BIM4EEB

BIM based fast toolkit for Efficient rEnovation in Buildings

D8.1 Report on management of real Best Practice Examples

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

Work Package	WP8
Lead Partner	PoliMi
Contributing Partner(s)	PoliMi, VTT, SOLINTEL, RISE, UCC, OneTeam, CAVERION, VisuaLynk, RegLomb, ALER VCMB, PROCHEM, Suite5
Dissemination Level	Public
Type	R: Report
Due date	30/06/2020
Date	Delivery 25/03/2021
Version	2.0

DOCUMENT HISTORY

Version	Date	Comments	Main Authors
0.1	22.01.2020	First draft	Sonia Lupica Spagnolo, Martina Signorini (PoliMi)
0.2	21.02.2020	Second draft with partners' feedbacks	PoliMi, VTT, ALER VCMB, RegLomb, RI.SE, CGI, Suite5
0.3	28.05.2020	Proofread, corrections and contributions	UCC/IERC, TUD, Suite5, Oneteam, Caverion, Prochem
0.4	03.06.2020	Final draft for internal review	PoliMi
0.5	08.06.2020	Internal Review	Teemu Vesanen (VTT)
0.6	10.06.2020	Internal Review	J.Drozdziel (PROCHEM)
0.7	19.06.2020	Final draft for coordinator's approval	Sonia Lupica Spagnolo, Martina Signorini (PoliMi)
1.0	22.06.2020	Final version approved and submitted	Sonia Lupica Spagnolo, Martina Signorini (PoliMi)
1.1	22.03.2021	Updated Figure 25 and related text added. Plagiarism check, Bibliography updating and citations.	Davide Madeddu (OneTeam), Kostas Tsatsakis (Suite5), Brian O'Regan.(UCC), Teemu Vesanen & Markku Kiviniemi (VTT), Martina Signorini (PoliMi)
2.0	25.03.2021	Final version for new submission on EU portal after officer's comments	Sonia Lupica Spagnolo, Martina Signorini (PoliMi)

Statement of originality:
This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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

EXECUTIVE SUMMARY

The report describes the three demonstration sites chosen because of their representativeness on the project's application target. These best practice examples will constitute a validation mean for the developed tools and the proposed methodology showing their applicability based on actions of development, piloting, testing, and validating in relevant environments. A deep analysis of each pilot site has been done in order to choose the most suitable sensors set-up according to the specific features of each building: location, number of floors, building construction technologies, technical state, etc. have been considered.

Moreover, relevant renovation activities performed in the last years have been taken into consideration and below described to have a complete picture of the study object. Site inspections of the current HVAC systems was undertaken to help in this analysis.

The first part of the report summarizes the gathered information about existing residential building and explains the reason why some apartments were selected for the validation of the developed tools: on one hand, the selection of apartments considered the availability of residents of individual apartments for demonstration activities and diversification due to their exposition; on the other hand, this selection was based on detailed analyses of the technical condition of individual apartments.

The second part of the report shows the testing methodology applied on the chosen pilot sites. In order to test and show the functionalities of the different tools within the BIM4EEB toolkit, it is planned to install some hardware at the different demo sites. Consequently, a hardware topology was defined to address the task requirements about:

- Thermal and visual comfort (i.e., temperature, relative humidity, occupancy, luminance);
- Indoor air quality (i.e., CO_2,PM2.5, PM10, VOC - Volatile Organic Compound);
- Electric power consumption (i.e., electricity meter);
- Gas consumption (i.e., gas meter)

Therefore, several sensors were selected to be installed in each demo site and their main technical features are hereafter explained. They are linked to a system gateway, thanks to the connection to its API, data can be stored into the BIMMS.

Finally, a validation methodology with the respective Key Performance Indicators (KPIs) was defined as stated in deliverable D3.5 [D3.5, 2019] in order to validate the level of achievement and assess the project results. KPIs have been selected according to project's objectives as identified in the DoA and they are in line with the BIM4EEB project's stakeholders' requirements, as defined in WP2 deliverables D2.2, D2.3, D2.4, D2.5 ([D2.2, 2019], [D2.3, 2019], [D2.4, 2019], [D2.5, 2019]).

PUBLISHING SUMMARY

The research activities for Demonstration in relevant environment (WP8) started from defining how to manage tools and methods on the three best practice examples selected for BIM4EEB validation. These pilot sites will allow testing and demonstrating the features of the different tools, according to a designed testing methodology and consequently a selected hardware topology.

In order to manage such validation activities, the report shows the gathered information about existing residential building and explains the reason why some apartments were selected for the validation of the developed tools: on one hand, the selection of apartments considered the availability of residents of individual apartments for demonstration activities and diversification due to their exposition; on the other hand, this selection was based on detailed analyses of the technical condition of individual apartments.
Moreover, it shows the testing methodology applied on the chosen pilot sites to check if functionalities of the different tools within the BIM4EEB toolkit work and, thanks to the use of Key Performance Indicators (KPIs), how much they can improve efficiency the renovation process and comfort conditions.

The hardware topology described in this report was defined for addressing the task requirements about:

- Thermal and visual comfort (i.e., temperature, relative humidity, occupancy, luminance);
- Indoor air quality (i.e., CO_2, PM2.5, PM10, VOC - Volatile Organic Compound);
- Electric power consumption (i.e., electricity meter);
- Gas consumption (i.e., gas meter)

Sensors and devices that measures such parameters are then linked to a system gateway, thanks to the connection to its API, data can be stored into the BIMMS.

Eventually the report describes the validation methodology with the respective KPIs in order to validate the level of success and assess the BIM4EEB project results.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

The document presents a description of the three pilot sites selected to test the applicability of the tools under development in BIM4EEB project and the chosen methodology showing how the tools can be applied based on actions of development, piloting, testing, and validating in significant surroundings.

The report is constituted by a first part, chapter 2, describing the chosen Best Practice Examples and containing a deep analysis of the demonstration sites placed in Italy, Poland and Finland with the consistent features that make them relevant. The following chapter 3 “The testing and validation methodology” is about the explanation of the testing procedure applied on them and the consequent validation methodology based on KPIs.

The set out KPIs are defined as stated in D3.5 [D3.5, 2019] and selected according to project’s objectives as identified in the DoA and in line with the BIM4EEB project’s stakeholders’ requirements, as defined in D2.2, D2.3, D2.4 and D2.5 (see [D2.2, 2019], [D2.3, 2019], [D2.4, 2019], [D2.5, 2019]).

2 The chosen Best Practice Examples

Three Best Practice Examples were selected as stated in DoA [DoA, 2018] "*according to their representativeness on the project's application target and because of the attention for selected end-users. They will be used to validate the developed tools and the proposed methodology showing their applicability through the development, piloting, testing, and validating in relevant environments*". The selected buildings are placed in three EU countries with different climatic conditions. Since the project takes care of the needs of fragile inhabitants, both social houses and residential apartments have been selected as case studies.

2.1 Italian demonstration site

2.1.1 Description

The Italian demonstration site is in Monza, the third biggest city in the region of Lombardy, in northern Italy, in Via della Birona 47. The chosen building was built in 1981 and it is a public housing managed by the BIM4EEB partner Aler Varese – Como – Monza e Brianza – Busto Arsizio (ALER VCMB). It has 9 floors above ground, one of which is a mezzanine floor (or raised ground floor) and another one is a *pilotis* floor at level -1.50m currently used as garage. It is composed of 65 apartments on 8 storeys, it has a central heating system using natural gas as heating source. At the same height cellars and boiler rooms are placed.

External facades are plastered, while the two stairwells and fronts balconies are fair-faced concrete. The raised ground floor, at height of +1.30m, is south exposed through a balcony characterised by large openings ad it is possible to access it by a concrete ramp (for users with reduced mobility) and two concrete stairs. The upper floors are served by stairs and by two elevators. The conservation status of the property is quite poor: signs of loss of plaster and flooring are important just like the damage of concrete cortical surface.

Figure 1 - Italian demonstration site [DoA, 2018]

The apartments are served by a **gas central heating system** installed with risers for heat production for winter heating. Its heating plant is composed by 3 condensing boilers by BALTUR installed in 2018 with cascade system with a total power of 363,0 kW. The system is equipped with climate probe operating on flow temperature of the plant. When replacing boilers, thermostatic valves and distributors for the metering of heat to each individual apartment were installed on each radiator present within the apartments.

Recently water plant with autoclave was installed. A gas water heater to produce domestic hot water is installed in each apartment. Also stoves for cooking are powered by gas. Gas meters, quite old, are positioned in the balconies of the apartments. There is another gas meter, positioned in the common areas, dedicated to the gas consumptions for central heating.

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. The data available so far are not unified into a model, instead they come from different sources, both digital and on paper, as well as from on-site inspections. Generally, the main interventions performed are external walls or roof thermal insulation, replacement of windows, installation of thermostatic valves, heat generator substitution.

Among the significant maintenance interventions performed on the Italian pilot case, we find the refurbishment of the roof and the replacement of boilers. In 2011 extraordinary maintenance works were realized for remediation of asbestos products. In fact, previous roof consisted of corrugated sheets in asbestos cement. The old roof has been replaced with a roof made up of panels constituted by a sheet metal coating among which expanded polyurethane foam is placed.

Figure 2 - Roof in asbestos cement before maintenance intervention

Figure 3 - Roof after the maintenance intervention

In 2018 the boilers of the heating plant were replaced with 3 condensing boilers manufactured by BALTUR with a total power of 363,0 kW (n. 2 *SMILE ENERGY MK 160*, n.1 *SMILE ENERGY MK 70*), installed following a cascade schema.
The three condensing boilers substitute the previous floor standing boiler in order to guarantee a total economic saving of the building by virtue of a moderate economic investment; in addition, with the new boilers, the energy consumption and the CO_2 emissions have been reduced.

Figure 4 - Condensing boilers

The main aim of the design for Italian pilot site is the general maintenance of the whole building from architectural and energetic/plant engineering point of view using materials and techniques with reduced environmental impact (in compliance with the minimum environmental criteria introduced in Italy with the decree D.M. 11/10/2017).

Figure 5 - Thermostatic valve

During renovation in 2018 also thermostatic valves “Art.1430-Two-pipe thermostatic valves” by Far were installed. They enable a manual, thermostatic or electrothermal adjustment. The valve is suitable for use on round circuits with the possibility of use in reversible configuration only if it is used manually. Since the circuit is a round circuit, the fluid that goes to the radiator is always equal to 100%.

Table 1 - Technical data of two-pipe thermostatic valve

Nominal pressure	10 bars	Probe	Galvanised steel
Max. working temperature	95 °C	Small items	Brass CW614N

Probe length	45 cm
Connections	For cooper, plastic and multilayer tube
Bolt	EPDM

Valve body	Brass CW617N e CB753S
Nut and pipe union	Brass CW617N
Gaskets, O-rings	EPDM

The interventions that will be realized are listed below.

- Refurbishment to improve the energy efficiency of the building:
  - Realization of insulating facade coat
  - Replacement of external windows with PVC windows for all the 65 apartments
  - Replacement of the external iron windows of the common areas
  - Insulation of heating pipes at the *pilotis* floor
- Measures to restore the external surfaces of the building:
  - Refurbishment of external surfaces in reinforced concrete and plaster that are not insulated
  - Restoration of balcony parapets, including the construction of glass-concrete enclosures
  - Restoration work on the external concrete surfaces of the roof cornice
- Maintenance works for the internal and external common areas of the building:
  - paving of *pilotis* floor
  - laying of epoxy resin on the ramp and on the stairs paving
  - replacement of tinwork
  - Painting of stairwells and perimeter fence of the building
  - Replacement of downspouts
  - Renovation of the driveway floor of the *pilotis* floor
  - Laying of new flooring for outdoor areas for parking
  - Restoration of no. 2-room garbage dump
- Installation of temperature and hygrometry monitoring systems within the apartments.

2.1.2 The adopted approach for apartments' choice

The eleven apartments, selected also according to the tenants' availability, are identified in the table below. They are representative of the low, medium, and high levels of the building and belonging to both two stairs (A and B).

Table 2 - List of the selected apartments

	Apartment ID Number	Staircase	Floor	Exposition	Type (2: two-room flat; 3: three-room flat)
1	02	A	raised ground	east-west	2
2	04	A	raised ground	east-west	3
3	13	A	3rd	north-east-west	3
4	14	A	3rd	east-west	2
5	30	A	6th	east-west	3
6	32	A	7th	east-west	3
7	38	B	raised ground	east-west	2
8	46	B	3rd	east-west	3
9	47	B	3rd	east-west	2
10	59	B	6th	east-west	2
11	60	B	6th	east-west	3

It is important to select one or two target tenants or families, the most available and cooperative, for testing of installation procedures and gathering of data, with a full equipment of sensors, to solve problems before installing all the equipment in all the apartments, to avoid excessive disturbance to tenants. Only few apartments will be fully equipped.

