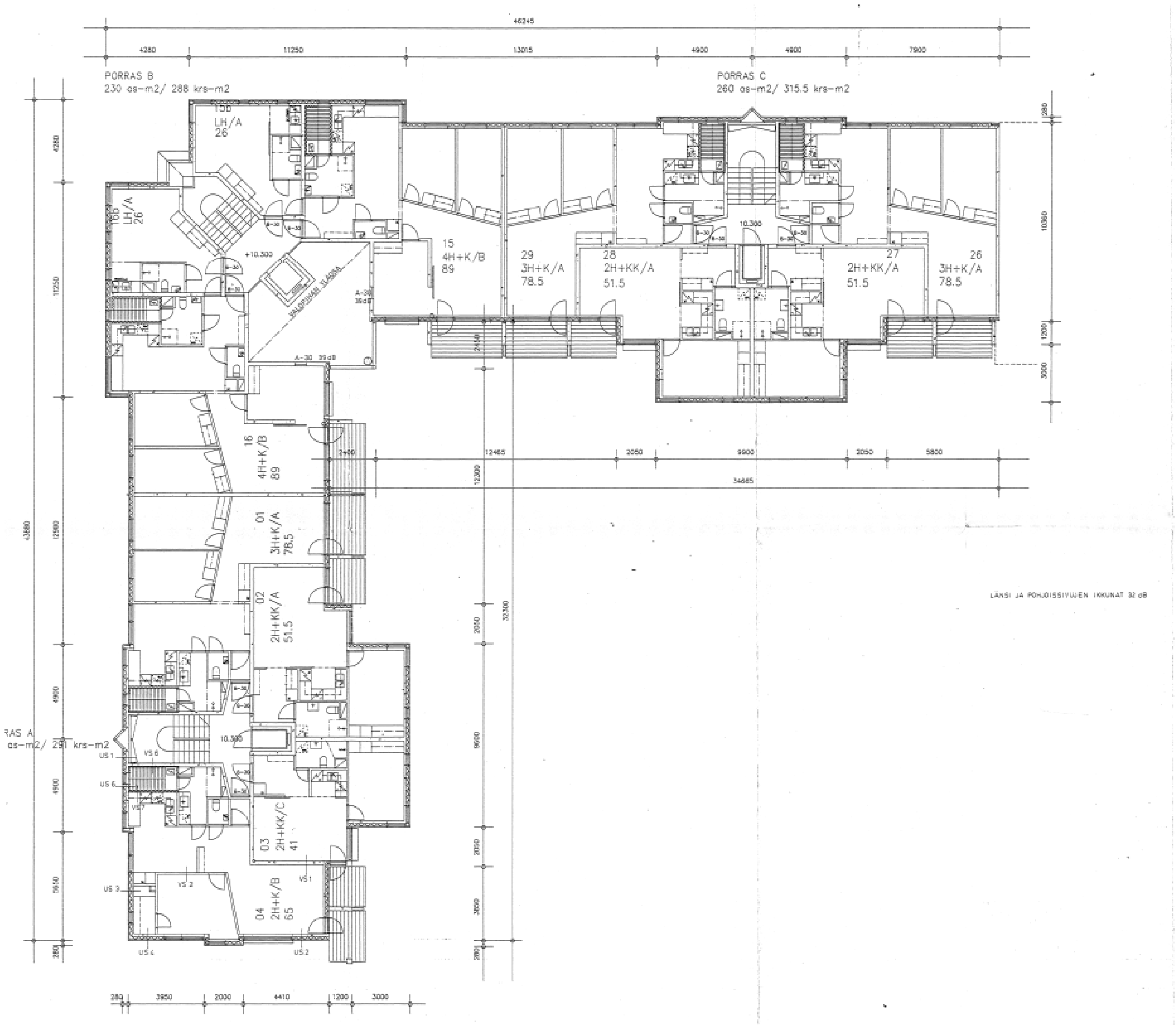

Figure 4 Original blueprint of the pilot building for floors 3-4 from 1990

The modelling was implemented with ArchiCAD BIM authoring software with raising the floor plans in 3D and adding needed data to the objects. The modelling in ArchiCAD was done at needed level of detail for the tested tools which were BIMeaser for energy simulation and BIMPlanner for site operation management. The foundations of building were not modelled, and all structures were modelled as simplified solid IFC-entities but including needed attribute data like U-values for the envelope structures. Detail geometry of the building envelope was simplified in modelling to reduce work not adding value for the test cases. The windows were modelled in right size and position with needed data but with generic window geometry.

After the modelling was finished in native authoring software it was exported in IFC-format and stored in BIMMS. In Figure 5 the IFC-model of the pilot building is shown in BIMMS viewer user interface. The IFC-model was exported in IFC2x3 format due to the restrictions of used third party energy simulation software (IDA ICE). At the time of the testing, it was not able to import newer versions of IFC. The IFC4 import is under development phase according to the software vendor.

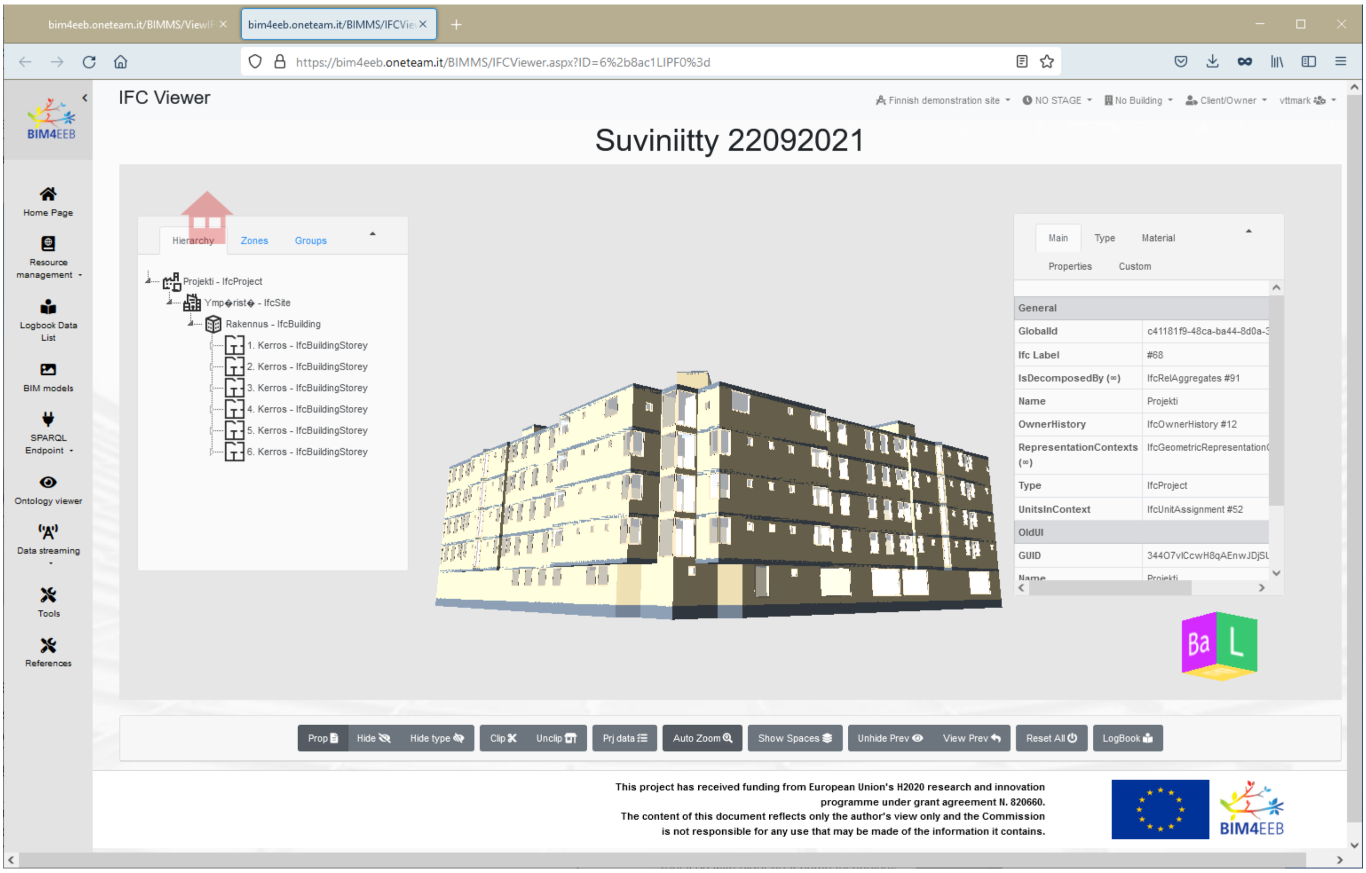

Figure 5 IFC-model of the pilot building viewed in BIMMS user interface.

3 Evaluation of the pilot

3.1 List of the KPIs to be demonstrated

Key performance indicators that are used in evaluating the pilot, are described in the Report on management of real Best Practice Examples (D8.1). The indicators are divided in two categories. The primary ones are the ones related to the project goals in the Grant Agreement while secondary ones are such that the project team saw important during the project. The indicators to be defined are related to the tools demonstrated on site and therefore not every indicator is assessed in all the pilots. Finnish pilot focuses mainly on indicators regarding renovation process, energy, economic and social aspects. The full list defined in D8.1 is shown in Annex 1.

After the assignment of indicators in D8.1 there were some changes. Social indicators 3 and 8 and quality issue indicators (REP 6 and REP7) are related to the BIM4Occupants tool that was not demonstrated in the Finnish pilot and therefore the indicators were not assessed. Comfort indicators (1, 2, 3, 4, 6, 7) were not assessed because the Finnish pilot was implemented purely in the common spaces of the building where comfort is not relevant. The heat pump will not affect directly on the amount of heating in the building. It just changes the heat source. Similarly, the environmental indicators 1, 2 and 3 regarding the CO2, small particles and volatile organic compounds the in apartments are not relevant for the pilot. GIS data was not needed nor utilised in the Finnish pilot.

3.2 Tool demonstrations

3.2.1 BIMMS

The BIMMS has been used in Finnish demonstration site as common data environment to store the building's BIM model, documentation, sensors streaming, activities and alerts. In addition to browse IFC-model in BIMMS viewer (e.g. Figure 5) the BIMMS has a functionality to attach any BIMMS resource, like a document file, to individual or set of IFC-objects of the IFC-model, see example in Figure 6. The demonstration focused on different use cases (defined in testing and validation activities described in detail in the Deliverable D4.10) participated by owners, inhabitants, and professional users as designers, technical providers, and developers. The BIMMS were officially presented in a workshop held in November 2021 to a broader audience of professional users, to show how to use the BIMMS in typical professional context focusing on specific functionalities to manage document resources and BIM models. The workshop is available at BIM4EEB YouTube channel. The BIMMS has been presented with a set of tutorials that explained the main functionalities and described with small hands-on sessions.

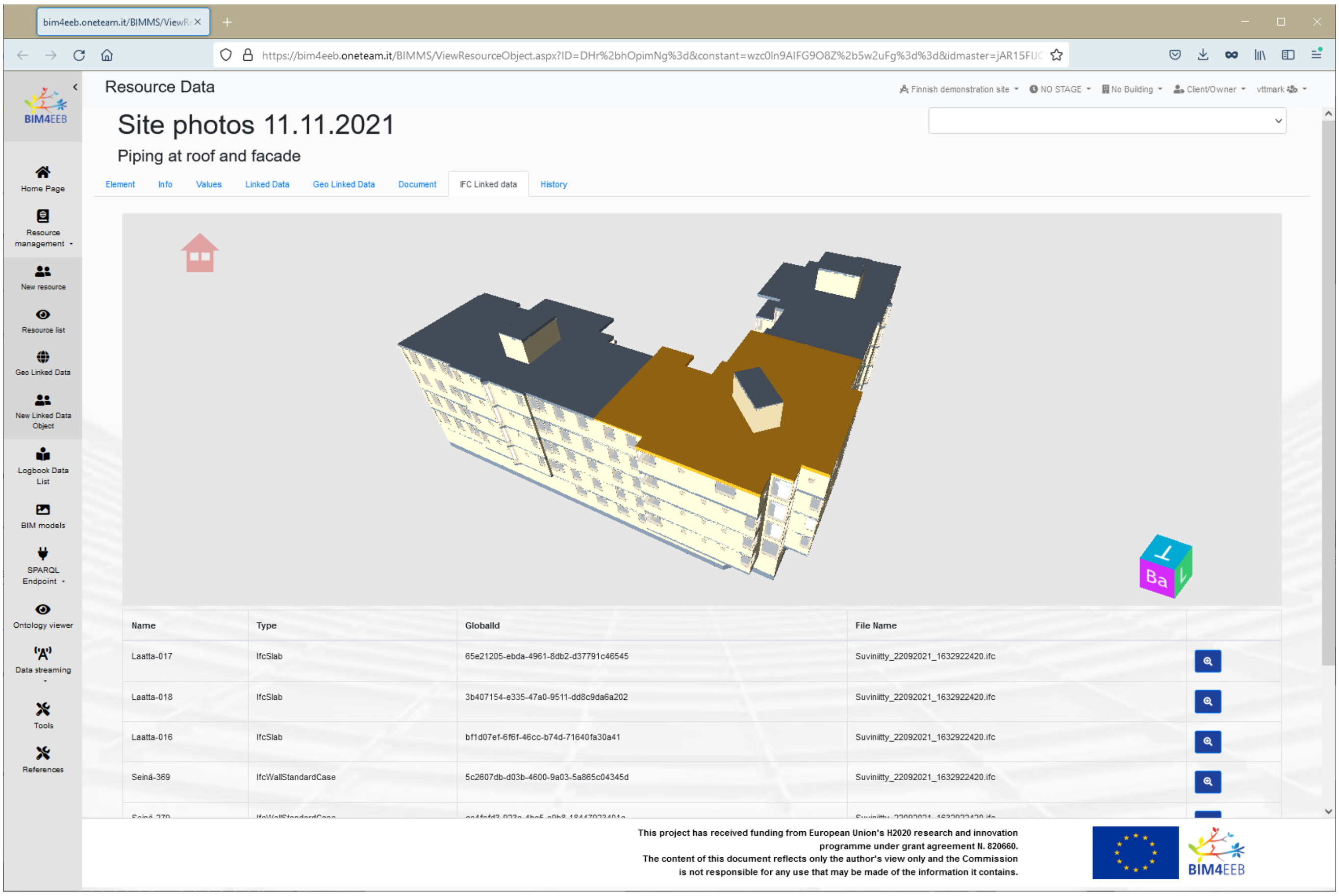

Figure 6 A document file of site operations attached to corresponding IFC-objects in BIMMS.

3.2.2 Fast Mapping Toolkit

Visualizing and modelling the existing construction can offer significant benefits in renovation business. 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 and see the hidden installations inside walls with the help of a HoloLens2. This procedure and tools are called Fast Mapping Toolkit.

Testing of the Fast-Mapping Toolkit is presented in the project report D5.5 “Technical report on testing and validation results” on Digital tools for fast mapping of buildings (geometrical data and materials).

Figure 7 Point cloud example

The point-cloud created from the boiler room (Figure 7) supports also the maintenance phase as a detailed 3D-viewing model. It does provide more precise information to the IFC-model created in the demonstration that was created for the energy simulation and site management use cases. The detailed viewing model enable possibility to remotely recap the details of the property and get ready for the needed maintenance activities at site.

3.2.3 BIMeaser and further modelling with a new pilot building

BIMeaser is a BIM Early-Stage Energy Scenario tool with the main purpose (use cases) of:

1. enabling easy build-up of the ”As-is” energy and indoor climate model in the early design stage (Concept design & Preliminary design).
2. applying the renovation scenarios to the “As-is” model.
3. presenting the impact of each renovation scenario in terms of Owners Project Requirements (OPR).

The expected benefit is that BIMeaser can speed-up the decision making, enhance the collaboration between design domains, enable cross domain transparency in technical details and finally result in better indoor climate and energy design.

The BIMeaser refurbishment scenario simulation functionalities were first tested in qualitative design workshop with Caverion professionals working with the Finnish pilot. Part two of the demonstration evaluated how much time could be saved by using BIMeaser compared to manual data entry.

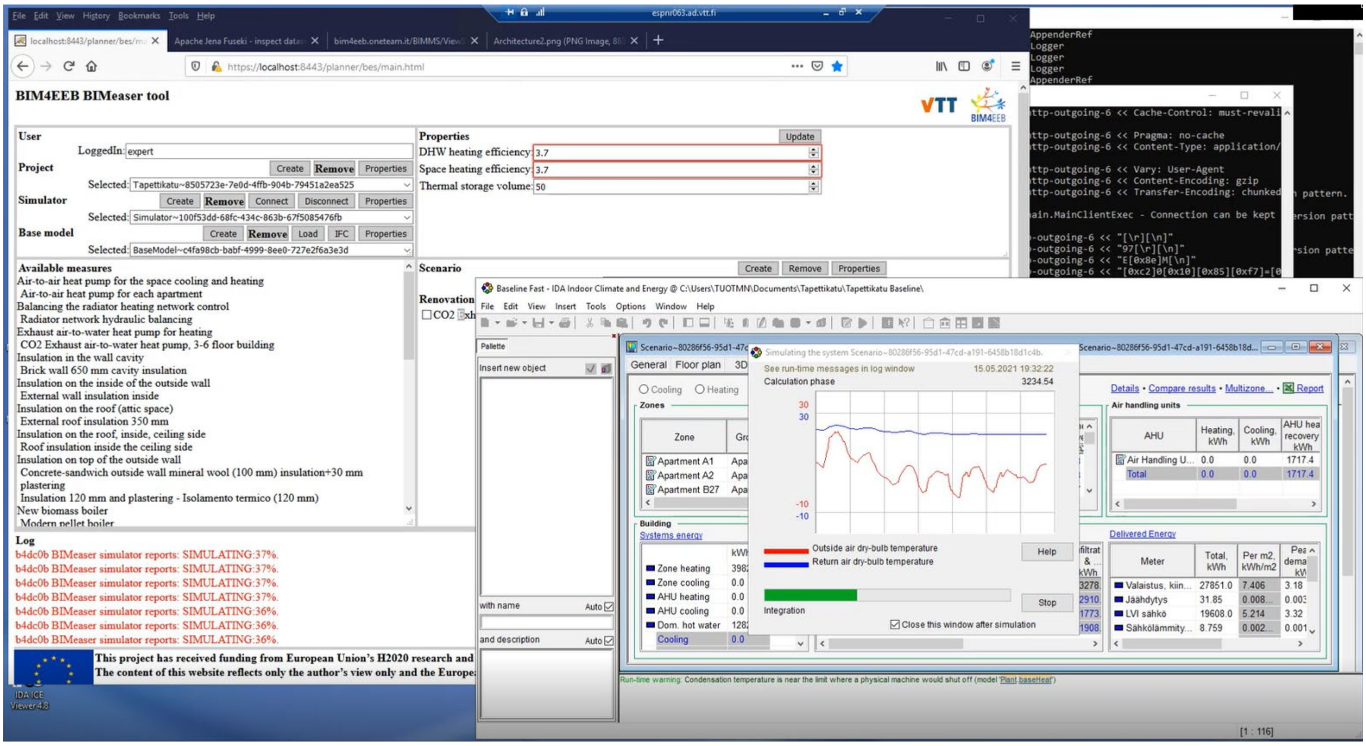

Figure 8. The Tapettikatu building (Finland) "CO2-exhaust air heat pump" renovation scenario defined and running in the BIMeaser-tool.

According to use cases above. The building was modelled and the exhaust air heat pump was added as a renovation measure.

Results of the BIMeaser demonstration in the first Finnish pilot are shown in Table 2. Note, the payback time which is 16.5 years. That is much more than a lifetime of a heat pump and means that the renovation is not economically feasible.

Table 2 The Owners Project Requirements (OPR's) in the Tapettikatu (Finland) workshop.

	Cost			Energy					Comfort	
Scenarior	Operational energy cost, €/floor-m^{2}a	Payback time, years	Investment, €/floor-m^2	Primary energy, kWhpr/m^{2}a	RES share, %	Heating, kWh/m^{2}a	Cooling, kWh/m^{2}a	Electricity, kWh/m^{2}a	Summer thermal h/year,zone (T_{indoor} >27 °C)	Summer thermal °Ch (T_{indoor} >27 °C)
Baseline	10.50		0.00	110	0.01	144	0.0	32	250	233
Heat pump	8.07	16.5	39.96	97	0.01	45	0.0	62	251	238

The demonstration workshops and evaluation of the achieved time savings are described in detail in the confidential project report on adoption of BIM-assisted Energy refurbishment assessment tool (D6.9). The results of the evaluation in terms of KPIs are included in this report.

When the pilot building was changed the BIMeaser demonstration presented in D6.9 for the previous building, was not repeated anymore as a support tool for the design process. However, the same indoor climate and energy simulation tool, IDA-ICE, that is used in BIMeaser, was used to define the energy performance indicators.

3.2.4 BIMPlanner

BIMPlanner tool was utilized on weekly basis to plan next week activities at the demonstration site and to record the status of ongoing activities. The contractor's master schedule of site activities (Figure 9) was imported in BIMPlanner from Excel-file to set targets for the detailed week planning.