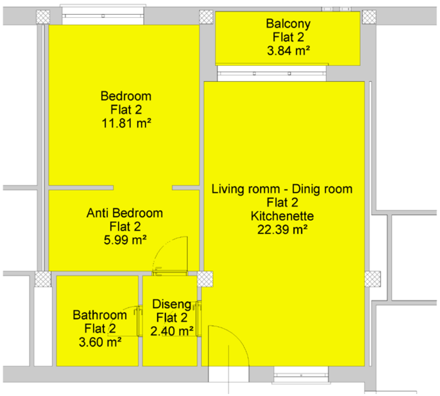

Figure 6 - Apartment n. 2

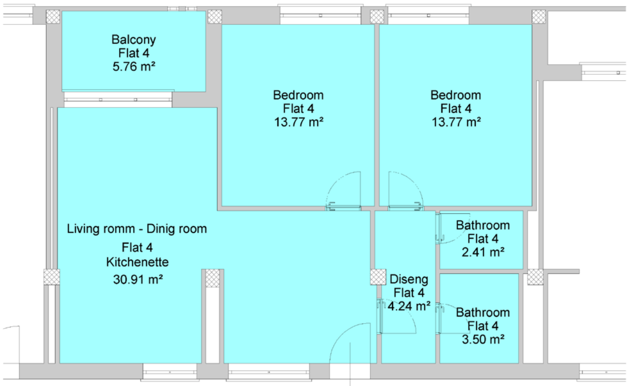

Figure 7 - Apartment n. 4

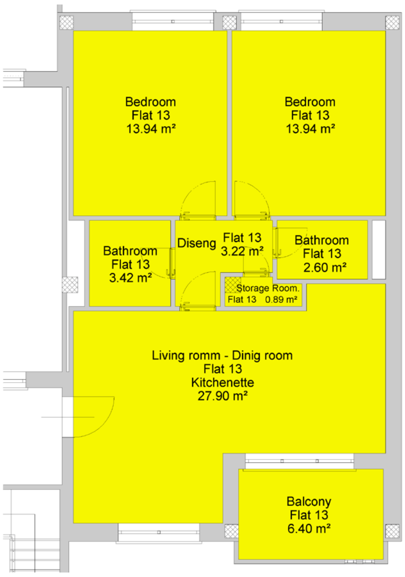

Figure 8 - Apartment n. 13

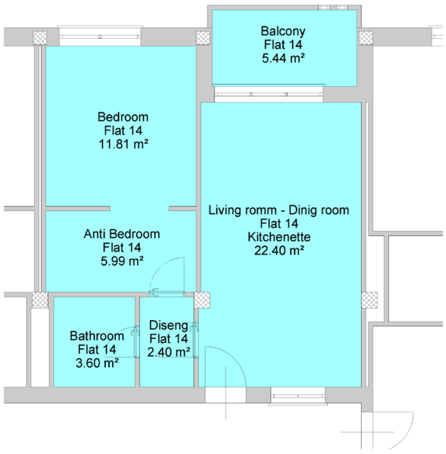

Figure 9 - Apartment n. 14

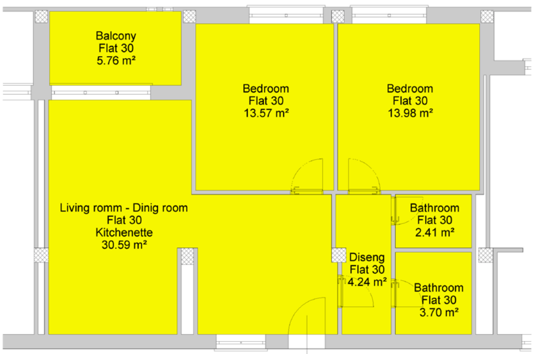

Figure 10 - Apartment n. 30

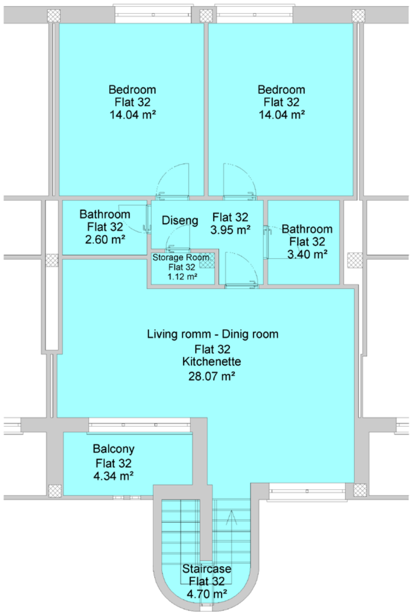

Figure 11 - Apartment n. 32

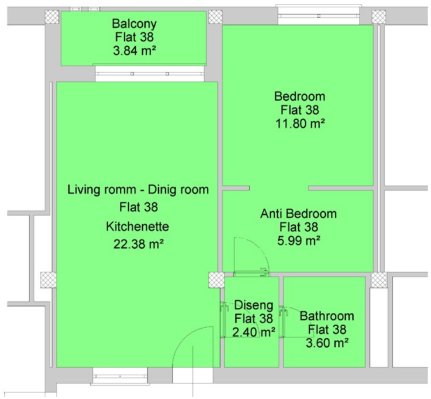

Figure 12 - Apartment n. 38

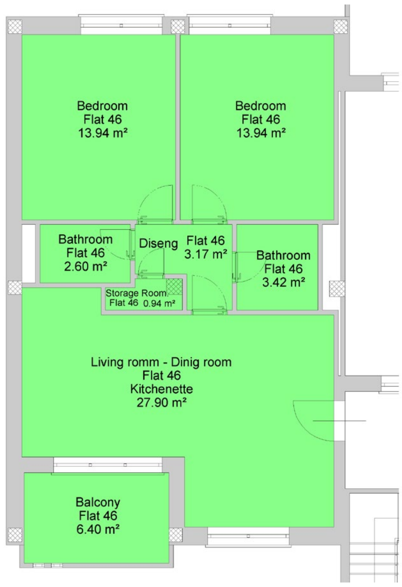

Figure 13 - Apartment n. 46

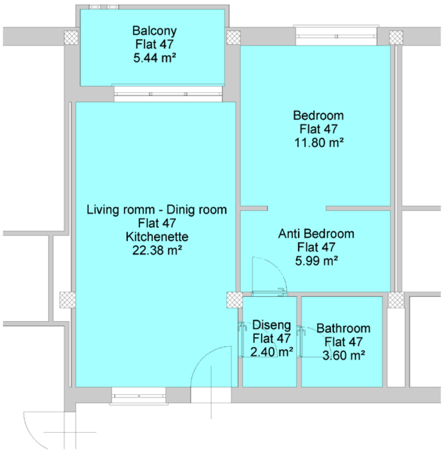

Figure 14 - Apartment n. 47

Figure 15 - Apartment n. 59

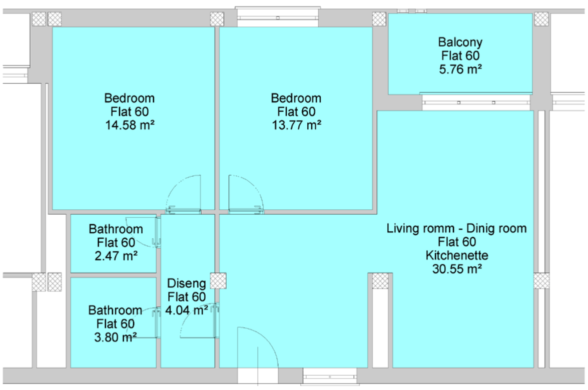

Figure 16 - Apartment n. 60

2.2 Polish demonstration site

2.2.1 Description

Figure 17 - Polish demonstration site [DoA, 2018]

The polish pilot site is in the south of Poland in Chorzow town. The object of the study is a residential building built in 1902 characterised by 5 floors, 12 apartments and 3 commercial areas located on the ground floor, for a total of 1330 m^2. The data available come from different sources, both digital and on paper and from on-site inspections. Geometric and topological data about the generic aspect of the building for preliminary assessments are available, while data regarding apartments are extracted from original 2D drawings. Within the context of the project, all these data will be digitized further enriched with information coming from the different tools to be developed in premises and considering also the installation of the WSN system that will enable tracking basic metrics required for the demonstration activities. The building itself would assess mainly design and planning functions of the platform, fast mapping capabilities and application of digital tools for HVAC design, operation, and efficiency management with the input of HMI and occupant´s profiling mechanism. Unlike the Italian demonstration site, no renovation involving construction work are planned or required.

2.2.2 The adopted approach for apartments' choice

The selection of apartments for demonstration activities on the Polish pilot site was based on detailed analyses of the technical condition of individual apartments and according to the strong need for inhabitants to undertake further renovations (in some apartments, renovation works were carried out previously). Moreover, the availability of inhabitants and diversification of flat expositions were considered.

The five apartments object of study are at ground floor, 1st floor, 2nd floor and attic. On the ground floor the apartment "D1/2", on the 1st floor apartments "D1/4" and "D1/5", on the 2nd floor "D1/6A" and on the attic the apartment "D1/10A" will be subjected to analysis.

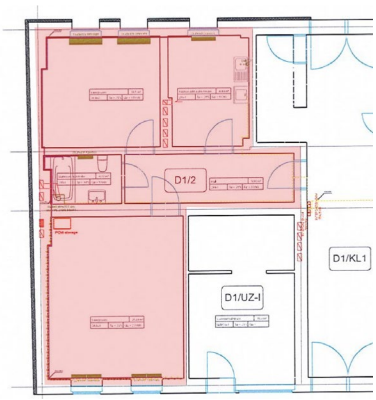

Figure 18 - Apartment n. D1/2

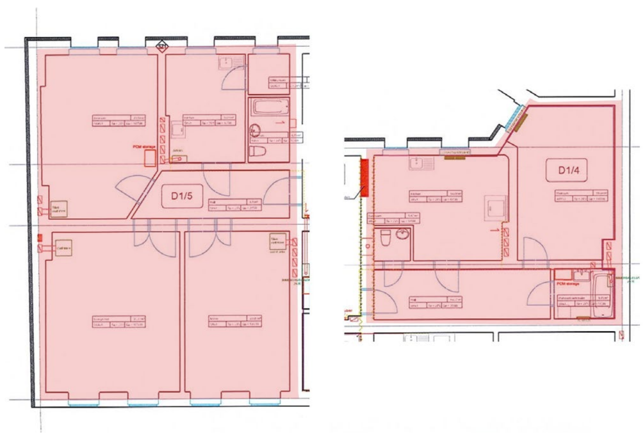

Figure 19 - Apartment n. D1/4 and D1/5

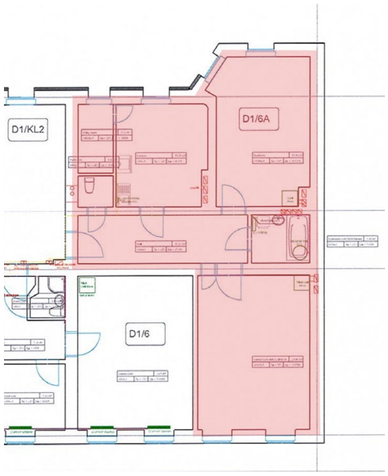

Figure 20 - Apartment n. D1/6A

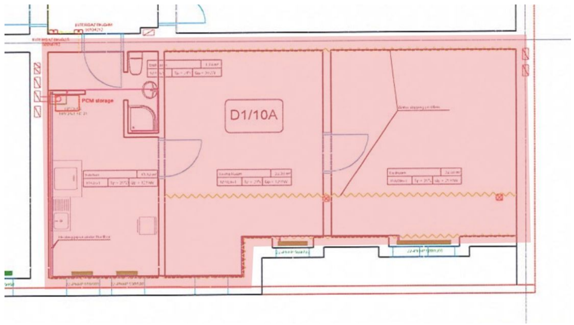

Figure 21 - Apartment n. D1/10A

After site inspections, some general conclusion about building technical state have been collected:

- Electric installation has cables that cannot stand the current, resulting in low possibilities of power supply. The apartment D1/6A cannot have electric devices installed. The electric installation requires complete renovation in D1/5.
- Every shaft would need additional revision and cleaning, so that the natural ventilation would be possible. Apartments D1/4, D1/4A and D1/6A have problems with shafts, reverse thrust.
- Most of the apartments would require change of boilers and distribution of domestic hot water.
- Radiators should be changed if working with lower temperature fluids.
- Piping in general are in good state, however some of the apartments require complete change of the system (D1/4, D1/4A, D1/6A, D1/10A, D1/5, D1/10).
- There are two apartments that are unconditioned (D1/5 and D1/6A).
- Humidity issue in the apartments (the right wing of the building is suffering major humidity problems, mould in apartments D1/4, D1/4A, D1/2, D1/10A).

The commercial section: two of the spaces are not used (in the frontal façade). No installation except of electric heating and DHW. The commercial zone with the biggest area located on the ground floor by the east wall of the building, has been renovated in 2017. Renovation activities involved the replacement of the installation.

Table 3 - Renovation activity description for the selected apartments

Flat	**Renovation activities**
D1/2	No renovation was done, the system is as the previous tenant left it. The system is compounded by two main sources of thermal energy: • Electric for domestic hot water • Gas boiler for heating and domestic hot water The apartment needs to be inspected in terms of shafts and humidity. Big problems from the basement. The tenants complain of moisture problems especially visible on the wall between the living room LR-1, bathroom B-1 and the hall H-1. It causes the plaster and paint to go away from the wall.
D1/4	The apartment does not have sufficient heating, therefore there is a problem in temperature maintenance. No heating in spaces like hall and second bathroom, from where the main temperature drop is noted. The tenant also reported problems with windows (infiltration).