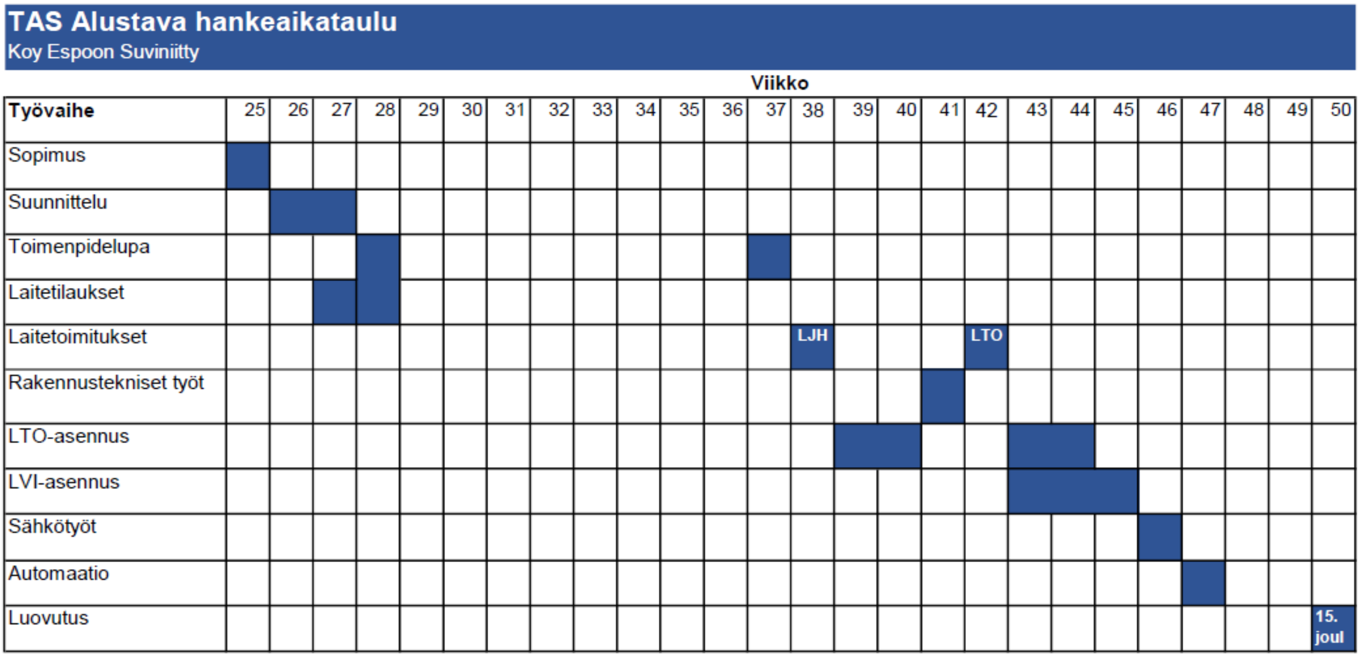

Figure 9 Initial master schedule of the project prepared by the contractor. The schedule contain timing also for contract preparation and procurement of the equipment on week 25-28. Only the activities at site starting on week 38 were covered in the demonstration.

Some of the master activities represent general level summary activity which were divided into actual work phases and defined in BIMPlanner as "sub-activities. For example, the master activity "Heat recovery installation" (in Figure 9: "LTO-asennus") was divided in sub-activities:

Heat recovery installation

- Piping
- Heat recovery unit installation
- Unit preparation
- Unit lift and installation
- Unit connection

In the Figure 10, there is an example of planned timing for sub-activities of the "Heat recovery installation", and also the recorded actual started ("S") and finished ("F") times. The sub-activities are presented with blue font, but it shall be noted that scheduling data is presented by "work locations" below the sub-activities (with black font).

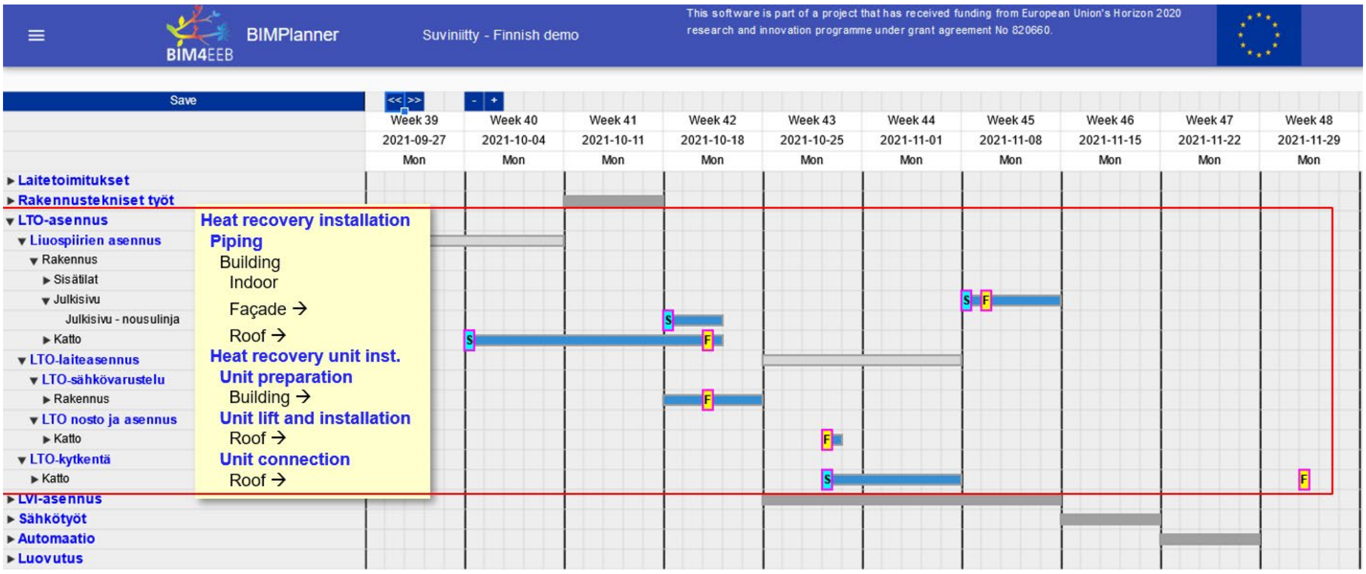

Figure 10 Scheduling and tracking example of master activity "Heat recovery installation". The detailed scheduling is done by "work locations".

BIMPlanner is based on Location-based Management System (LBMS) approach where scheduling is done by "work locations" to define also the physical working areas at site. In the BIMPlanner, the user predefines the "work locations" as a Location-breakdown structure (LBS) in a specific user interface. The definition of the LBS is done by linking intended BIM-objects to the user defined work locations that are needed for LBMS scheduling (Figure 11).

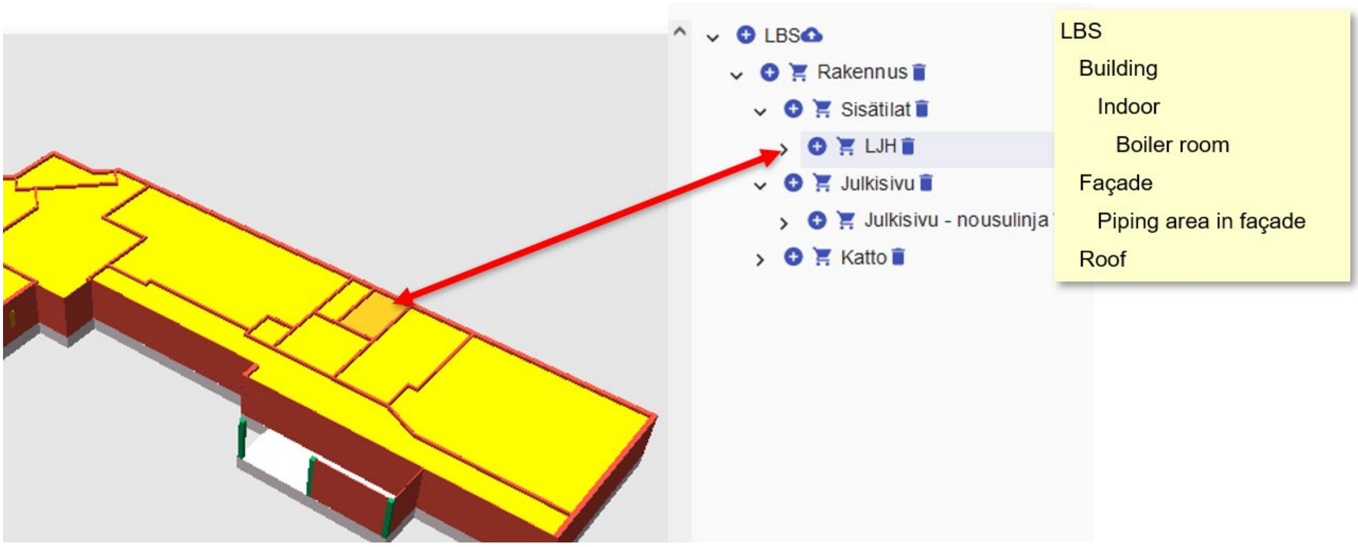

Figure 11 Example for definition of a work location linked to BIM-objects in BIMPlanner user interface.

3.3 Final workshop

A workshop to present tools and methods used in the Finnish pilot and to collect feedback was arranged in January 18, 2022. The workshop has been described in a public reporting describing all the demonstration workshops of the project (D10.12).

Recording of the workshop is also available in BIM4EEB Youtube[4] channel.

Figure 12 Workshop recording is in the BIM4EEB Youtube channel

[4] https://youtu.be/_cWGIPIQ8Jc

4 Primary KPIs assessment

4.1 Renovation process indicators

4.1.1 REP 1 Renovation Time Reduction

BIMeaser demonstration report (D6.9) describes renovation time reduction based on time measurements. The overall increase in modelling time reduction can be concluded to be more than 75% with BIM assisted process compared to the manual modelling. The value is for the modelling time only. The time savings were calculated with the assumption of the existing established business processes so that the users have been trained to use both the BIM Management Server -system (BIMMS) and the BIMeaser scenario simulator. Also, the manual simulation tool usage was done with the energy simulation professionals. This BIMeaser process was compared to the manual data input to get the same outcome than the BIMeaser.

BIMPlanner was demonstrated for scheduling and managing the site operations. In the master schedule agreed by the client and contractor there were reserved 63 working days for the activities at site (20.9.-15.12.2022). In the master schedule there were no site activities scheduled in the last 2 weeks and those were reserved as time buffer for possible delays during the work. In the demonstration was recognized that the master schedule had also other short time buffers spanning over the construction period and master schedule represent more like the time slots for the site activities than real planned timing.

In the demonstration project the handover was implemented at planned time. During the project there were some periods (days) when no activities were implemented at site or those were suspended temporarily. Some inactivity periods occurred within planned time frame while waiting for a material supply or a subcontractor to perform an activity. However, some sick leaves and some cases that needed further finishing work afterwards, caused a delay in the schedule.
In actual implementation of the activities there was need to use 3 working days out of the 10 days reserved time buffer before the handover of the project delivery. So, there was 7 unoccupied days in the finishing period of site activities. It was also identified in demonstration that the site activities started 9 working days later than was presented in the master schedule and in the middle of the implementation there was 5 days unoccupied period at site according to the recorded implementation in BIMPlanner tool. During these (9+5+7=) 21 days there have been some minor work or events implemented at site, but it is expected that those could have been implemented during active working periods.

According to these findings, the construction period could have been shortened by one third. However, this would have required more precise delivery times for material supplies and also more detailed management of work resources that were needed for limited periods at the site. It seems that in such cases the contractor is willing to have a loose schedule to manage better the resources as the contractor has same kind of parallel projects which reserve same resources. It is expected that reducing construction time at site is difficult for such small energy renovation projects. So probably there should be several parallel energy renovation projects of same kind in client's building stock where the contractor can optimize the process and shorten construction time in individual projects.

4.1.2 REP 2 Renovation Cost Reduction

Renovation time reduction due to the BIMeaser is mainly related to the reduction of working time. However, BIM-assisted BIMeaser process also brings data accuracy and helps to avoid modelling errors, which are quite common in the manual approach.

BIMPlanner tool is intended to boost the effectiveness of site operations with detailed work planning and continuous follow-up. The improved management approach will reduce disruptions and rework and improve productivity. The selected management method enables possibilities to shorten the renovation time with more tight scheduling without unneeded lead times between activities. The shorter renovation time will reduce the time related cost of site operations. Time related costs are e.g. machinery and equipment rentals, maintaining the site environment or some management personnel costs. According to Caverion, typical baseline for time related costs is 15% of total construction costs. As in REP1 was identified, the duration of the site operations in demonstration project could have been reduced by one third. So, this renovation time reduction would lower the total construction costs by 5%.

4.2 Social indicators

BIMMS, Fast Mapping Toolkit and BIMPlanner improve the information exchange and tracking (SOC 9) by making the digitalizing the data and making it available in the common data environment. The improvement in interoperability and data storage capability (SOC 11) in the BIMMS platform is obvious. BIMMS is the platform to connect BIM4EEB Toolkit tools and to store the data.

All the tools promote the use of BIM in renovation business (SOC 12) by bringing new benefits to the building owner who has created a model. For example, Fast Mapping Toolkit promotes the use of BIM by supporting the creation of it. While it is not yet possible to create a full BIM with the toolkit, it can be used to verify the locations of the structures modelled otherwise. BIMeaser promotes the use of BIM in renovation business by helping the designers to create and utilise it faster therefore making it more feasible.

BIMeaser also promotes the use of dynamic simulation tools (SOC 13) by decreasing the amount of manual work required to use them in the building to be renovated. Currently, BIMeaser is built to support Equa IDA Indoor Climate and Energy.

BIMMS includes a logbook service (SOC 15) for building related data. Fast Mapping Toolkit helps in collecting and verifying the data.

4.3 Energy performance indicators

4.3.1 ENE 3 Primary Energy Savings

Primary energy refers to an energy as it is found in nature before any human engineered conversion process. Primary energy is the primary indicator agreed to be used in the European Union as an indicator for comparing buildings.

“The energy performance of a building shall be expressed by a numeric indicator of primary energy use in kWh/(m2.y) for the purpose of both energy performance certification and compliance with minimum energy performance requirements.” [EPBD]

ENE3 indicator is defined as a percentage difference between measured and baseline primary energy consumption data within a predefined period. ENE1 savings are converted to primary using national conversion factors and pilot specific shares for different energy sources.

By enabling more accurate models, BIMeaser will help finding the optimal renovation measures to find balance between primary energy saving and other Owners’ Project Requirements. Primary energy reduction affects for example the energy performance certification class and is often used as indicator in the building permit process.

4.3.2 ENE 4 Energy Performance Accuracy

ENE4 is the accuracy of the assessed energy performance. BIMeaser helps in getting the accurate simulation results by supporting the modelling process. The model is more accurate as all the available data is used and simple mistakes easily made in manual work are left out.

The value of the indicator is based on a percentage difference between simulated and measured consumptions, which will result as deviation percentage. Accuracy is calculated from the deviation.

5 Secondary KPIs assessment

5.1 Renovation process indicators

5.1.1 REP 3 Actual/planned conformance – time

Fast Mapping Toolkit can be used to secure the planned changes to structures. While locations of the pipes and wires are known, there is less surprises and additional work in repairing damaged equipment.

BIMeaser helps in utilising all the available data and in reducing the number of modelling errors, which results in improved understanding of the building behaviour already in the early design phases. This enables more accurate planning in terms of time. Less time needs to be allocated to prepare for surprises. There is also less changes in the project due to the errors.

BIMPlanner improves the scheduling process by bringing locations into the discussion. Thus the risk of the scheduling problems due to different workers having to work in the same location in the same time and disturbing each other is minimised.

5.1.2 REP 4 Actual/planned conformance – cost

Fast Mapping Toolkit in avoiding the costs related to damaged equipment as described in the previous chapter.

BIMeaser helps in making the right decisions in the early design phases. Therefore, it helps in avoiding costly mistakes and changes in the later project phases. Figure 13 illustrates the impact on performance (e.g. design decisions), cost commitments (e.g. ordered items) and cost accumulation (e.g. delivered items) in a construction project. Changes in the project and much more difficult and expensive in the later phases when commitments have already been made.

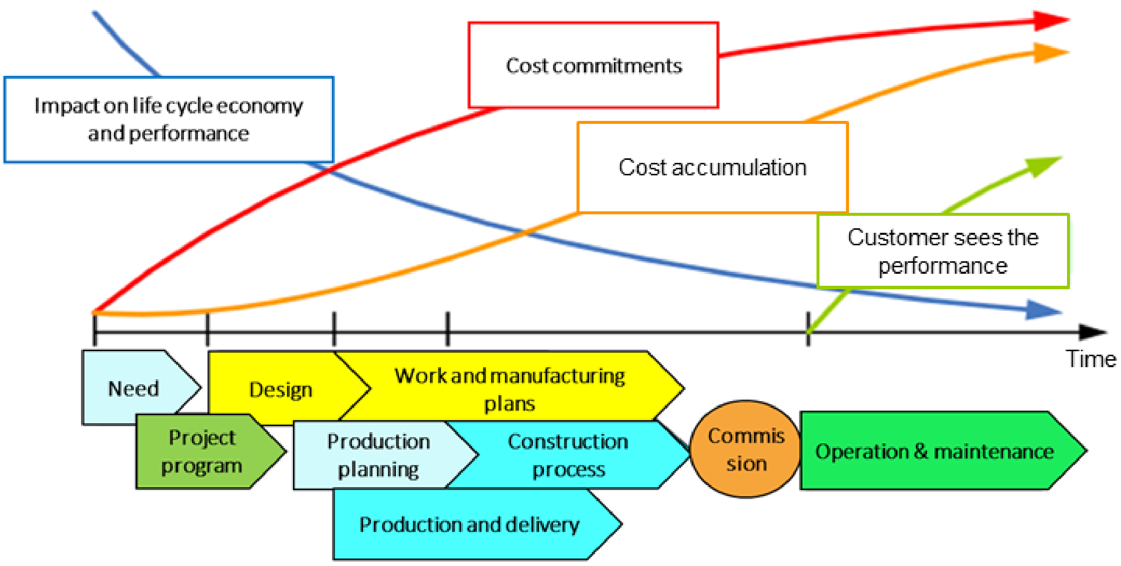

Figure 13 Committed costs and possibilities to affect on energy performance. Adapted from [Pietiläinen et al. 2007]

5.1.3 REP 5 Actual/planned conformance – actions Fast Mapping

Required actions can be better planned with Fast Mapping Toolkit that allows mapping the routes and installation places in the early phases.

5.2 Social indicators

Secondary social indicators for the Finnish pilot are listed below

- SOC 1 Ease of use for end users of the solution
- SOC 2 Beneficial for end-users
- SOC 4 Productivity improvement
- SOC 5 Improvement in collaboration among teams
- SOC 6 Improvement in safety at construction site
- SOC 7 Level of intuitiveness in user applications

While the tools in the Finnish pilot are used by the experts only, a questionnaire was not arranged for the users to ask about the tools individually. Instead, we discussed in the final workshop.

Regarding BIMMS, the participants of the workshop saw the value of the tool (Figure 14) and commented that

  - From designer point of view, BIMMS platform as a CDE platform is the most sufficient environment for construction industry. BIMMs platform is intuitive to use and has a very well-detailed interface.
  - Having all content in the same place [is important].
  - The platform to have everything on the same place"

- Participants suggested that the following features could be added to the platform:
  - A possibility to generate QR and to easily share content for a temporary amount of time
  - Model viewer could be enriched with additional more advanced function for viewing IFC models.

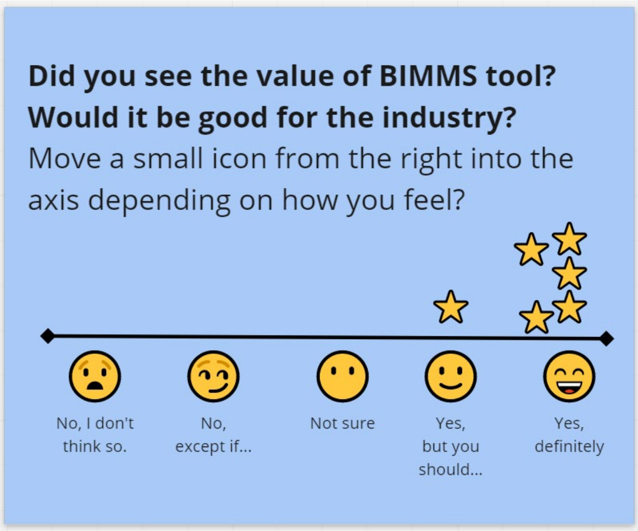

Figure 14 BIMMS evaluation in the Finnish workshop

Regarding Fast Mapping Toolkit participants saw the value (Figure 15) and the gave the following comments:

- Are you able to operate in a room with lot of installations (technical/boiler room)?
- Automatic IFC file creation form point cloud is in some sense kind of game changer for the inventory phase in renovation process. Even if tool isn't fully completed yet at this stage to put at the market, it is very embracing and for the construction market it is very important path to follow.
- The easiest creation of a n IFC model and the possibility to discover which building services are in the existing building

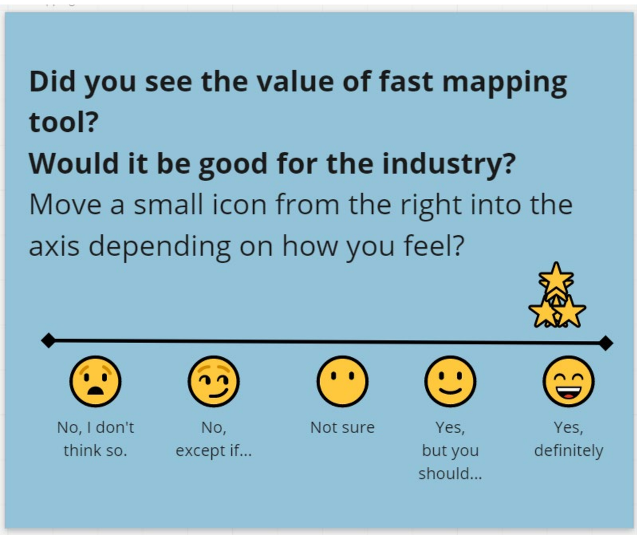

Figure 15 Fast Mapping Tool evaluation in the Finnish workshop

The targeted end-user of the BIMeaser is the energy expert in the renovation project design team. To ensure the end-user centric development, the tool was developed in a close collaboration with Equa Simulation Finland, a company that represents the indoor climate and energy simulation tool utilized in BIMeaser. Equa had a member in the project advisory board. When the first working version of BIMeaser was available, it was presented to pilot partners Aler and Caverion to get feedback for the development. In the end, BIMeaser received good feedback (Figure 16) in the final workshops. The figure below shows the feedback received in the Finnish workshop where a Miro tool was used for interactive collaboration. We also got a comment that *"Reducing of time for renovation scenario in early design stage is really impressive."*.