	The additional inspection of shafts should be done (soot coming out from ventilation duct). Electric installation to be changed (insufficient power).
D1/5	There are 3 coal stoves in the apartment. They are in bedroom, living room and in second room. The one in last room cannot be used. There is also old gas boiler installed in the kitchen for preparing DHW. Only few electric sockets are in use in the apartment. The installation is very old and badly maintained. This space has no heating or domestic hot water installation. The boiler that is placed in the kitchen is shut down from usage.
D1/6A	The apartment has no gas heating operating system due to natural ventilation failure (after inspection of shafts it was impossible to install the gas boiler). The electric installation cannot sustain fully operative electric heating, that is why two coal stoves are in use. The domestic hot water is supplied by the electric pre-heaters. In bathroom there is placed additional electric heater to sustain room temperature of around 24°C in shower hours. The electric installation must be changed. Revision of shafts is needed. There is no heating installed. The problem with ventilation must be solved to install gas boiler. Apartment's entrance door is very old and there are a lot of heat losses under the door.
D1/10A	The apartment in the attic has not been refurbished. The installation is one of the oldest considering the whole building and it needs to be changed. The roof needs to be sealed because it is leaking. The ventilation system should be improved to avoid unnecessary heat losses. Sometimes water drips from the boilers chimney. Probably the chimney on the roof is not protected properly during rain. Sometimes, water drips also from the ceiling in correspondence to the wall between the apartment and the attic.

Table 4 - Examples of HVAC equipment installed in apartments

• Gas Boiler *BEOJTE WGB-KH* 	• Radiators *Stelard – Novoferm* 	• Electric water heater *Regent 50V EU2 50* 

2.3 Finnish demonstration site

2.3.1 Description

The Finnish demonstration site is in the city of Tampere, in Tapettikatu 13. The complex is owned by YH kodit, an organisation that supports BIM4EEB, and it is part of the Winter neighbourhood area, which is itself part of Epilä area. It consists of two buildings of 5 storeys each, with a total of 52 apartments with a total volume of 12700 m^3. The residences were built in 1998 with a reinforced concrete structure and a district heating system. It consists of two main distribution typologies (type "A" and type "B" apartments) and various common areas, besides storage rooms and technical spaces. It represents a very common solution of residential building in Finland, proving to be a suitable demonstration site.

Geometric and topological data about the generic aspect of the building for preliminary assessments are available, while data regarding apartments are extracted from original 2D drawings.

This demonstration site wants to demonstrate information collection from existing residential building through fast mapping techniques and use that information as input for BIM and to apply BIM data at construction site by coupling tradition BIM model data with scheduling, 4D, and logistics in order to reduce lead-time at site by 20%. In addition, it would enable energy performance simulation assessment and further promote the validation of this tool at the demo site.

As stated in [DoA], for demonstrating the improvements when adopting BIM4EEB methods and tools, the Finnish pilot case has been selected to:

- "*control energy consumption as well as indoor climate in existing residential building,*
- *perform economic evaluation,*
- *demonstrate simplified information collection from existing residential building and use that information as input for BIM models,*
- *enable BIM-based energy analysis for residential renovation projects,*
- *combine BIM with ERP system to provide BIM models updated along the whole lifecycle of the building,*
- *combine specified Building Automation equipment with BIM models to enable close to real time indoor climate and energy monitoring, and*
- *provide best practise examples*".

Figure 22 - Finnish demonstration site [DoA, 2018]

2.3.2 The adopted approach for apartments' choice

Finnish demonstration focuses on improving energy efficiency by heat recovery from exhaust air. Currently the ventilation ducts lead the exhaust air to the roof of the building where fans blow the air outside of building. The renovation activities can be carried out in common spaces outside of apartments. Thus, disturbance for tenants is minimized. However, some apartments will be equipped with sensors to ensure good indoor air quality. Quantities such as temperature, CO_2 and humidity will be controlled from selected apartments. The monitored apartments will be selected to cover different floors and point of the compass. The floor area of selected apartment varies from 59 m^2 up to 93 m^2.

With this approach, the selected apartments “A”, “B”, “C”, “D” and “E” present two main typologies presented below.

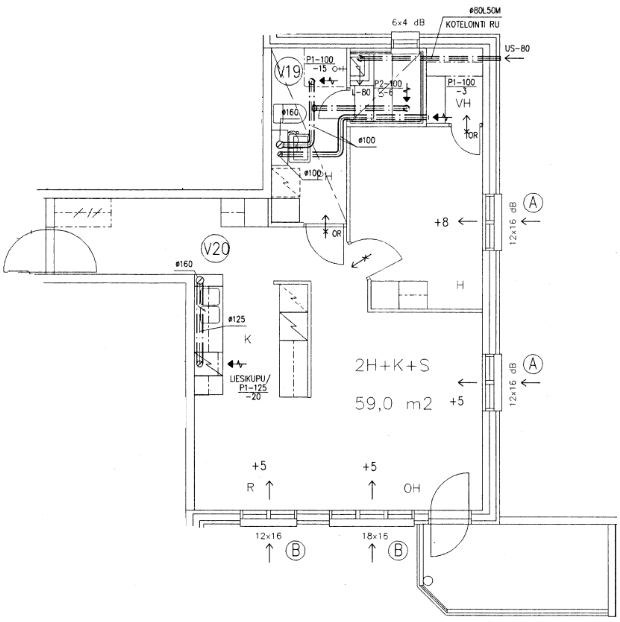

Figure 23 - Floor plan 1 with the type of apartments A, B and C

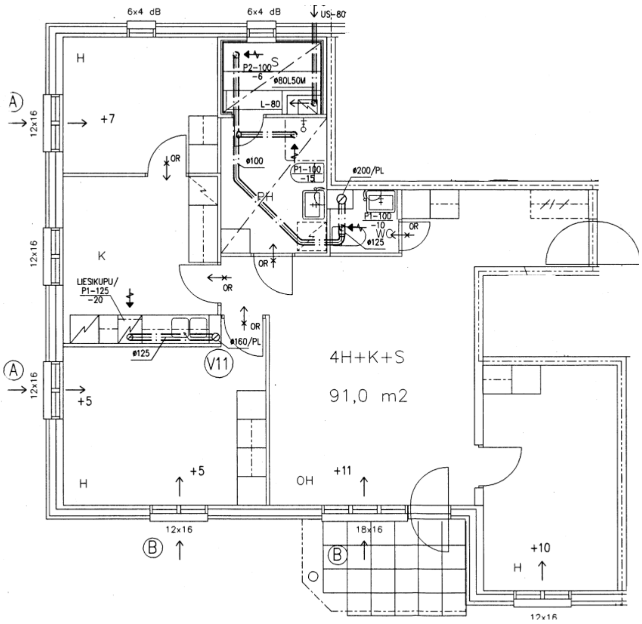

Figure 24 - Floor plan 2 with the type of apartments D and E.

3 The testing and validation methodology

BIM4EEB wants to offer a practical and easy-to-use toolkit for different stakeholders of the construction sector with the aim to increase the adoption of BIM in renovation businesses based on an interoperable flow of information. The BIM4EEB toolkit is composed of different tools that are connected thanks to the BIM management system (BIMMS).

In Figure 25 a general overview of the tools composing the toolkit and their relation is presented. The flow of information from different sources is represented by the arrows going from left to right. As *Sources*, the techniques or the processes of producing the information start the data flow and give input to the tools. The *Target users* are defined as the end users of the tools, as visible in Table 6. The *Output* of the tools is then uploaded or made available to the BIMMS through SPARQL queries. File formats are specified for every information exchange.

Considering Privacy, data are exiting BIMMS are considered as safe for privacy issues as they come in aggregated and pseudonymized form. The same principle is valid for BIM4Occupants and BIMcpd.

The BIM4EEB toolkit consists of the BIMMS platform and the different tools developed to serve the business functionalities envisioned in the project. The BIMMS platform is acting as the data management layer of the BIM4EEB platform that links, converts and stores data from heterogeneous data sources in the building environment. On top of the BIMMS platform, the BIM4EEB tools are developed as independent applications with their respective front-ends (User Interfaces), interchanging data with the BIMMS platform but also with 3rd party data sources and applications.

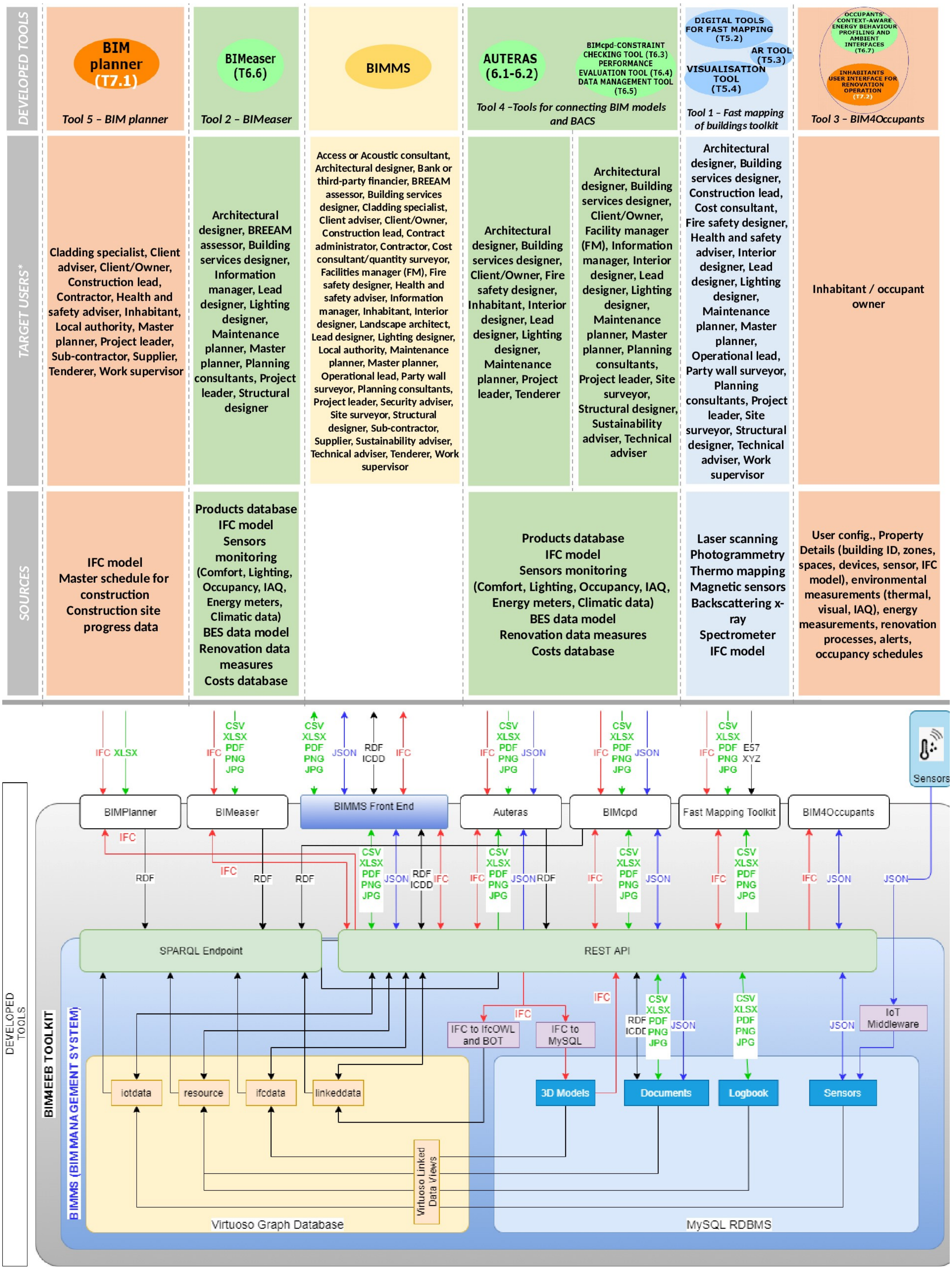

Figure 25 - General overview of the BIM4EEB toolkit

3.1 The BIM4EEB toolkit and applications

To test and validate the developed toolkit, different tools will be applied to each demonstration site as indicated in the table below.

Table 5 - Tools application on demonstration sites

Demo site	BIM Management system (BIMMS)	Tool 1 – Fast mapping of buildings toolkit	Tool 2 – BIMeaser	Tool 3 – BIM4Occupants	Tool 4 – Toolkit for connecting BIM models and BACS		Tool 5 – BIM Planner
					AUTERAS	BIMcpd	
Italian	X	x	x	x	x		x
Polish	X	x	-	x	x		-
Finnish	X	x	x	-	-		x

The main tools and applications by which the BIM4EEB toolkit will be composed of are:

3.1.1 BIM management system (BIMMS)

The BIM4EEB BIM Management System (BIMMS) is an open and interoperable data management platform. The internet-based environment enables information to be gathered from different sources throughout the building's life cycle. As specified in [D4.1, 2019] ,BIMMS core part is Common Data Environment (CDE) that acts as "*a single source of truth (SSOT), with dedicated interfaces and capabilities that work as a central repository enabling the data exchange with connected tools for providing better coordination among users and building process phases.*
All the data are shared and accessed with pre-established rules, traceable with historical records and revisions, and interoperable through service-based software interfaces. Building related geometry shall be stored and viewed as BIM Models using an AEC industry recognized standards as ISO 16739 Industry Foundation Classes IFC.
The BIM management system shall provide a set of Application Programming Interface (API) and Services specifically developed to give complete and interoperable access to the BIM4EEB project data. The BIM Management System shall be developed as a web platform and it will serve to all project partners to connect their tools and applications used and developed during the project".

As specified in [D4.1, 2019], the main BIMMS key elements are:

- **Resource management**: "*The main feature of the BMS is the possibility of insert, view and manage the information related to a renovation process. The BIM Management System shall then have an interface to upload and manage the resources stored in the CDE. Users will be able to see the list of resources stored in the CDE, and carry out basic operations like check their properties, download, copy, rename and manage document versions, according with their role permissions. The resource management services shall enable users to upload resources, define a property information their classification and mappings against linked data ontologies*".
- **SPARQL Endpoint**: "*Once the resources are inserted in the CDE, a SPARQL Endpoint enables to explore the resources stored in the CDE using SPARQL queries.*"
- **BIM Viewer**: "*Some of the users (e.g. designers, owners) shall be able to view 3D IFC model in a viewer. The viewer enable users to select model elements and view element properties, zoom in to selection, isolate, hide and unhide model elements. The elements in 3D model can be also selected from a hierarchical tree view and can be used to link the model items to linked data sources.*"
- **Ontology viewer**: it "*allows to view in a graphical form the ontological data stored to see how data is linked together and their relationships. This visualization tool will be useful to explore the richness of semantic nets, creating graph layouts of resources.*" The BIMMS implements the WebVOWL application as interactive viewer to explore in a web graph visualization form the ontology data stored in the BIMMS. The WebVOWL web application was developed by Vincent Link, Steffen Lohmann, Eduard Marbach, Stefan Negru, and Vitalis Wiens and it is registered

under MIT License (Vincent Link, 2014). The version used in the BIMMS is the 1.1.7 released in November 2019 at http://vowl.visualdataweb.org/webvowl.html.

3.1.2 Tool 1 - Fast mapping of buildings toolkit

The Fast Mapping of Buildings toolkit includes the development of quick mapping techniques and an Augmented Reality (AR) tool. The aim of developing a user-friendly AR tool is to create a tool that will be able to use existing geometrical drawings and installation schemes but also, during the mapping process, to add other parameters found in the building, or – if there are no available drawings – to generate easily not only simple 2D drawings but also BIM models of the building.

AR visualization tool [D5.3, 2020] "*is used to visualize detailed information about a placed virtual object, in this case hidden pipes and cords inside the walls and materials*". The data from the mapping done by the tool will be BIMMS tool as IFC file.

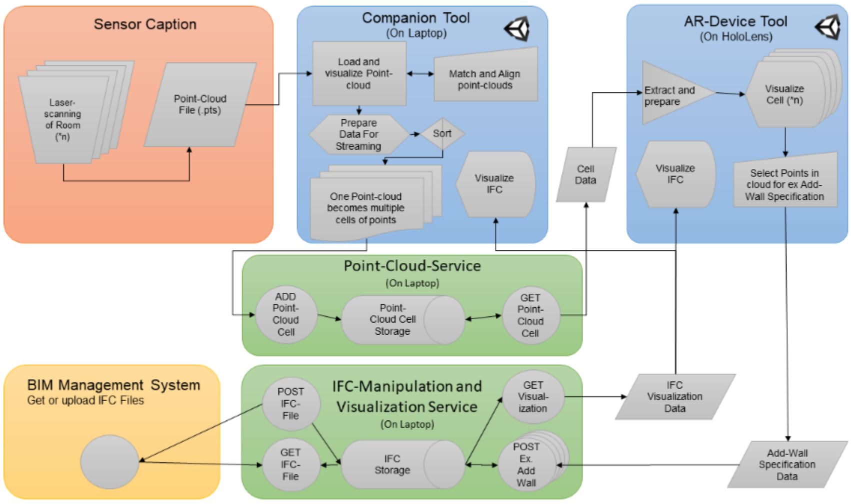

Figure 26 - The fast mapping of buildings toolkit [D5.2, 2019]

The fast mapping toolkit shall speed up the mapping process and visualize the building as a help for quality assurance in the building process. It combines monitoring techniques from laser scanning and mapping by a developed Sensorstick for identification of the building's geometric layout, installations and materials.

Its use during building renovations will speed up the renovation process with a quick, precise and effective mapping and the AR-tool will visualize a 3D-model of the mapped areas. The digital user-friendly AR-tool will visualize by HoloLens the 3D-model and transfer mapped data as an IFC-file. The data in IFC-format is then transferred into the BIMMS. The toolkit will be tested and used in all three demonstration sites during the project.

3.1.3 Tool 2 - BIMeaser

BIMeaser tool (BIM **Ea**rly **S**tage **E**ne**r**gy Scenario tool) is a BIM assisted energy refurbishment assessment tool (see also [D2.2, 2019]. [D6.6, 2020]). The BIM4EEB BIMeaser tool is designed to support the decision-making process in the **early design stage of the renovation process**. The tool enables the assessment of several energy refurbishment design options - so called scenarios - enabling architects and engineers to provide solutions that best fit to the client requirements while

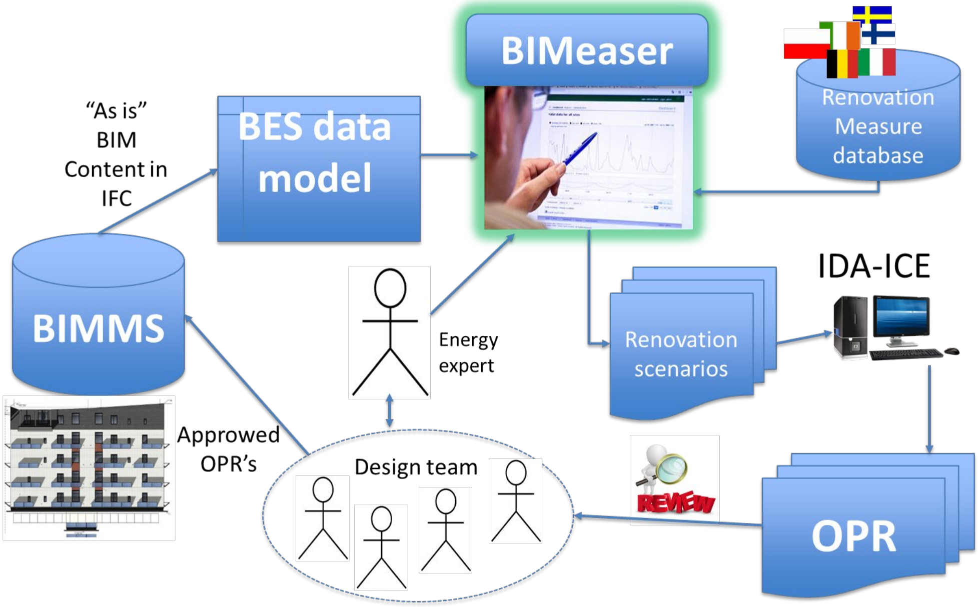

Figure 27 - General architecture of the BIMeaser Simulator tool [D6.6, 2020]

optimising the energy use and comfortable indoor climate conditions for occupants. BIMeaser tool enhances the functionalities of an existing energy simulator by using the BIM and linked data from the BIMMS to enable faster initialisation of the actual state of the refurbished building resulting to more accurate modelling. The user of the tool is a professional role called "*Energy expert*", which can be a separate consultant or one of the members in the design team e.g. Building Service designer.

The targeted design phases are: (1) *Concept design* and (2) *Preliminary Design.*

The main functionalities of the BIM4EEB BIMeaser tool are:

1. **Easy build-up of the "As-is" energy and indoor climate model** of the building by using the BIM and linked data for accurate modelling in the early design stage, where the most important design selections are made according to costs and performance.
2. **Apply the renovation scenarios** to the "As-is" building. The BIMeaser tool **enhances the collaborative work** of the design team in the early stage of the design, which usually lacks the sophisticated indoor climate modelling tools. The indoor climate and energy design is a multi-domain challenge and it should always be considered as a team work.
3. Present the **impact of each renovation scenario in terms of Owners Project Requirements (OPR)**. The OPR's - e.g. operational energy cost, payback time of renovation and summer thermal comfort - are important part of the **performance-based building design** process, which assumes that design selections are validated according to the OPR's in each design stage before moving to a following design stage. The design team will handle the detailed technical energy selections affecting to the OPR's using the tool as part of the collaborative work.

The tool will use EQUA's IDA Indoor Climate and Energy as a simulation engine. However, the tool is separated from the simulation engine.
BIMeaser needs a connection to the BIM Management system to request the "As is"-stage of the building to be renovated (*the energy and indoor climate related subset of the building BIM data*). The tool will also need to store the simulation results and OPR's into the "As is" model in BIM management system. The high level OPR's will be stored in RDF format and if more detailed information - like hourly simulation results of energy and indoor climate conditions - is needed the export format is CSV.

3.1.4 Tool 3 - BIM4Occupants

A key innovation of the project is the incorporation of building inhabitants' preferences and needs in the overall renovation management framework with special focus about preserving their level of comfort. This key aspect was highlighted in WP3 through the definition of domain specific ontologies focusing on occupants' comfort and indoor air quality conditions preservation.

Towards this direction, a holistic occupancy profiling management solution is developed and tested on Italian and Polish demo sites on the way to incorporate comfort as a key aspect of the overall building management process and as a fundamental factor for the optimisation of energy performance of buildings.

An **occupants' context-aware behaviour modelling engine** is delivered in order to extract the comfort related preferences and non-preferences of inhabitants in building conditions. These models are not defined as static elements; in contrary the core part of the occupants profiling framework will continuously monitor and learn transparently the operational and inhabitants' behavioural patterns (user preferences). More specifically, the analytics engine continuously retrieves and utilises information streams from environmental and IAQ sensors installed in demo sites and along with information provided through the interaction with the users, the engine defines dynamic and context-aware occupants' profiles to be further exploited for simulation (and even more control optimisation) purposes, properly balancing energy performance with comfort and indoor quality requirements. The details of this analytics process are reported in D6.7 [D6.7, 2020].

In addition to the analytics engine, a user interface (end user application) is developed for the building occupants that will allow individual occupants to continuously provide relevant information regarding preferences, daily schedules, and control patterns. As stated, input feedback from the users will be utilized for fine graining the occupants profiling analytics engine. On the other hand, sample analytics over the indoor environmental conditions and total energy performance will be available to the end users in order to get better insights about building performance during and post renovation process. The details about the development of the ambient user interface which is associated with the occupants profiling engine are reported in D6.8 [D6.8, 2020].

3.1.5 Tool 4 - Toolkit for connecting BIM models and BACS

The tools developed in Work Package 6 (specifically in tasks 6.2, 6.3, 6.4 and 6.5) are intended to enhance the HVAC-Design, Operation and Efficiency Management [BIMcpd, 2020]. They contain three distinct intuitive applications, that will allow the user to:

- find recommended devices for required room automation functionality;
- find recommended positions for HVAC, lighting, and other devices;
- analyse data from sensors, energy bills and other sources (weather for example);
- manage the data above mentioned and create new data sets that they can share with other tools.

These tools were designed to ensure minimum complications for the user while maximising the outputs of each tool. Through a series of form wizards, the users are guided throughout each step.

Tool 4 for connecting BIM models and BACS is composed of:

1) **AUTERAS** (AUTomated Engineering of Room Automation Systems) that was developed for describing room automation functionality semi-automated by standardized function blocks and searching for suitable devices. AUTERAS workflow is divided in several steps:
    1. The user (automation planner etc.) chooses room automation functions, which have to be integrated in the different locations (e.g. rooms) of a building.

2. AUTERAS automatically generates a directed graph of connected standardized function blocks (German guideline VDI 3813) which describe the automation functionality. This graph is platform- and vendor-independent and can be used for the procurement process.
3. The next step of AUTERAS chain is the search process for suitable devices, which can fulfil the functionality described in the function block graph (step 2). The main challenge is the interoperability checking between the devices.
4. AUTERAS can also be used for renovation or retrofit scenarios. The existing devices in the system can be described and only devices for additional functionality will be searched and integrated in the existing system.

2) **BIMcpd** (where C stands for Constraints, P for Performance and D for Data) that is divided into the following modules as explained in [BIMcpd, 2020] and [D6.3. 2020]:

a. The **constraint checking tool** is *“designed to include as many references to building regulations as possible and calculations were made using recommended guidelines.”*

b. The **performance analysis tools** consist of separate modules:

- *Data viewer – “for viewing data uploaded in the data management module and apply outlier detection methods to the data*”;
- Measurement and Verification (M&V) – “*for creating a baseline model of the building prior to the implementation of Energy Conservation Measures (ECM’s) or building renovation; for documentation of improvements with creating of a reporting period model to calculate energy and other savings*”.

c. The **data management tool** is “*designed to reduce the time consumed in data entry, it allows users to map data uploaded to our database schema and make the data immediately useable in the performance analysis tools”* for evaluation of user comfort and systems performance. Moreover, *“new computer-aided solutions and approaches have been developed to enable the automated selection of interoperable BAC-devices to meet specified requirements. These approaches supporting both - the development process of a new BAC as well as the retrofit process of an existing BAC. Furthermore, this allows realization of backtracking processes along with new system modelling and adaptation of the existing system model*”.