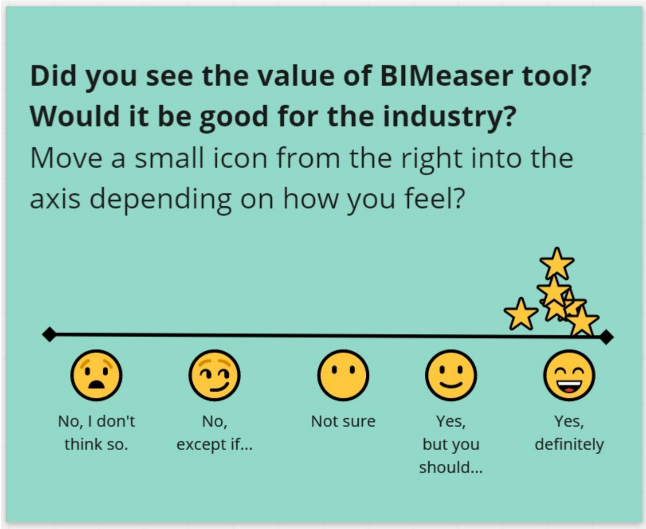

Figure 16 BIMeaser evaluation in the Finnish workshop

Finally, also BIMPlanner got good feedback (Figure 17). The comments were the following:

- Despite that the process of construction during renovation of the buildings is a very complicated and multi-threaded, BIMPlanner allows proper management of it using the data retrieved from CDE(BIMMS)."
- A tool to guide the planner in the optimization of the process [could be added].

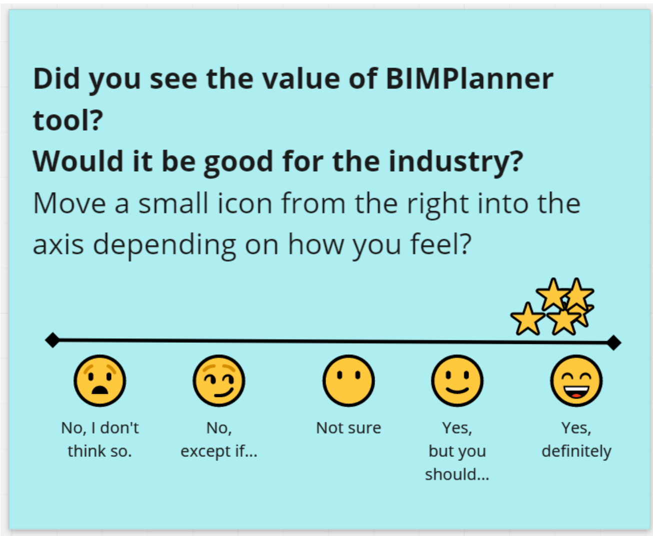

Figure 17 BIMPlanner evaluation in the Finnish workshop

5.3 Economic indicators

Annual Cost Saving are calculated considering the cost saved by the time reduction occurred during the renovation phases. The result considers the architect activities. The reduction time calculation is based on a simulated typical workflow that consider a team of users working together using the BIMMS. The BIMMS functionalities allows to update the design resources avoid repetitive and time-consuming tasks like the export-upload-download-import chain. The results of the tests indicate a reduction time up to 70% when the data exchange does not include changes in geometries. The KPI is calculated assuming that the costs savings can be related directly with the reduction time. Economic indicators are described in detail in the report for the Italian pilot (D8.2).

BIMeaser will enable lower life-cycle costs (ECON 5) as better design decisions can be made during the renovation process. Of course, the most important decisions are made during the later, more detailed design phases, but still there are decisions and commitments made in the early design phases that have an effect to the final planning and implementation. Life-cycle cost will be lower due to building systems that provide the same output with less energy used. Better design in the systems also enables better indoor environment quality and comfort. which may and should have an effect to rents or prices of the apartments. This may not be just the measurably better indoor environment, but also the modern and high-end image of the building, which may have much larger effect to the building owners' income than what could be reasoned with physical measurements.

5.4 Environmental and safety indicators

If the structures of a building to be renovated are unknown, they sometimes need to be inspected by breaking them in a selected spots. That is always a risk that can lead to issues/incidents/accidents. Non-breaking inspection methods of the Fast-Mapping Toolkit remove this risk and therefore improve the value of ENV 5 Safety issues/ incidents/accidents (during inspection) indicator.

The key idea in the BIMeaser that existing data in the BIMMS platform is utilised automatically in creating the model. Therefore, the amount of site visits can be minimized and left for experts that can do it most safely. For example, if the building inspector has visited the building during project initiation phase, they can share the data and the energy expert may avoid going on site and inspect technical spaces, attics and crawling spaces that could risk for incidents and accidents.

5.5 Energy performance indicators

BIMeaser will enable energy saving as better design decisions can be made during the renovation process. The tool helps in selecting the right energy saving measures for the building.

5.5.1 ENE 1 Energy Savings

Energy savings refers to the delivered energy saving, which is of course an important factor in terms of financial feasibility of the renovation. Delivered energy is the amount of energy that the building owner and/or tenants will need to buy from the market. By enabling more accurate models, BIMeaser helps in finding the optimal renovation measures to find balance between delivered energy saving and other Owners' Project Requirements.

5.5.2 ENE 2 Energy Savings (per building component)

BIMeaser promotes the use of BIM and dynamic simulation in renovation business by making it faster and easier. One important result of this transfer is the possibility to get accurate information how energy is used per building system and building component. This information can be very beneficial to the building owner when they plan for future renovations.

5.5.3 ENE 5 Total Use of Primary Energy

ENE5 indicator is calculated as an operative primary energy during the renovation project for selected life-cycle. Material embodied energy is not included, just the actual energy consumption of the building. This is also one Owners' Project Requirement that could be included in the BIMeaser analysis although it is currently not supported. Of course, one can just multiply yearly energy consumption with the number of years in the expected life-cycle, but that is not the full picture. Dynamic simulation tools such as IDA Indoor Climate and Energy also enable simulation of multiple years. It would be easily possible to change the climate or energy prices during the multi-year simulation. One example of a phenomena that would require more than one year simulation is a ground source heat pump. If too much heat is drawn from the ground, it may not recover during the summertime and temperatures may start to slowly decrease. It could also be assessed with a minor addition to the BIMeaser.

6 Results in the pilot

Quantitative results of the social survey and energy analysis of the Finnish pilot are presented in this chapter.

6.1 Renovation process indicators

Improvement in renovation process indicators is mainly based on qualitative assessment presented in chapters 4 and 5. Measured quantitative results about the renovation time reduction are presented amongst the qualitative analyses but are summarized here for clarity.

BIMeaser renovation time reduction based on time measurements is more than 75% with BIM assisted process compared to the manual modelling. The value is for the modelling time only.

In the demonstration of BIMPlanner tool, it was identified with detailed scheduling and tracking of site operations that one third of the total duration there were not on-going major activities at site (see details in 4.1.1). This indicates possibility to reduce the through-put time up to 33%.

6.2 Economic indicators

The economic indicators for the new pilot site in Finland were calculated during the renovation process. With the exhaust heat pump energy upgrade the building owner will achieve a substantial cost saving when considered annual cost of capital, energy cost savings and maintenance costs. In terms of the economic indicators, the numbers are:

- 4,7% annual cost saving (ECON 1)
- 50 000 € Net Present Value after 15 years (ECON 2)
- 11,2 years pay-back period (ECON 3)
- 9% return on investment (ECON 4)

Net-present value is based on energy cost only and is therefore just a rough estimate, where the real value of the building is not assessed.

As part of the preplanning of the energy upgrade project an assessment of life cycle cost of 15-year period was measured for four viable options for the heating system. The results of the assessment were presented to the building owner as part of the tendering process. Based on the results of the assessment the exhaust heat recovery pump solution was chosen over the other solutions. The life cycle cost comparison is presented in Figure 18 below.

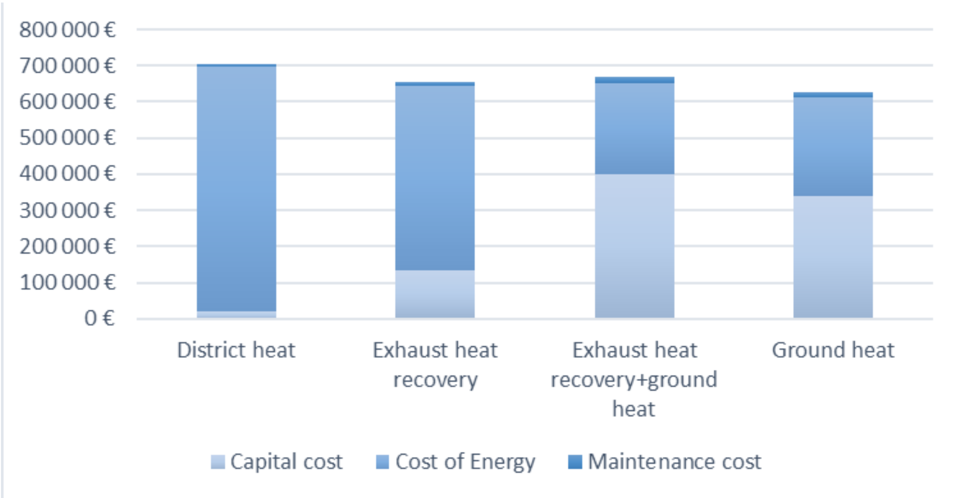

Figure 18 Life cycle cost comparison for different heating system options

Despite that the ground heating (ground source heat pump) was found to be the best option in the life cycle cost calculations, it was the exhaust air heat recovery system, that was chosen by the building owner. To set a scale for the investment for this kind of project, the investment of heat recovery system was in the magnitude of 150 000 €, and the investment cost for ground heat system is around 380 000 €. According to the assessment done during preplanning and the tendering process, exhaust air heat recovery system investment payback period would be 11,2 years with 9% of return on investment for the building owner. In comparison, the ground heat system option for this building would have had an investment payback period of 12 years with 8% of return on investment. Based on this data the building owner opted to choose the exhaust heat recovery system for this site.