3.1.6 Tool 5 - BIMPlanner

The BIMPlanner is a Linked Data based project management software for a fast tracking of activities that has been adapted for residential renovation projects and especially in case of energy retrofitting. The tool provides awareness of the statuses of the renovation activities providing transparency of the project progress. Hence, this will allow scheduling the site activities with shorter lead times to reduce the total construction duration while immediately taking control of possible deviations in implementation.

The main targets for the BIMPlanner tool are:

1. Set a master schedule of the construction phase as a baseline target for detailed planning;
2. Support weekly planning and progress control of site activities following location-based planning principles;
3. Support the management of actual work locations at site in order to notify occupants of ongoing work and reserved locations;
4. Inform the occupants of disturbances caused by planned construction work.

The master schedule will be uploaded in BIMPlanner and it is forwarded in detailed planning of the workflows in different work locations. The planning is detailed and task statuses are updated on weekly basis. The actual plans will be prepared with common tools which are familiar to users like desktop project management or spreadsheet software. The users are provided with planning template files and the prepared plans will be uploaded in BIMPlanner cloud service and converted into RDF format.

BIMPlanner is primarily addressed to main contractor to plan and control site activities. The week plans can be delivered to subcontractors for guidance or also for updating the start and Finnish statuses of week tasks to create near real time situational awareness of the work progress. The planning and execution data is available to other services as Linked Data following the workflow ontology developed in BIM4EEB project. BIMPlanner uses services provided by BIM Management System (BIMMS) like retrieving IFC-models for defining work locations or gathering contact information enabling to notify other stakeholders of safety issues and other site events.

With a tool developed in Task 7.2, the users will receive notifications and alerts about on-going works; moreover, they will receive safety hints and information (e.g. to avoid specific areas where works have not been finished yet, while, as planned in [DoA, 2018] "*enabling them to upload information that might be requested ad-hoc by contractors or any other relevant input they may consider useful, thus contributing to the constant and collaborative updating of BIM and as-built documentation*").

In addition, the building occupants can receive information about on-site work planning and schedules. Overall, the scope of this application is to enable building occupants as active participants during the renovation process. The core design principles for this user-friendly app should be like the same principles of the comfort/context related application as defined above (part of the human machine interface). The details of this application are described in deliverable D7.2.

Concerning the several target users in renovation process, their access/use to the five tools just described is indicated in the table below.

Table 6 - End-users of the tools

Target users	BIMMS	Tool 1 – Fast mapping of buildings toolkit	Tool 2 – BIMeaser	Tool 3 – BIM4Occupants	Tool 4 – Tools for connecting BIM models and BACS		Tool 5 – BIM Planner
					AUTERAS	BIMcpd	
Access consultant	x	-	-	-	-	-	-
Acoustic consultant	x	-	-	-	-	-	-
Architectural designer	x	x	x[1]	-	x	x	-
Bank or third-party financier	x	-	-	-	-	-	-
BREEAM assessor	x	-	x[1]	-	-	-	-
Building services designer	x	x	x[1]	-	x	x	-
Cladding specialist	x	-	-	-	-	-	x
Client adviser	x	-	-	-	-	-	x
Client/Owner	x	-	-	x	x	x	x
Construction lead	x	x	-	-	-	-	x
Contract administrator	x	-	-	-	-	-	-
Contractor	x	-	-	-	-	-	x
Cost consultant/ quantity surveyor	x	x	-	-	-	-	-
Facilities management (FM) adviser	x	-	-	-	-	x	-
Fire safety designer	x	x	-	-	(x)[2]	-	-
Health and safety adviser	x	x	-	-	-	-	x

Information manager	x	-	x[1]	-	-	x	-
Inhabitant	x	-	-	x	x		x
Interior designer	x	x	-		x	x	-
Landscape architect	x	-	-		-	-	-
Lead designer	x	x	x[1]		x	x	-
Lighting designer	x	x	x[1]		x	x	-
Local authority	x	-	-	-	-	-	x
Maintenance planner	x	x	x[1]	-	x	x	-
Master planner	x	x	x[1]	-	-	x	x
Operational lead	x	x	-	-	-	-	-
Party wall surveyor	x	x	-	-	-	-	-
Planning consultants	x	x	x[1]	-	-	x	-
Project leader	x	x	x[1]	-	x	x	x
Security adviser	x	-	-	-	-	-	-
Site surveyor	x	x	-	-	-	x	-
Structural designer	x	x	x[1]	-	-	x	-
Sub-contractor	x	-	-	-	-	-	x
Supplier	x	-	-	-	-	-	x
Sustainability adviser	x	-	-	-	-	x	-
Technical adviser	x	x	-	-		x	-
Tenderer	x	-	-	-	x	-	x
Work supervisor	x	x	-	-	-	-	x

x[1] BIMEaser is mainly used by the energy design team that can typically include these roles.
x² in general it is possible, but not included because of current missing standardization

3.2 The sensors set-up for data gathering from pilots

As stated above and in order to provide the functionality envisioned in the project through the different applications, hardware installations are going to be installed in the different demo sites. Therefore, a hardware topology was defined within the scope of this task to address the project requirements about:

- monitoring the indoor environmental conditions covering temperature, humidity, luminance and IAQ parameters
- monitoring the building and zone level energy consumption
- correlating the indoor environmental conditions with user presence related information.

To gather the acquired sensorial data for energy consumption, environmental ecosystem parameters and to provide appliance control where needed, a system gateway will be installed. The developed connecting tool to the BIM management system will ensure a permanent data transmission directly to the BIMMS and the different applications for further processing.

Along with the core functional requirements, additional non-functional requirements were analysed towards setting the final solution for BIM4EEB hardware set up. More specifically:

- Adaptability: the overall design must ensure that it will be able to serve the needs of each individual pilot end user.
- Modularity: the software architecture will be designed focusing primarily to reduce complexity. The solution should be based on logical partitioning allowing to be manageable for the purpose of implementation and maintenance.
- User needs and acceptance: the pilot users and, thus, owners must accept the technology and willing to participate in the project as pilot users.

Therefore, the hardware solution was chosen to be:

- a plug-and-play device ensuring ease of installation
- a user-friendly device in both aesthetic and ease of use criteria
- a secure solution: given the fact that the selected WSN topology will provide control functionality (automated / ad hoc), only technologies that implement sophisticated security mechanisms have been considered
- a reliable solution: using a network that has a high probability to work continuously and properly in a time interval, capable to unceasingly deliver an accurate service
- bearable from an economic point of view: a compromise had to be found between the availability of low-cost sensors and the data and related parameters that need to be gathered towards meeting scope and ensuring that its goals will be demonstrated, to the extent possible, in the pilot users
- Well-known, well-established, and mature solution: the hardware deployment is, in fact, not part of the core innovation of the project and thus a maturity on the adopted technologies with a supporting active community is expected. Although there are emerging technologies (e.g. 6LoWPAN) that seem very promising, the maturity of their implementation is a remaining issue. In addition, we need to select a standardized approach for the WSN topology of the project. For example, there are some RF-based efforts that focus mainly on energy efficiency, though these are customized approaches with minimum support and deployment scale and thus are not examined in our analysis.

Monitored data can therefore be used by other tools as below indicated.

Table 7 - Sensors data and necessary tools

Measured data	Sensor	Tools that use these data					
		BIMMS	Tool 1 – Fast mapping of building toolkit	Tool 2 – BIMeaser	Tool 3 – BIM4Occupants	Tool 4 – Tool for connecting BIM models and BACS	Tool 5 – BIM Planner
Temperature (°C)	Multipurpose sensor "A"	x	-	x[1]	x	x	-
Relative humidity (%)		x	-	-	x	x	-
Occupancy (1/0)		x	-	x[1]	x	x	-
Illuminance (lux)		x	-	x[1]	x		-
CO_2 (ppm)	Multipurpose sensor "B"	x	-	x[1]	x	x	-
PM2.5 (µg/m^3)		x	-	-	x	-	-
VOC (ppb)		x	-	-	x	-	-
Energy meter	Electricity meter	x	-	x[1]	-	x	-
	Heat meter	x	-	x[1]	-	x	-
Gas meter	Gas meter	x	-	-	-	x	-

[1] BIM assisted energy performance assessment tool will utilise data that includes temperature and ventilation setpoints and thermal load profiles from lighting, appliances, and people. That input data can be defined by taking in the account the measured data. However, converting measurements to input data profiles is not included in the tool, but needs to be done with other means in the design team. The possibilities to utilise the measured data will be tested in T6.8.

Table 8 - Other data and necessary tools

Other data	Tools that need these data					
	BIMMS	Tool 1 – Fast mapping of buildings toolkit	Tool 2 – BIMeaser	Tool 3 – BIM4Occupants	Tool 4 – Tool for connecting BIM models and BACS	Tool 5 – BIM Planner
Geometry (ifc, rvt, rta, nwc, nwd, dwg, dxf, or through SPARQL/ IFCOWL	x	x	x	x	x	x

queries)						
Point cloud (rcp, rcs)	x	x	-	-	-	x
Inhabitants preferences (xls)	-	-	-	x	-	-

By considering the aforementioned criteria, an assessment of different ready-made topologies and set ups was performed. Different wireless topologies (Wi-Fi, Zwave, Zigbee), different product vendors and market ready components were considered. The selected solution fully meets the requested criteria, but of course it is not the only option that satisfy the requirements: the BIM4EEB toolkit is interoperable so it can be used with different solutions.

The below described market available gateway was selected because it enables the integration of different sensors and metering devices, allowing ad hoc developments to facilitate any customization required in the project. In addition, the different types of sensorial technology were individualised. The chosen set-up is the same for the Italian and polish demo sites, while in the Finnish demo site another set up will be used because there it is possible to exploit the IoT radio solution network called Sigfox. In case of difficulties in purchasing the below described sensors, they can be easily substituted with compatible alternatives.

3.2.1 The Italian and Polish sensors set-up

The hub

Figure 28 - The chosen hub

(https://www.smartthings.com/products/smartthings-hub)

SmartThings is a home automation technology by Samsung that allows the user to manage and connect different IoT devices including small and large appliances, sockets, motion and humidity sensors, surveillance cameras, TV, etc. The SmartThings Hub is a central unit for remote management of several compatible home automation devices, compatible with other several sensors of different manufacturers because it supports also Bluetooth, Z-Wave and Zigbee, so this hub is a product compatible with a wide and growing range of devices. The device is managed through a specific app for iPhone or Android that, once downloaded and logged in, will automatically search for nearby supported devices. SmartThings allows not only the management of individual home devices connecting wirelessly with them, but it also makes them work together, monitoring and managing them remotely.

Table 9 - Technical data SmartThings Hub

Model Number	GP-U999SJVLGDB, GP-U999SJVLGDA
Colour	White
Protocol	ZigBee, Z-Wave, Cloud-to-Cloud, LAN, ZigBee3

Dimensions	5.0" x 5.0" x 1.2"
Weight	4.8 oz
Power Source	Wall-Powered

Therefore, the management and connection to the sensors applied in the demonstration sites to measure the various performance has been allowed by this specific hub just described. The already available API and a developed specific connecting tool allow then to read and store the monitored data inside the BIM management system.

- **MULTIPURPOSE SENSOR “A”: temperature, humidity, occupancy, lighting**

Figure 29 - Z-Wave Multisensor (https://aeotec.com/z-wave-sensor/)

The sensor "Z-Wave Plus Multisensor 6" by Aeotec offers an integrated solution for staying connected with its own house providing real time updates and notification. Though a 6 in 1 Z-Wave Plus sensor registers occupancy, temperature, humidity, light, UV and vibration measurement, we focus only on the first four data. It's small in size (42 mm) and very light: it can be used on a shelf, in a corner, within a wall cavity or on a wall as a beam sensor. It can be powered in two different ways: by batteries (the device delivers 50% more battery life, with the average lifespan extended to two years) or via a USB cable and adapter.

Regarding the **occupancy**, MultiSensor 6's motion sensor has 5 metres range and a 120° field of view to capture motion data. Then, MultiSensor 6 comes equipped with a calibrated sensor that can monitor indoor **temperature** in the range of -10~50°C. It allows to look at house's heating, controlling motorised curtains, windows, fans and thermostats.
In addition, the sensor checks moisture and **humidity** offering a monitoring of a humidity ranging from 0% to 100%. It is possible to see the humidity levels and automatically configure fans, air-conditioners or dehumidifiers to maintain the perfect environment.
Finally, it detects ambient **lighting**. Its digital light sensor allows to detect the ambient lighting in a room and configure home automation system to open or close curtains, or control the installed lights and dimmers based on its own home's illumination.

The technical details of Aeotec Z-Wave Plus Multisensor 6 are reported in the table below.