6.3 Social results

An online survey to assess social indicators regarding BIM4EEB Toolkit was send to participants of the Finnish workshop. Unfortunately, only four people answered to the survey. The questions that were asked were:

1. I found that the BIM4EEB solutions are easy to use
2. I find that the User Interface of the BIM4EEB solutions and their user applications have intuitive design
3. Thanks to BIM4EEB solutions I can monitor easily the construction works and schedules during the renovation, compared to a traditional renovation approach
4. BIM4EEB makes it easier for me to exchange/track information with other stakeholders
5. The modular design of BIM4EEB makes it easier to address other types of requirements from the various business actors
6. I find that the BIMMS platform offers increased data interoperability among the provided tools and data storage/reusability capabilities.
7. I believe that utilising BIM in renovation projects, provides the means to overcome typical barriers (e.g. financial, technical) identified in the traditional process, as well as produce more accurate energy savings estimates through simulation tool
8. I believe that use of BIM enriched models produced by BIM4EEB improve the quality of my designs

and generally can boost the renovation market uptake potential

9. I believe that linking BIM models with GIS can enhance the accuracy of building energy simulations
10. I find that the use of a digital logbook, enables better management of the building information and generally can boost the renovation market uptake
11. I believe that BIM4EEB solutions offer clear advantages in the renovation process in terms of cost reduction
12. I believe that BIM4EEB solutions offer clear advantages in the renovation process in terms of time saving
13. I believe that by using BIM4EEB I become more productive
14. I think that BIM4EEB promotes a more collaborative work environment
15. I believe that I can use the BIM4EEB solutions with no technical support
16. I find that the BIM4EEB functions are well integrated
17. I believe that my knowledge is sufficient to use the BIM4EEB solutions
18. Using BIM4EEB makes me feel safer around the construction site

The results are presented in Figure 19.

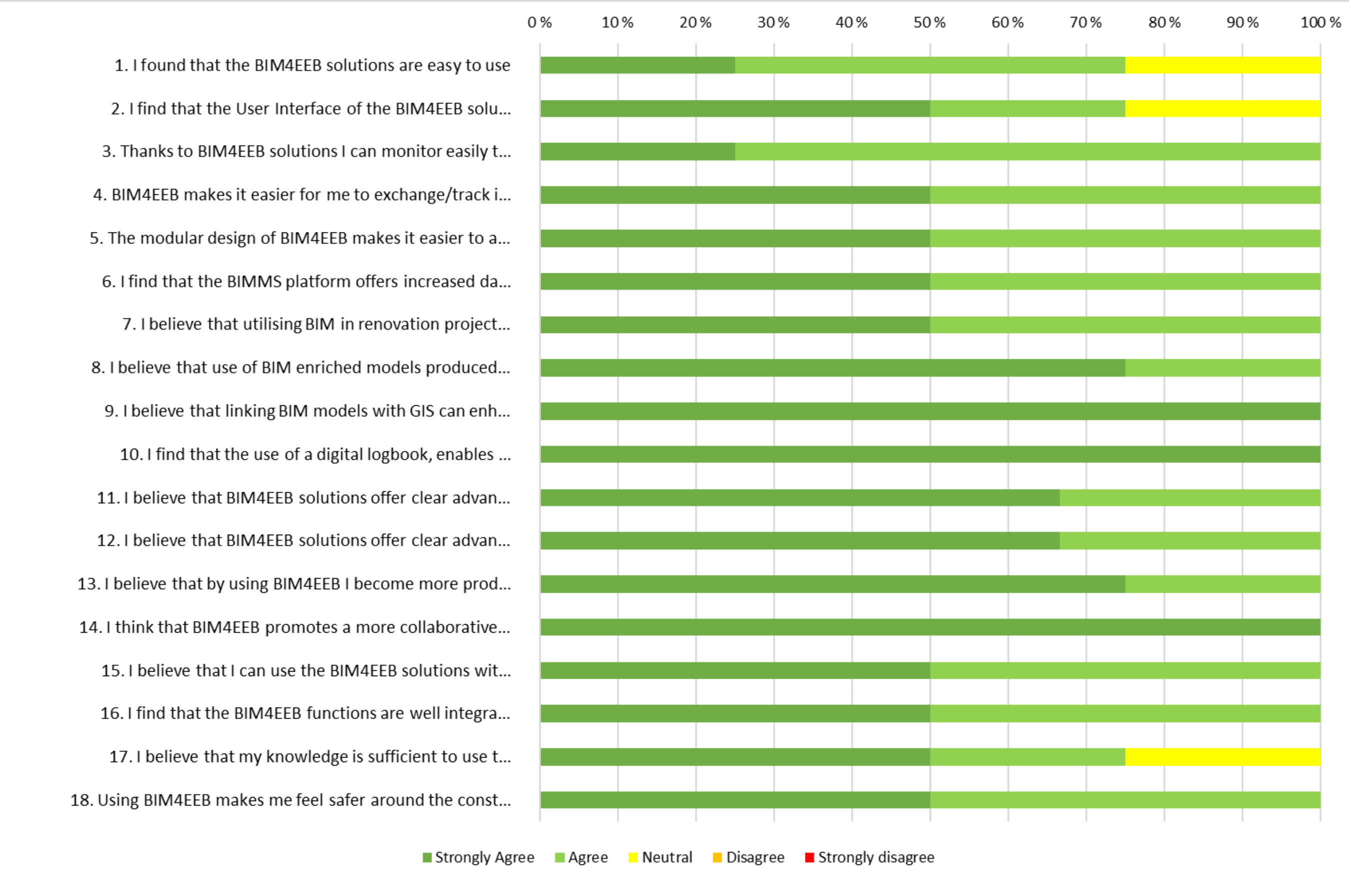

Figure 19 Results of the BIM4EEB Toolkit social indicators survey after the Finnish workshop

6.4 Energy results

Many of the energy performance indicators are partly based on a simulation model. The simulation model used in the BIMeaser demonstration described in D6.9 was made for the previous pilot site. Later when KPIs were assessed, it was decided that BIMeaser wouldn't be demonstrated with the new building, but the building was manually simulated with the same simulation software that is used with BIMeaser. In addition to the simulated results, the validation and the KPI assessment takes into account the actual measured values before and after renovation works. The simulation methodology and validation are described in the following chapter, followed with the Energy KPI evaluation.

6.4.1 Simulation methodology and validation

A simulation study was performed with a commercial energy simulation tool IDA ICE. The study enables energy KPI evaluation and supports the work done with the original pilot site with BIMeaser in evaluating the best option for renovation measures to be conducted to the pilot building. The simulation model used the IFC-model created for the demonstration (described in 2.3).

From the blueprints the simulation model got a definitive description of the physical building which was translated into the digital environment. Respective U-values of most common wall constructions as well as the respective space volumes, window sizes and floor areas were translated into the simulation model. Further variables (schedules for occupation, equipment and lighting) needed for energy simulation in the IDA ICE environment were estimated with available examples in such apartment buildings in Finland. The 3D view of the simulation model is seen in Figure 20.

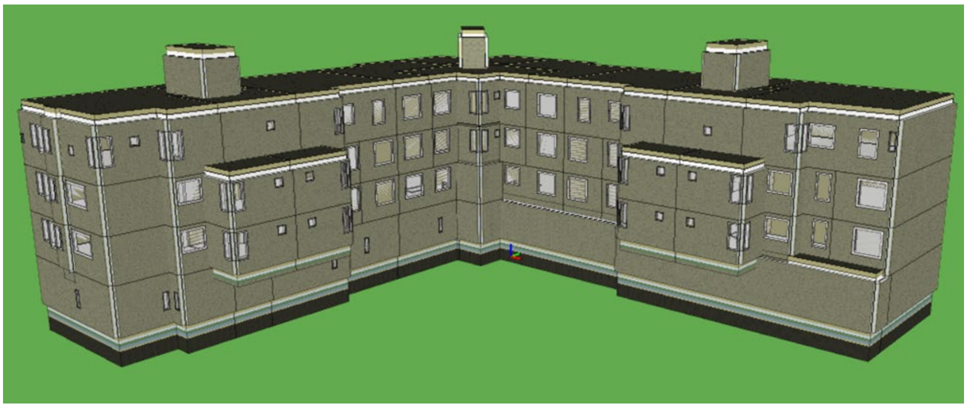

Figure 20 3D view of the pilot building in IDA ICE environment

After the physical description of the building was translated into the digital environment the calibration of the HVAC system was conducted to match the real-life counterpart. IDA ICE provides a relatively good average HVAC system as default for energy simulations. As default the HVAC system contains a typical air handling unit, which has both supply and return air subsystems. This particular building has no mechanical supply air. The fresh air is provided mainly by supply air valves in the window frames and the air is ventilated outside with return air units that are placed on the roof of the building. An example of the return air handling units on the roof are pictured in the Figure 21 below.

Figure 21 Return air handling units on the roof of the pilot building

Therefore, the typical air handling unit of the default simulation model was replaced with an air handling unit with return side only. Different setpoints for the heating, ventilation and the HVAC plant including the domestic hot water use were calibrated to correspond the real systems. After these were done through multiple iterations of simulation model calibration, the simulation model gave good results when compared to the measured energy consumption of the baseline system.

After the baseline simulation model was calibrated to match the real system, the exhaust air heat pump that was to be installed to the pilot building, was modelled into the simulation model. The installed heat pump has maximum power of 56kW with COP of 4.5 and a typical operation power is 39kW. Preliminary planned values for return air volumes for the three exhaust air units were included to the simulation model, and after the exhaust heat pump was in operation, the values were adjusted to the simulation model from the actual data collected from the building. The average of combined air flow to the three heat recovery coils was 1840 l/s with brine mass flow of 1.88 kg/s. After some iterations of simulations, the model revealed good results for the electrical heating and district heating consumption. The results of the simulations done with the baseline model and the renovated simulation model with heat recovery system are used to demonstrate the achievements of the energy upgrade project and are shown with different energy indicators below.

An overview of the energy use in the renovated building is shown in Figure 22. Facility related electricity consumption is the part purchased by the building owner. That part of the electricity consumption could be compared to the measured data. Each household in the building has its own electricity subscription for the apartment. That part of the electricity is estimated in the simulation as comparison data was not available due to privacy reasons.

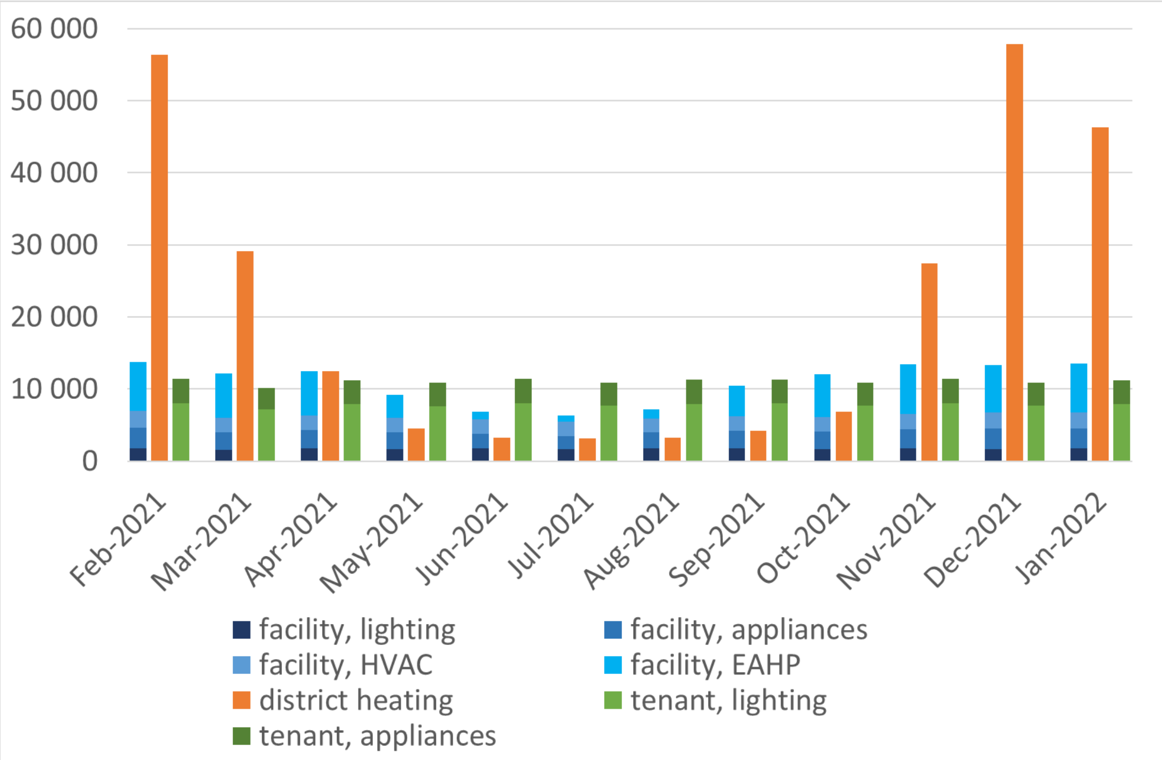

Figure 22 Simulated energy use in the renovated building.

6.4.2 ENE1 Energy Savings

ENE1 indicator is the delivered energy saving in the pilot, which is defined as a ratio between measured energy consumption in the baseline period and the measured energy consumption in the monitoring period. All the simulations were performed using actual climate data of the period from the Finnish Meteorological Institute. The indicator is expressed for the district heating and facility electricity (apartment not included) separately.

The heat pump that is installed into the building, saves district heating but uses electricity. The results for ENE1 and energy savings in the measurement period are shown in **Table** 3.

Table 3 ENE1 results, measured final energy saving

	AHU Heat recovery (kWh)	**facility electric (kWh)**	**district heat (kWh)**	**total final energy, facility** (electricity + heat)
baseline (average January 2018-2021)	0	2 490	83 860	86 350
after renovation (January 2022)	32 842	13 849	43 833	57 682
saving percentage		-456 %	48 %	33 %

6.4.3 ENE2 Energy Savings (per building component)

ENE2 indicator is the delivered energy saving in the pilot which defined in the pilot as a ratio between simulated energy consumption in baseline period and simulated energy consumption in the monitoring period. Simulations are used building component specific measurements are not available. The indicator is expressed for district heating and facility electricity components separately. Domestic hot water and ventilation heating is included in the district heat. Tenant electricity is excluded. The results for ENE2 are shown in Table 4.

Table 4 ENE2 results, comparison per building component

	Lighting, facility	Equipment, facility	HVAC aux	Exhaust air heat pump, electricty	District heating	total facility electricity
simulated baseline (January 2022)	293.6	387.6	2107	0	88418	2788.2
simulated renovated (January 2022)	293.6	387.6	5182	6814	47453	12678.2
saving percentage	0 %	0 %	-146 %	-	46 %	-78 %

6.4.4 ENE3 Primary Energy Savings

ENE3 indicator is defined as a percentage difference between measured and baseline primary energy consumption data within a predefined period. ENE1 savings are converted to primary using national conversion factors. Conversion factors of 1,2 was used for electric heating and 0,5 for district heating. The values are from Government Decree on the values of the energy conversion factors (VNA 788/2017). These values are used in the energy performance and permit calculation for buildings in Finland. It should be noted that in other countries these conversion factors may vary since the source of electricity might be vastly different in other countries. The results for ENE3 are shown in Table 5.

Table 5 ENE3 results, primary energy saving

	facility electric (kWh)	district heat (kWh)	total facility energy (kWh)	saving percentage
baseline (average January 2018-2021)	2988	41930	44918	14.2 %
after renovation (January 2022)	16618	21916	38535	

6.4.5 ENE4 Energy Performance Accuracy

ENE4 indicator is the accuracy of the assessed energy performance. BIMeaser helps in getting the accurate simulation results by supporting the modelling process. The model is more accurate as all the available data is used and simple mistakes easily made in manual work are left out. The value of the indicator is calculated as a percentage difference between simulated and measured consumptions. The simulation accuracies for AHU heat recovery, electric heating, total facility electricity consumption, district heating and total facility during the measurement period are shown in Table 6 .

Table 6 ENE4 results, energy performance accuracy

	EAHP heat recovery	EAHP electricity use	facility electricity	district heat	total facility energy
measured renovated (January 2022)	32 842	6 892	13 849	43 833	57 682
simulated renovated (January 2022)	28 185	6 814	12 678	47 453	59 582
accuracy percentage	86%	99%	92%	92%	97%

7 Conclusions

Four of the BIM4EEB toolkit tools were demonstrated in the Finnish pilot. BIM Management System (BIMMS) was used as a common data environment to store the building's BIM model, documentation, sensors streaming, activities and alerts. The Fast Mapping Toolkit demonstrated visualizing and modelling features and BIM Early Stage Energy Scenario tool (BIMeaser) collected the available data for semi-automatic energy modelling. Construction production management tool (BIMPlanner) demonstrated how the renovation project site activities can be planned and monitored using BIM based location breakdown structure. Tools also demonstrated the ontology and Linked Data approach in data exchange as detailed in the reports describing the tools.

All the demonstration were successful in a way that the stakeholders could see the benefit of the tools to the renovation business. BIMMS is closest to be exploited in real-life. Although, the other tools have reached the TRL6 target in the features that were included in the project scope, they would still require development and maybe partnering with some existing tools to be viable in the real-life market.

The first priority in the Finnish demonstration was to apply BIM data at construction site by coupling traditional BIM model data with schedulings in order to reduce lead-time at site by 20%. The scheduling data was connected to other BIM4EEB tools via BIMMS and construction documents were attached to BIM model in the BIMMS. Demonstration results showed time reduction of 75 per cent in BIMeaser based energy simulation and up to 33 percent time reduction in construction duration at site with BIMPlanner supported management.

Other quantifiable result shows a 11.2 year pay-back period for the investment due to energy saving in district heat. There was a 48 per cent saving in the district heating consumption in the measured energy. Facility electricity consumption in the building was only 3 per cent of the district heat consumption in the baseline, but increase 456 % due to the electricity use in heat pump. In Finland, primary energy factor of the electricity (1.2) is much higher than the one for the district heat (0.5), resulting in smaller saving in terms of primary energy. The total primary energy saving was 14 per cent.

The pilot is a typical renovation case that has no source BIM data available. The pilot demonstrated information collection from existing residential building and use that information as input for BIM, which was then used in simulating the building systems. The renovation focus was in installation of an exhaust air heat pump as part of mechanical exhaust air ventilation system and centralized hydronic heating system.

The building is connected to a remote monitoring service that can utilise the collected information during the operation and maintenance phase. The exhaust air heat pump requires adjustment period where the control settings are optimised. The period is currently ongoing. In case something unexpected is found, the simulation model could be used to analyse different control strategies.

Finally, the Finnish pilot building represents a residential building that is very common in Finland and Northern Europe. The building was built in the 1990's, but similar buildings with mechanical exhaust ventilation missing a heat recovery have been built also during 1980's and 1970's. All these buildings can be equipped with a similar heat pump solution. For newer buildings with a mechanical ventilation, an ordinary heat recovery unit may be more feasible, but also heat pump can be beneficial in some cases. In older buildings with a natural ventilation, the exhaust air ducts might be difficult to install making the heat pump solution too expensive to install

The key performance indicators were calculated and evaluated to analyse the impacts of the tested tools. In such testing environment some manual work and expert work were needed to prepare the setup and these activities were not considered in KPI evaluations. It shall be noted that the benefit of the tools cannot be separated from the other design choices in a single pilot. We are confident that the tools help make better choices and improve performance more in further projects.

In the larger scale, the demonstration project represented this specific limited energy renovation content and provided valuable knowledge of such energy performance improvements. Number of such projects is increasing rapidly and raising potential application of BIM4EEB results and tools. This type of projects would benefit from centralised management of multiple buildings in a single project. One building owner, or a group of building owners, could order the renovations in a bundle. Then the creation and storage of the BIM models, energy analyses, construction management and related data storage using BIM4EEB Toolkit could be arranged as a one big project, which would bring economic scale benefits and enable the use of tools that would otherwise be infeasible. The arrangement would enable the optimization of the renovation activities in parallel and improve productivity.

While looking for such group project to continue the development of the full BIM4EEB Toolkit, the exploitation planning of individual tools continues in the exploitation work package of the project.