Table 10 - Technical data Multipurpose sensor "A"

Technology	Z-Wave Plus (868.42MHz)
Clamp Rating	60A with 1% accuracy
Clamp size	Fits cables up to 10mm
Metering	Current consumption (W) and accumulated consumption (kWh)
Measured temperature range	-10°C to 50°C
Temperature Accuracy	±1°C
Measured humidity range	20%RH to 90%RH

Humidity Accuracy	±3%RH (at 25°C/77°F)
Operating humidity	8% to 80%
Operating temperature	0°C to 40°C
Lighting	0 LUX to 30000 LUX
Max motion sensitivity	5 metres. 15 feet.
Rating	IP43 - withstands most outdoor weather conditions
Dimensions (LxWxH)	108 x 67 x 30mm (unit)
Power	230VAC, 50Hz, 10mA

Outdoor environment data will be considered too, using external weather databases, or adding a weather station to SmartThings.

- **MULTIPURPOSE SENSOR "B": CO_2, PM2.5, VOC sensor**

Figure 30 - CO_2, PM2.5, VOC sensor (https://getawair.co.uk/?currency=eur)

Awair created a device that tracks fine dust and chemicals in the air giving the user personalized recommendations about safety and healthy. Awair's sensors are designed and tested to measure **CO_2** with a range of 400-5000ppm, **TVOCs** from 0 to 60000 ppb and **PM2.5** considering an interval of 0-1000 µg/m^3. Beside these key factors of air quality, Awair allows the measurement of temperature and humidity too. The air quality can be seen on the Awair display or in the Awair app. The multipurpose sensor also works with other devices like Nest, Alexa and Google Home.

Table 11 - Technical data Multipurpose sensor "B"

Sensors	Fine dust (PM2.5): 0-1000 $\mu g/m^3$ ± 15 $\mu g/m^3$ (or ± 15%) Chemical (TVOCs): 0-60000 ppb ± 10% CO_2: 400-5000 ppm ± 10% Temperature: - 40 to 125°C ± 0,2°C Humidity: 0-100% ± 2% RH Ambient light: 0,96 to 64000 lux Ambient noise: sensitivity -26BFS; SNR (signal to noise radio): typical 61 dB (A-weighted, 20 Hz-20 kHz)
System requirements	Wi-fi connection Smartphone or table with IOS 9 or later, or Android 4.4 or later
Wireless	Working wi-fi connection: 802.11 b/g/n @ 2,4 GHz (single stream) - IEEE 802.11b: 1 - 11Mbps - IEEE 802.11g: 6 - 53Mbps - IEEE 802.11n: 7.2 - 150Mbps Bluetooth 4.1 (Bluetooth Low Energy) Sub-1GHz - 868 MHz (EU) and 915 MHz (US) ISM - Excellent Receiver Sensitivity –124 dBm, (–110 dBm at 50 kbps) - Programmable Output Power up to +26 dBm
Power	Input: AC 100/240V, 50/60Hz - Output: 5V/2.0A external power adapter
Dimensions	160 x 50 x 90mm (LxWxH)

- **Electricity meters**

Figure 31 - Z-Wave Plus Home energy meter Gen5

(https://aeotec.com/z-wave-home-energy-measure/)

The smart meter "Z-Wave Plus Home energy meter Gen5" by Aeotec records up to 200 amps of house electricity use in real-time with 99% accuracy. The device allows to meter current energy consumption (W) and the accumulated consumption (kWh). Paired with Z-Wave gateway, it is possible to identify and diagnose which electronics in the house are costing the most and then actionable steps to reduce them could be taken.

It is built upon wireless technology, utilising Z-Wave Plus and Gen5. Without interference, Home Energy Meter can transmit data over a distance of 150 metres.

The technical details of Z-Wave Plus Home energy meter Gen5 are reported in the table below.

Table 12 - Technical data Home energy meter Gen5

Technology	Z-Wave Plus (868.42MHz)	Measurement Accuracy	Over 99%
Clamp Rating	60A with 1% accuracy	Operating humidity	8% to 80%
Clamp size	Fits cables up to 10mm	Operating temperature	0°C to 40°C
Metering	Current consumption (W) and accumulated consumption (kWh)	Rating	IP43 - withstands most outdoor weather conditions
Power	230VAC, 50Hz, 10mA	Dimensions (LxWxH)	96 x 70 x 230mm

The sensor “Z-Wave Data Logger for E-meters” by NortQ allows to read meter values from mechanical and electronic meters with precision to 0.1kWh. . The unit reports a meter reading to the Z-Wave network controller every 15-minutes. It has an internal memory of 512 KB and if there is not a Z-Wave network, the device can store the acquired data for 3 months. The device is provided with an internal battery 2AA.

Figure 32 - Z-Wave Data Logger for E-meters

(http://manual.zwave.eu/backend/make.php?lang=en&sku=NOQ_NQ-9021)

On a mechanical meter, the electricity consumption is read by using a rotating disc seen at the front of the meter. The disc rotates a certain number of times per kWh. On an electronic meter, the electricity consumption is read by using an LED that blinks a certain number of times per 1 kWh.

Table 13 - Technical Data Logger for E-meters

Technology	Z-Wave Transmitter (868.42MHz)	Routing	No
Sensor	Contact sensor for reading meter	FLiRS	No
Internal Memory	512KB (equivalent to 3-months meter readings)	Firmware Version	2.55
Power	Internal battery (included) 2 * AA	Dimensions (LxWxH)	93x73x34 mm
Software	Windows application software to analyse meter readings	Weight	144 gr
Explorer Frame Support	No	EAN	5707162002242
SDK	5.02 pl3	Z-Wave Version	02.4e
Device Type	Slave with routing capabilities	Certification ID	ZC08-11060002
Generic Device	Class Meter	Frequency	Europe - 868,4 MHz
Specific Device Class	Simple Meter	Maximum transmission power	5 mW

- **Remote thermostat used in Italian pilot site: heat cost allocator with thermostat valve**

In Italian pilot site, simultaneously with boilers replacement, thermostatic valves, and heat cost allocator for the metering of heat were installed on each radiator present within each single apartment. In particular, “566 series heat cost allocators” by Watts have been chosen in order to meter heating. This specific heat cost allocator is suitable for installation on any type of radiator in use in buildings equipped with centralised heating system with risers and other typologies in which direct heat accounting cannot be adopted.
Installed together with the thermostatic valve (see paragraph 2.1.1) allows the detection of the heat actually used in each room and the breakdown of heating costs according to the actual consumption of each unit on the one hand and the possibility to reduce heating costs by adjusting the temperature in each unit of apartment according to real needs on the other hand.

Figure 33 - 566 Series heat cost allocator

(https://wattswater.it/catalog/heat-measuring/ripartitori/)

The advanced two-way radio technology of the 556 Series Distributors ensures excellent signal coverage and a high-quality remote communication for parameterization and reading. Parameterisation is possible at any time after installation, from the outside of the building and also in motion (Walk By), via the radio interface Modem 636 in combination with a PDA handheld via Bluetooth or in pairing with a PC/laptop/Windows tablet via Bluetooth that allows you to avoid entering the apartments by reducing the time of setting up the accounting system. The consumption reading is active only on demand, from 6.00 to 18.00, resulting in reduced battery consumption. Previously installed in the building of the concentrator WATTS GSM/GPRS 646, in the amount of 1 per 1000 radio devices, the reading can also be done from fixed station equipped with PC and modem suitable for communication via GSM or with download, via GPRS, to FTP internet partition freely configurable.

Among the specific technical information supplied by the table below, it could store 18 biweekly values or 36 monthly values of radiator temperature.

Table 14 - Technical data 566 Heat cost allocators

Maximum power of radiator	16.000 W
Switchover temperature in heat storage mode	28°C (Maximum ambient temperature) winter period
Beginning counter temperature	25°C (Radiator temperature) winter period
Bidirectional communication	433,82 MHz, 10mW (parameterization and reading)
Counting cycle	4 min
Lithium battery, life span up to 10 years.	3V
Multifunction display	LCD 6 digits
Length cable (external probe)	1,75 m
Function test	Automatic with malfunction and/or tampering display

- **Gas meter**

The sensor “Z-Wave Data Logger for Gas-Meters" by NorthQ is designed to read data from magnetic or electronic meters equipped with optical ports. It can be installed close to any gas meter because of its small size and its wireless external transmitter; it is powered by batteries and it transmits data to the Z-Wave network controller every 15-minutes. The gas meter keeps track of gas consumption, allowing to have an overview of home gas consumption and at the same time change consumption habits and savings.

Figure 34 - Z-Wave Data Logger for Gas meter

(http://manual.zwave.eu/backend/make.php?lang=en&sku=NOQ_NQ-9121)

Table 15 - Technical data Data Logger for Gas meter

Technology	Z-Wave Transmitter (868.42MHz)
Sensor	Contact sensor for reading meter

Internal Memory	512 KB (equivalent to 3-months meter readings)
Power	2 AA batteries
Battery lifespan	10 to 15 months
Software	Windows application software to analyse meter readings
Explorer Frame Support	No
SDK	5.02 pl3
Device Type	Slave with routing capabilities
Generic Device	Class Meter
Specific Device Class	Simple Meter
Routing	No
FLiRS	No
Firmware Version	2.55
Dimensions	93x73x34 mm
Weight	149 gr
Hardware Platform	ZM3102
EAN	5707162002310
Z-Wave Version	5.02 (PATCH 3)
Certification ID	ZC08-11060002
Frequency	Europe - 868,4 MHz
Maximum transmission power	5 mW

3.2.1.1 Sensors distribution in Italian and Polish demonstration site

The above-described sensors and meters will be installed in the Italian and Polish pilot sites as indicated in the following table.

Table 16 - Sensors distribution for the Italian pilot site

		Apartments																											
		1 (A38 PT)		2 (A4 PT)			3 (A2 PT)		4 (A46 P3)			5 (A47 P3)		6 (14 P3)		7 (A13 P3)			8 (A59 P6)		9 (A60 P6)			10 (A30 P6)			11 (A32 P7)		
DEVICES		living room	bedroom	living room	bedroom	bedroom	living room	bedroom	living room	bedroom	bedroom	living room	bedroom	living room	bedroom	living room	bedroom	bedroom	living room	bedroom	living room	bedroom	bedroom	living room	bedroom	bedroom	living room	bedroom	bedroom
Multisensor	Temp	x	x	x	x	-	x	x	x	x	-	x	x	x	x	x	x	-	x	x	x	x	-	x	x	-	x	x	-
	Humidity	x	x	x	x	-	x	x	x	x	-	x	x	x	x	x	x	-	x	x	x	x	-	x	x	-	x	x	-
	Occupancy	x	x	x	x	-	x	x	x	x	-	x	x	x	x	x	x	-	x	x	x	x	-	x	x	-	x	x	-
	Luminance	x	x	x	x	-	x	x	x	x	-	x	x	x	x	x	x	-	x	x	x	x	-	x	x	-	x	x	-
IAQ Sensor	CO2	x	-	x	-	-	x	-	x	-	-	x	-	x	-	x	-	-	x	-	x	-	-	x	-	-	x	-	-
	PM2.5	x	-	x	-	-	x	-	x	-	-	x	-	x	-	x	-	-	x	-	x	-	-	x	-	-	x	-	-
	PM10	x	-	x	-	-	x	-	x	-	-	x		x	-	x	-	-	x	-	x	-	-	x	-	-	x	-	-
	VOC	x	-	x	-	-	x	-	x	-	-	x	-	x	-	x	-	-	x	-	x	-	-	x	-	-	x	-	-

Thermostatic vale[1]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Electric power meter	x		x			x		x			x		x		x			x		x			x			x		
GAS meter	-		-			-		-			-		-		-			-		-			-			-		
HUB	x		x			x		x			x		x		x			x		x			x			x		
Internet connection	x		x			x		x			x		x		x			x		x			x			x		

Table 17 - Sensors distribution for the polish pilot site

		Apartments							
		D1/2		D1/4	D1/5		D1/6A		D1/10A
DEVICES		D1/2.2 living room	D1/2.3 bedroom	D1/4.4 living room	D1/5.4 living room	D1/5.2 bedroom	D1/6A.5 living room	D1/6A.8 bedroom	D1/10A.2 living room
Multisensor	Temp	x	x	x	x	x	x	x	x
	Humidity	x	x	x	x	x	x	x	x
	Occupancy	x	x	x	x	x	x	x	x
	Luminance	x	x	x	x	x	x	x	x
IAQ Sensor	CO2	x	x	x	x	-	x	x	x
	PM2.5	x	x	x	x	-	x	x	x
	PM10	x	x	x	x	-	x	x	x
	VOC	x	x	x	x	-	x	x	x
Thermostatic valve[2]		x	x	x	-	-	-	-	x
Electric power meter		x		x	x		x		x
GAS meter		x		x	x		x		x
HUB		x		x	x		x		x
Internet connection		x		x	x		x		x

3.2.2 The Finnish sensors set-up

Finnish demo will use SigFox NB-IoT sensors (narrow-band internet-of-things). The system is based on radio network that is available in many European countries. In Finland, the system is operated by Connected Finland.
Data will be transmitted directly from sensors to the Sigfox cloud service by using Sigfox Iot network and they will be available for application immediately after measurement. API for the cloud is available at: https://support.sigfox.com/docs/api-documentation. Because each sensor sends information independently, no hub is needed.
Since each sensor can communicate directly with the cloud, there is no need to install and maintain any additional network in the building. The installation and maintenance work on site are limited to taping the sensors into walls and changing batteries after some years of operation.