8 Bibliography / References

Project deliverables:

- D4.9 Tested version of the platform, public report
- D4.10 Testing and validation results on demonstration sites, public report
- D5.5 Technical report on testing and validation results, public report
- D6.6 Decision-support tool, confidential report describing the tool
- D6.9 Report on adoption of BIM-assisted Energy refurbishment assessment tool
- D7.1 Server software to manage interlinked BIM-workflow data for construction production management, confidential report describing the software
- D8.1 Report on management of real Best Practice Examples, public report
- D8.2: Report on demonstration in Italy, public report
- D8.3: Report on demonstration in Poland. public report
- D10.12 Final workshops, public report

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[VNA 788/2017] Valtioneuvoston asetus rakennuksissa käytettävien energiamuotojen kertoimien lukuarvoista (Government Decree on the values of the energy conversion factors in buildings) 788/2017, https://www.finlex.fi/fi/laki/alkup/2017/20170788

Annex I – The table of indicators for the Finnish pilot

Table 7 Indicators for the Finnish pilot. (Adapted and simplified from D8.1 table 27)

Category of KPI	kpi	Name of the KPI	Description of the KPI	Unit	BIMMS	Fast Mapping Toolkit	BIMeaser	BIMplanner
Renovation process	REP 1	Renovation Time Reduction	This is the time saving performed during the renovation process based on the better management of the renovation activities, compared to the baseline/traditional process. A multi-vectoral analysis should be considered addressing the different steps of the renovation process (e.g. audit time, data retrieval, renovation actions etc.,)	%	X	X[1]	X[2]	X
	REP 2	Renovation Cost Reduction	This is the cost saving performed during the renovation process based on the better management of the renovation activities, compared to the baseline/traditional process	%	X	X	X	X
	REP 3	Actual/planned conformance - **time**	Better accuracy of the renovation process **time** considering the design phase, compared to the baseline/traditional process	%		X	X	X
	REP 4	Actual/planned conformance - **cost**	Better accuracy of the renovation process **cost** considering the design phase, compared to the baseline/traditional process	%		X	X	X
	REP 5	Actual/planned conformance - **actions**	Better accuracy of the renovation process time, considering the share of **actions** completed on time as on the design phase, compared to the baseline/traditional process	%		X		X
	REP 6	Non-conformance Issues during inspection reduction	Number of non-conformance report items: #qualityIssues, compared to the baseline/traditional process	%				X
	REP 7	Time Reduction to fix quality issues	Reduction of time required to fix quality issues	%				X
Comfort	COM 1	Adaptive Predicted Mean Vote (PMV)	Adaptive PMV (based on PMV) predicts the mean value of the overall thermal sensation of a person as a function of environmental parameters: air temperature, mean radiant temperature, air velocity, and air humidity	Numerical (-3 to +3)			X	
	COM 2	Predicted Percentage of dissatisfaction (PPD)	Percentage of the people who felt more than slightly warm or slightly cold	%			X	
	COM 3	Thermal discomfort factor	Assessing the people's satisfaction with the thermal environment	Probability (0-1)			X	
	COM 4	Operative Illuminance	Assessing the people's satisfaction in terms of illuminance compared to a reference value.	lux			X	

	COM 6	Average Indoor Noise Level	The level of noise in the building environment compared to reference values	dB		**X**		
	COM 7	Occupancy Profiling Accuracy	Deviations about real and predicted occupancy schedules	%				**X**
Economic	**ECON 1**	Annual Cost Savings	Reduction of cost due to the renovation activities; compared to the baseline values	%	**X**			
	ECON 2	Net Present Value (NPV)	Calculated based on nominal costs and discount rate based on the projected actual future costs to be paid, including general inflation and deflation.	€	**X**			
	ECON 3	Pay-back Period	The period required to recover the funds expended in an investment on renovation.	Time (years)	**X**			
	ECON 4	ROI - Return on Investment	Assessment of the energy measures for the whole building by using the overall investment costs and the saving in running costs energy	%	**X**			
	ECON 5	Life Cycle Cost (LCC)	LCC defines the business framework for renovation activities, by comparing the investment costs with the economic savings achieved due to the energy conservation measures introduced in during the renovation. LCC analysis considers all cash inflows and outflows over the useful life of the project, reducing each flow to its present value.	€			**X**	
Energy performance	**ENE 1**	Energy Savings	Calculating the percentage difference between measured and baseline consumption data within a predefined period	%			**X**	
	ENE 2	Energy Savings (per building component)	Calculating the percentage difference between measured and baseline consumption data within a predefined period for different building components (e.g. HVAC, lights etc…)	%			**X**	
	ENE 3	Primary Energy Savings	Calculating the percentage difference between measured and baseline primary energy consumption data within a predefined period	%			**X**[3]	
	ENE 4	Energy Performance Accuracy	Deviation between predicted and actual energy use by comparing predicted and real energy consumption	%			**X**	
	ENE 5	Total Use of Primary Energy	User of primary energy expressed as the indicator Cumulative Energy Demand during the lifecycle of the project (considering the different phases)	MJ or %			**X**	
Social	**SOC 1**	Ease of use for end users of the solution	It provides the means for assessing the acceptability of the framework from BIM4EEB end user (i.e. Construction Companies, Designer, FMs, Occupants). *"I found the system easy to use"*	Likert scale (1-5)	**X**	**X**	**X**	**X**
	SOC 2	Beneficial for end-users	The extent to which BIM4EEB offers clear advantages for end users (i.e. Construction Companies, Designers, FMs, Occupants). Advantages can vary from cost savings, improved quality and increased comfort. It is presumed that solutions which have a higher level of advantages to end users will be more likely to be adopted than solutions which have negative or no advantages. *"I believe that BIM4EEB solutions offer clear advantages in the renovation process (e.g. cost/time savings)"*	Likert scale (1-5)	**X**	**X**	**X**	**X**
	SOC 3	Occupants active involvement in the renovation phase	The extent to which occupants have been involved in the renovation process. *"With BIM4EEB, it was easier for me to be involved in the renovation process, compared to a traditional renovation approach."*	Likert scale (1-5)				**X**

			"With BIM4EEB, the renovation of my residence caused me less discomfort than what is expected with the traditional renovation approach"					
	SOC 4	Productivity improvement	The extent to which BIM4EEB improves the productivity of its users (i.e. Construction Companies, Designer, FMs), during the various stages of the renovation. *"I believe that by using BIM4EEB I become more productive."*	Likert scale (1-5)	**X**	**X**	**X**	**X**
	SOC 5	Improvement in collaboration among teams	The extent to which BIM4EEB can improve the collaborations among its stakeholders (i.e. Construction Companies, Designer, FMs, Owners) *"I think that BIM4EEB promotes a more collaborative work environment."* (Designers, Construction Companies, FMs) *"Through BIM4EEB it's easier for me to exchange information and collaborate with other stakeholders."* (Occupants)	Likert scale (1-5)	**X**	**X**	**X**	**X**
	SOC 6	Improvement in safety at construction site	The extent to which BIM4EEB can improve the H&S on site during the renovation works for Construction companies, FMs and Occupants. *"Using BIM4EEB makes me feel safer around the construction site."*	Likert scale (1-5)	**X**	**X**		**X**
	SOC 7	Level of intuitiveness in user applications	How the users (i.e. Construction Companies, Designer, FMs, Occupants) of the BIM4EEB find the design of the system/toolkits understandable and easy to use. *"I find that the User Interface of BIM4EEB and its user application have intuitive design."*	Likert scale (1-5)		**X**	**X**	**X**
	SOC 8	Improved monitoring/access on information during renovation works	The extent to which BIM4EEB provides improved monitoring capabilities of the renovation works for Construction Companies, FMs and Occupants. *"With BIM4EEB I can monitor easily the construction works and schedules during the renovation, compared to a traditional renovation approach."*	Likert scale (1-5)	**X**	**X**		**X**
	SOC 9	Increased easiness in information exchange and tracking (data accessibility)	The extent to which BIM4EEB improves tracking and information exchange among its various stakeholders (i.e. Construction Companies, Designer, FMs, Occupants) *"BIM4EEB makes it easier for me to exchange/track information with other stakeholders"*	Likert scale (1-5)	**X**	**X**		**X**
	SOC 11	Interoperability and data storage capability of BMS platform	The extent to which BIM4EEB incorporates standards-based data models to ensure interoperability among the different tools and data reusability of the platform to large scale applications *"I find that the BMS platform offers increased data interoperability among the provided tools and data storage/reusability capabilities."*	Likert scale (1-5)	**X**			
	SOC 12	Use of BIM in renovation business	The extent to which BIM utilisation in the renovation industry can alleviate typical process, financial and technical barriers by reducing costs of building information acquisition and generate more accurate energy savings forecasts, as declared by the BIM4EEB stakeholders involved or Advisory Board (construction / renovation companies, /service companies) *"I believe that utilising BIM in renovation projects, provides the means to overcome typical barriers (e.g. financial, technical) identified in the traditional*	Likert scale (1-5)		**X**	**X**	

			process, as well as produce more accurate energy savings estimates through simulation tools"					
	SOC 13	Use of dynamic simulation tools for energy assessment	The extent to which utilising enriched BIM models can speed up the market uptake and move towards data collection for digital built environment, as declared by involved stakeholders or (building managers and energy managers involved in the Advisory Board) *"I believe that use of BIM enriched models produced by BIM4EEB improve the quality of my designs and generally can boost the renovation market uptake potential."* (Designers) *"I believe that use of BIM enriched models can boost the renovation market uptake potential."* (Construction Companies, FMs)	Likert scale (1-5)			X	
	SOC 14	Integration of GIS data in BIM model for energy purpose	The extent to which connecting BIM and GIS towards can enhance the accuracy of building energy models; as declared by involved BIM4EEB stakeholders or Advisory Board (construction/renovation companies, service companies) *"I believe that linking BIM models with GIS can enhance the accuracy of building energy simulations."*	Likert scale (1-5)		X		
	SOC 15	Development of digital logbooks for renovated building; management of as-built data in operational BIM models	The extent to which use of enriched BIM model with detailed as built data orderly stored in digital logbooks can accelerate the market uptake of BIM; as declared by involved stakeholders (designers, construction/renovation companies, inhabitants, clients, service companies) *"I find that the use of a digital logbook, enables better management of the building information and generally can boost the renovation market uptake"* (Designers) *"I find that the use of a digital logbook, enables better management of the building information and generally boost the renovation market uptake"* (Construction Companies, FMs) *"I find that the use of a digital logbook, enables better management of the building information"* (Occupants)	Likert scale (1-5)	X	X		
Environmental/safety	**ENV 1**	CO_2/ CO compounds reduction	Assessing the level of pollutant emissions (CO_2/CO) compared to a reference value	ppm			X	
	ENV 2	Particulate Matter (PM) reduction	Assessing the level of pollutant emissions compared to a reference value	Likert scale (1-5)			X	
	ENV 3	Volatile Organic Compounds (VOC) reduction	Assessing the level of pollutant emissions compared to a reference value. VOCs can impact severely the IAQ and may have effects ranging from internal conditions	mg/m³			X	
	ENV 5	Safety issues/ incidents/accidents (during inspection) reduction	Reduction of the number of non-conformance report items: #safetyqualityIssues; compared to the baseline/traditional process	%		X	X	X