Data will be collected from Sigfox cloud service into Caverion service platform for the remote management of buildings. BIM Management System can read the data from service platform through an API. Pseudonymisation of the data will be done in service platform according to GDPR.

[1] On each heat radiator it is also installed a heat cost allocator (data are periodically downloaded in csv format)
[2] As it will be necessary to replace existing heaters valves, this integration is strongly related with consent of the inhabitants. We will investigate this issue, we can't confirm at this stage. We have in mind that this equipment could give us more precise heaters consumption. This is also some additional cost for our senor's budget, which is limited.For now maybe in our report thermostatic valves we can put as a option?

Quantities to be measured from selected apartments: Temperature, humidity and carbon dioxide. In addition, other quantities are measured in common spaces: Air pressure before inside ventilation duct, temperature inside ventilation duct both before and after heat recovery, power consumption of heat recovery system.

- **MULTIPURPOSE SENSOR: CO_2, temperature, humidity**

Figure 35 - CO_2, temperature, humidity sensor

(https://www.connectedfinland.fi/en/products/connected-airwits/)

Sensors are available for multiple purposes, such as "Connected AirWits CO_2 RC1" that measures **carbon dioxide** (CO_2), **temperature** and **humidity** metering device. The device measures and sends the CO_2, temperature (range of -20/+50°C with +/- 0.3°C accuracy) and humidity (range 0/95% with +/- 3% accuracy) once in every 30 minutes. AirWits CO_2 uses worldwide Sigfox IoT-network for data transmission. The product features are listed below.

Table 18 - Technical data Multipurpose sensor

Size	80 x 80 x 27 mm
Weight	110g
Sensor	Sensirion SHT30
Battery pack	AA 3,6V
Battery life	5 years
Temperature range	-20…+50°C
Humidity range	0…95%
Accuracy	+/- 0.3C, +/- 3%
Connectivity	Sigfox 868 MHz
Operating zone	RCZ1 Europe
Certifications	CE, Sigfox
Warranty	2 years
Product code	CS-TRH-2

- **Sensors in HVAC systems**

Several quantities are measured in technical spaces. Such as quantities are air pressure, temperature inside ventilation duct both before and after heat recovery, power consumption of heat recovery system. The sensors to control heat recovery system will be located in technical spaces, such as heat distribution room. Those sensors will be connected with bus.

Figure 36 - Humidity transmitter

"Produal KLK 100" duct humidity transmitters are designed for measuring humidity and temperature inside ventilation ducts.

(https://www.produal.com/shop/web_humidity_transmitters/sku-1132240)

Table 19 - Technical data Humidity transmitter

Product number	1132240
EAN	6419767001498
Supply	24 Vac/dc, < 1 VA

Range (humidity)	0...100 %rH
Range (temperature)	-50...50 °C
Output (humidity)	0...10 Vdc, 2 mA, / 4…20 mA < 600 Ω
Output (temperature)	0...10 Vdc, 2 mA, / 4…20 mA < 600 Ω
Output (control)	humidity or temperature output can be configured to control output
IP protection class	IP54, cable or probe downwards
Ambient temperature	-50...50 °C
Cable gland	M16
Mounting	with flange, probe depth adjustable < 150 mm
EAN13 code	6419767001498

Produal "IML" is made for measuring and controlling air volumes in air handling units and room spaces. The transmitter includes pre-set settings for most common fan models and a common formula for air flow volume. The display shows alternately either air volume or differential pressure or the desired variable can be locked on the display. The transmitter zero point is kept accurate by using the regular automatic zeroing, eliminating the possible zero-point drifting. The range of measuring can be chosen at commissioning from four different ranges (0...1000, 0...2000, 0...5000 or 0...7000 P).

Figure 37 - Air flow transmitter

(https://www.produal.com/shop/web_transducers_and_accessories)

Table 20 - Technical data Air flow transmitter

Product number	1131600
EAN	6419767001368
Supply	24 Vac/dc, < 1.5 VA
Input	0…10 Vdc, < 2 mA (external set point)
Range	0...1000, 0...2000, 0...5000 or 0...7000 Pa
Time constant	1...20 s (factory setting is 8 s)
Output (air volume)	0...10 Vdc, 2 mA
Output (diff. pressure or control)	Output 0...10 Vdc, 2 mA
Zeroing	automatic; regularly eliminates the possible zero-point drifting
IP protection class	IP54, cable downwards
Ambient temperature	0...45 °C
Cable gland	M16
Mounting	with screws, external lugs
Modbus	-
EAN13 code	6419767001368

"Produal PEL 2500" is a pressure transmitter for measuring pressures and pressure differences in air handling systems. The pressure measurement is temperature compensated according to the ambient temperature.

Figure 38 - Differential pressure transmitters for air

(https://www.produal.com/shop/web_differential_pressure_transmitters_for_air/sku-1131210)

Table 21 - Technical data Differential pressure transmitters for air

Product number	1131210
EAN	6419767000743
Supply	24 Vac/dc, < 2 VA
Range	0...100, 0...200, 0...500, 0...1000, 0...1500, 0...2000, 0...2500 or ±100 Pa
Time constant	2 s or *8 s
Output	0...10 Vdc, 2 mA
Output	4...20 mA, 700 ohm
Zeroing	automatic; regularly eliminates the possible zero-point drifting
IP protection class	IP54, cable downwards
Ambient temperature	0...45 °C
Cable gland	M16
Mounting	with screws, external lugs
Dimensions	105 x 102 x 46 mm
EAN13 code	6419767000743

“Produal TEKA NTC10” temperature sensors are made for measuring the average temperature in a large air duct.

Figure 39 - Temperature sensor

(https://www.produal.com/shop/web_ntc_10_sensors/sku-1175130)

Table 22 - Technical data Temperature sensor

Product number	1175130
EAN	6419767005984
Nominal resistance	10 kΩ / 25 °C
Range	-50...70 °C
IP protection class	IP54, cable or probe downwards
Length	3 m
Cable gland	M16
Mounting	with flange and springs
Materials	PBT, PC, PA, stainless steel

Modbus	-
EAN13 code	6419767005984

“Produal TEAT NTC10” temperature sensors are designed for measuring heating and cooling water temperatures in HVAC automation systems. The sensors can also be used for air temperature measurements from ventilation ducts, for example.

Figure 40 - Temperature sensor

(https://www.produal.com/shop/web_ntc_10_sensors/sku-1175070)

Table 23 - Technical data Temperature sensor

Product number	1175070
EAN	6419767005830
Nominal resistance	10 kΩ / 25 °C
Range	-50...120 °C
Time constant	5 s
Accuracy	±0,2 °C (25 °C)
Probe	Ø 6 x 85 mm
IP protection class	IP54, cable or probe downwards
Cable gland	M16
Mounting	water applications: with Produal pocket (R½”), air applications: with MT4270 flange
Materials	PBT, PC, PA, acid proof steel
Mounting depth	80 mm; 50, 100, 150, 200, 250, 300, 350 and 450 mm mounting depths also available. To order these sensors, add the depth to the product type (e.g. TEAT NTC 10-300)
Modbus	-
EAN13 code	6419767005830

“Produal VPL 16” pressure transmitter (3-wire) for heating and cooling systems. VPL 16 has four selectable ranges up to 16 bar.

Figure 41 - Pressure transmitter

(https://www.produal.com/shop/web_water_pressure_transmitters/sku-1134050)

Table 24 - Technical data Pressure transmitter

Product number	1134050
EAN	6419767001863
Supply	24 Vac/dc, < 1 VA
Range	0...2,5, 0...6, 0...10 or 0...16 bar
Output	0...10 Vdc, 2 mA, / 4...20 mA, 800 Ω
IP protection class	IP54, cable or probe downwards
Ambient temperature	0...60 °C
Cable gland	M16
EAN13 code	6419767001863

"Produal TEU NTC10" temperature sensors are designed for automatic HVAC systems to measure outdoor temperature.

Figure 42 – Outdoor temperature sensor

(https://www.produal.com/shop/web_ntc_10_sensors/sku-1175090)

Table 25 - Technical data Temperature sensor

Product number	1175090
EAN	6419767005953
Nominal resistance	10 kΩ / 25 °C
Range	-50...50 °C
IP protection class	IP54, cable downwards
Cable gland	M16
Mounting	with screws on wall, external lugs
Materials	PBT, PC, PA
EAN13 code	6419767005953

Figure 43 - Energy meter

(https://www.aquip.com.au/wp-content/uploads/2017/05/MULTICAL-%C2%AB-603-Data-Sheet-English.pdf)

“Kamstrup Multical 603” is suitable as heat meter, cooling meter or combined heat/cooling meter together with 1 or 2 flow sensors and 2 or 3 temperature sensors for residential and industrial buildings. It has 2 flow sensor inputs that can be used for both electronic and mechanical flow sensors. The pulse figure can be programmed from 0.001 to 300 pulses/liter, and the calculator can be programmed to all nominal flow sensor sizes from 0.6 to 15,000 m³/h.

The data logger is programmable to deliver yearly, monthly, daily, hourly and minute values. Multical 603 is powered by an internal D-cell lithium battery with a lifespan of up to 16 years or a 2xAA lithium packet with a lifespan of up to 9 years.

Ambient temperature	5…55 °C non-condensing, closed location (installation indoors)
Storage temperature	25…60 °C (drained flow sensor
Connection cable	ø3.5…6 mm
Supply cable	ø5…8 mm
Battery	D-cell lithium with 16 years lifetime

3.2.2.1 Sensor distribution in Finnish demonstration site

The above-described sensors and meters will be installed in the Finnish pilot sites as below indicated.

Table 26 - Sensors distribution for the Finnish pilot site

		Apartments					Common spaces
		A	B	C	D	E	
DEVICES		Living room	Living room	Living room	Living room	Living room	
Multisensor	Temp Humidity CO_2	x	x	x	x	x	-
Sensors in HVAC systems	Humidity transmitter	-	-	-	-	-	x
	Air flow transmitter	-	-	-	-	-	x
	Differential pressure transmitters for air	-	-	-	-	-	x
	Temperature sensor	-	-	-	-	-	x
	Pressure transmitter	-	-	-	-	-	x
	Outdoor temperature sensor	-	-	-	-	-	x
Energy meter		-	-	-	-	-	x
HUB[3]		-	-	-	-	-	-
Internet connection[4]		x	x	x	x	x	x

[3] As each sensor sends information to the cloud independently, no hub is needed.
[4] Data are transmitted to the cloud using SIGFOX IoT Radio solution

3.3 The validation methodology

Along with the definition of demo hardware specificities and the evaluation scenarios, the validation activities to be performed during the demonstration period have to be defined. In order to evaluate the level of achievement of a given objective and assess the project results, the BIM4EEB PMV methodology with the respective Key Performance Indicators (KPI) as defined in early stage of the project will be applied.

As stated in D3.5 [D3.5, 2019], BIM4EEB KPIs have been selected according to project's objectives as identified in the DoA and they are in line with the BIM4EEB project's stakeholders' requirements, as defined in WP2 deliverables D2.2, D2.3, D2.4 and D2.5 (see [D2.2, 2019], [D2.3, 2019], [D2.4, 2019], [D2.5, 2019]).. The overview of KPIs considered to assess the BIM4EEB outcomes are collected in table 26 according to the considered tool and demonstration sites. It is also noteworthy to mention that D3.5 KPIs are also the key element for social impact study in D1.5 [D1.5, 2020].

Starting from the ones proposed in DoA, the D3.5 developed a more complete list of KPIs dividing them in categories (Renovation Process KPIs; Energy Performance KPIs; Human Comfort KPIs; Economic Performance KPIs; Social Related KPIs; Environmental & Safety KPIs) in order to highlight the different pillars of interest in the project and to conduct a solid assessment process that addresses at the same time the BIM4EEB objectives and stakeholders' requirements investigating, for instance, the performance of the renovated buildings such as energy consumption or the impact of BIM4EEB regarding occupants thermal and visual comfort and building acoustics comfort.

The KPIs have been divided in "mandatory" and "secondary" KPIs: mandatory KPIs, described in the previous tables, are based on the BIM4EEB objectives which have to be clearly addressed during the project; secondary KPIs are extra success indicators linked with the literature analysis and the review of project use cases and tools that will be also aimed to be addressed by the project and BIM4EEB tools. For homogeneity reason with D3.5, the distinction of mandatory and secondary KPIs is provided by the colour red for those based on the project objectives.

An early review of the demonstration actions and the association of KPIs was reported in D3.5. The analysis was provided in a high level following a top down approach, identification of the DoA details and mapping activities getting a preliminary feedback from the demo partners.

In this document, a deeper through analysis is provided focusing mainly at the demo pilot specificities as considered in the project. A more in detail consultation with the demo partners was performed towards the selection of the KPIs for evaluation at the different demo sites. Therefore, we can consider this analysis as a more elaborate analysis of the analysis performed in D3.5.

Regarding Italian demo site, the BIM management system and Common Data Environment will be tested on the case study in order to ensure the prompt data gathering process. Additionally, as planned in [DoA] "*the fast energy audit will be performed before the retrofit interventions to precisely define the baseline energy consumption/performance and the current users' behaviours. On the other hand, the operation and performances of the retrofitted building will undergo an intense and detailed monitoring activity, to support and validate the results of the project. The operating parameters of the case-study building (energy consumption, specific energy loads, equipment operation, comfort levels, etc.) will be carefully monitored in order to demonstrate the actual performances and to manage collected information within a digital logbook of the building*". Finally, along with other tools to be deployed in the demo site (energy performance simulation assessment tool, BIM to BACs system) will facilitate the faster and more accurate implementation of the renovation activities directly impacting to the total cost required for the renovation.

The planned goal of Polish demo site as stated in [DoA, 2018] is "*to apply the tools in order to compare traditional methodology and the proposed BIM4EEB one to demonstrate improvements achieved in reality*"

The BIM management system and CDE will be tested on the case study, with the creation of the digital logbook for the building. In addition, the fast-mapping tool will be applied in order to measure the time that is necessary to generate an exhaustive BIM model for a building further compared with the traditional methods. Moreover, sensors will be installed to gather data for the WP6 tools “Human machine interface” and “HVAC-Design, Operation and Efficiency Management” enabling that way the accurate performance evaluation of both energy and comfort related KPIs as specified in the project.

The main aim for Finnish demo site as stated in [DoA, 2018] is “*to provide demonstration of the tools and methods developed in the project on a relevant residential building to be refurbished during project demonstration period*”. Among the Finnish pilot case objectives there are the information collection from existing residential building through fast mapping techniques and use that information as input for BIM, , applying location-based planning and control method with BIM for reserving work spaces and tracking transparently work progress to reduce lead-time at site by 20% and enabling energy performance simulation assessment and further promote the validation of this tool at the demo site. In addition, the BIM management system will contribute to reduce the cost of renovation activities providing annual savings.

A synoptic table is hereafter presented in order to show the association among KPIs, tools and demonstration sites.

Table 27 - KPIs to be measured in each pilot sites according to the applied set of tools

NOTE: this synoptic table merges the KPIs from table 18 of D3.5 (for the Italian pilot site), table 19 of D3.5 (for the Polish pilot site), table 20 of D3.5 (for the Finnish pilot site). **Please note that KPIs highlighted in red are the compulsory ones to be demonstrated with the application of BIM4EEB toolkit.**

Category of KPI	kpi	Name of the KPI	Description of the KPI and formula	Unit	Italian site						Polish site				Finnish site			
					BIMMS	Tool 1	Tool 2	Tool 3	Tool 4	Tool 5	BIMMS	Tool 1	Tool 3	Tool 4	BIMMS	Tool 1	Tool 2	Tool 5
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.,) $\frac{Actual\_Renovation\_Time - Baseline\_Renovation\_Time}{Baseline\_Renovation\_Time}$	%	X	X[5]	X[6]		X	X	X	X[1]		X	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 $\frac{Actual\_Renovation\_Cost - Baseline\_Renovation\_Cost}{Baseline\_Renovation\_Cost}$	%	X		X			X	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 $\frac{Actual\_Renovation\_Time - Planned\_Renovation\_Time}{Planned\_Renovation\_time}$	%		X	X			X		X				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 $\frac{Actual\_Renovation\_Cost - Planned\_Renovation\_Cost}{Planned\_Renovation\_Cost}$	%						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 $\frac{\#\ of\ delayed\ actions\ during\ renovation}{\#\ of\ delayed\ actions\ in\ baseline\ renovation}$	%			X											X
	REP 6	Non-conformance Issues during inspection reduction	Number of non-conformance report items: #qualityIssues, compared to the baseline/traditional process $\frac{\#\ of\ quality\ Issues\ during\ Renovation}{\#\ of\ quality\ Issues\ in\ Baseline}$	%						X								X

5 Time reduction on digital data acquisition and on BIM models creation
6 Reduction on energy audit time and time reduction on decision-making for different renovation scenarios

	REP 7	Time Reduction to fix quality issues	Reduction of time required to fix quality issues $\frac{Time\ to\ fix\ quality\ issues\ during\ Renovation}{Time\ to\ fix\ quality\ Issues\ in\ Baseline\ Renovation}$	%						**X**								**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 $PMV=(0.303e^{-0.036M}+0.028)*\{(M-W)-3.05*10^{-3}*[5733-6.99*(M-W)-p_a]-0.42[(M-W)-58.15]-1.7*10^{-5}M(5867-p_a)-0.0014M(34-t_a)-3.96*10^{-8}f_{cl}[(t_{cl}+273)^4-(t_r+273)^4]-f_{cl}h_c(t_{cl}-t_a)\}$	Numerical (-3 to +3)				**(X)**	**X**				**X**	**X**			**X**	
Comfort	**COM 2**	Predicted Percentage of dissatisfaction (PPD)	Percentage of the people who felt more than slightly warm or slightly cold $PPD = 100 - 95e^{-0.03353}PMV^4 - 0.2179PMV^2$	%				**(X)**	**X**				**X**	**X**			**X**	
Comfort	**COM 3**	Thermal discomfort factor	Assessing the people's satisfaction with the thermal environment $y_{th} = p(Y_{th} = 0 \mid X_t = x_t) = \frac{1}{p(X_t = x_t)} p(Y_{th} = 0)p(X_t = x_t \mid Y_{th} = 0)$	Probability (0-1)				**X**					**X**				**X**	
Comfort	**COM 4**	Operative Illuminance	Assessing the people's satisfaction in terms of illuminance compared to a reference value. $Operative\ Illuminance = \frac{\sum^{time} Illuminance}{time}$	lux				**X**					**X**				**X**	
Comfort	**COM 5**	Visual discomfort factor	Identifying the feeling of visual discomfort defined from sensing and actuation data. $y_{vis} = p(Y_{vis} = 0 \mid X_v = x_v) = \frac{1}{p(X_v = x_v)} p(Y_{vis} = 0)p(X_v = x_v \mid Y_{vis} = 0)$	Probability (0-1)				**X**					**X**					
Comfort	**COM 6**	Average Indoor Noise Level	The level of noise in the building environment compared to reference values $Average\ Noise = \frac{\sum^{time} NoiseLevel}{time}$	dB				**X**										
Comfort	**COM 7**	Occupancy Profiling Accuracy	Deviations about real and predicted occupancy schedules $\frac{(Actual\ Occupancy - Planned\ Occupancy)}{Planned\ Occupancy}$	%				**X**					**X**					**X**
Economic	**ECON 1**	Annual Cost Savings	Reduction of cost due to the renovation activities; compared to the baseline values $CS = 1 - \frac{CS_C}{CR_E} x100$	%	**X**						**X**				**X**			
Economic	**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. $NPV = \sum_{n=`1}^{N} \frac{C_n}{(1+d)^n} - Ca$	€	**X**						**X**				**X**			

	ECON 3	Pay-back Period	The period required to recover the funds expended in an investment on renovation. $Payback\ Time = \frac{C_{INV}}{S}$	Time (years)	X						X				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 $ROI = \frac{(\sum^{time} Revenues - Investement\ Costs)}{Investments\ Costs} * 100$	%			X								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. $LCC = Acquisition\ (capital\ investment\ for\ initial\ work) + NPV\ [(use\ \&\ maintenance) + (operating\ cost) + (major\ repairs + modernisation + rehabilitation) + (residual\ value) + (environmental\ LCA\ factors) + (occupational\ LCA\ factors) + (location\ LCA\ factors)]$	€			X										X	
Energy performance	**ENE 1**	Energy Savings	Calculating the percentage difference between measured and baseline consumption data within a predefined period $ES = 1 - \frac{ES_C}{ER_E} x100$	%			X							X			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…) $ESes = 1 - \frac{ES_C}{ER_E} x100$	%			X							X			X	
	ENE 3	Primary Energy Savings	Calculating the percentage difference between measured and baseline primary energy consumption data within a predefined period $PES = 1 - \frac{PES_C}{PER_E} x100$	%			X [7]		X					X			X [3]	
	ENE 4	Energy Performance Accuracy	Deviation between predicted and actual energy use by comparing predicted and real energy consumption $EPA = abs\ (1 - \frac{ES_C}{EB_E} x100)$	%			X [8]		X					X			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							X			X	

[7] Reduction of net primary energy use
[8] Use of dynamic simoulation tools for energy assessment

			$TUPE = \sum_{k=0}^{n} PE, \quad during\ lifecycle$																
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**	**X**	**X**	**X**	**X**	**X**	**X**	**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**	**X**	**X**	**X**	**X**	**X**	**X**	**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."* *"With BIM4EEB, the renovation of my residence caused me less discomfort than what is expected with the traditional renovation approach"*	Likert scale (1-5)				**X**					**X**					**X**
	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**	**X**	**X**		**X**	**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**		**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**		**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**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**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	X	X	X		X	X		X
	SOC 9	Increased easiness in information exchange	The extent to which BIM4EEB improves tracking and information exchange among its various stakeholders (i.e. Construction Companies, Designer, FMs, Occupants)	Likert scale (1-5)	X	X			X	X	X	X		X	X	X		X

		and tracking (data accessibility)	*"BIM4EEB makes it easier for me to exchange/track information with other stakeholders"*															
	SOC 10	Modular design and development of the BMS platform	The extent to which BIM4EEB can be expanded to address additional types of requirements from the business actors (i.e. Construction Companies, Designer, FMs, Occupants) *"The modular design of BIM4EEB makes it easier to address other types of requirements from the various business actors"*	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						X				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 process, as well as produce more accurate energy savings estimates through simulation tools"*	Likert scale (1-5)		X	X					X				X	X	
	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										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)														
	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)	Likert scale (1-5)	X						X				X			

			"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)															
Environmental/safety	**ENV 1**	CO2/ CO compounds reduction	Assessing the level of pollutant emissions (CO2/CO) compared to a reference value $CO2/CO\ Concentrations = \int CO/CO2\ Compounds$	ppm					X				X	X			X	
	ENV 2	Particulate Matter (PM) reduction	Assessing the level of pollutant emissions compared to a reference value $\text{Particulate Matter (PM) Concentration}\backslash= \int PMx\ Compounds$	Likert scale (1-5)					X				X	X			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 $\text{tVOCs Concentration} = \int tVOC\ compounds$	mg/m^3					X				X	X			X	
	ENV 4	GHG emissions reduction	The amount of GHG emissions produced due to the energy consumption of the building can be measured by monitoring the consumption type and multiply for the respective conversion factor $\text{GHG} = \sum_{i=1}^{N} \text{Ec} \times \text{Ef}$	Tonnes of CO_2 eq. or %					X					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 $\frac{\#\ of\ safety\ Issues\ during\ Renovation}{\#\ of\ safety\ Issues\ in\ Baseline\ Renovation}$	%	X						X						X	X

4 Conclusions

Presented report aims at describing the testing and validation methodology for the tools under development applied to three best practise examples, chosen for their representativeness.

In order to test the developed toolkit, a set-up of sensors was designed to detect thermal and visual comfort, indoor air quality, electric power and gas consumption.

Concerning the set-up and sensors chosen and installed in Italian and polish pilot sites, a Zwave-based hub has been chosen thanks to its capability to integrate different types of sensors and metering devices, to gather the acquired sensorial data for energy consumption, environmental ecosystem parameters and to provide appliance control where needed.

Sensors chosen for the Finnish demo are different: SigFox NB-IoT sensors transmit data directly to the Sigfox cloud service by using Sigfox IoT network and since each sensor sends information independently no hub has been considered.

The methodology to validate tools is based on several KPIs describing renovation process, energy performance and comfort, economic, environmental/safety and social aspects. The selected KPIs can be used to assess and measure the satisfaction level of each tool applied to the three different pilot sites.

5 Bibliography

[BIMcpd, 2020] BIMcpd – "*A combined toolkit for Constraint checking, Performance evaluation and Data management for BIM renovation projects*", available at: http://bimcpd.com/ (last access: 2 February 2021).

[DoA, 2018] BIM4EEB project, "*Description of Action, Annex 1 of Grant Agreement Number 820660 - BIM4EEB*", H2020-NMBP-ST-IND-2018-2020/H2020-NMBP-EEB-2018, BIM4EEB (BIM based fast toolkit for Efficient rEnovation in Buildings) project, H2020, 03/12/2018.

[D1.5, 2020] BIM4EEB project, Deliverable "D1.5 Report on societal impact RP1", version 1.0, 11/06/2020.

[D2.2, 2019] BIM4EEB project, Deliverable "D2.2 List of designers' needs and requirements for BIM-based renovation processes", version 1.0, 28/06/2019.

[D2.3, 2019] BIM4EEB project, Deliverable "D2.3 List of construction companies' needs and requirements for BIM-based renovation processes", version 1.0, 20/06/2019.

[D2.4, 2019] BIM4EEB project, Deliverable "*D2.4 List of service companies' needs and requirements for BIM-based renovation processes"*, version 1.0, 19/06/2019.

[D2.5, 2019] BIM4EEB project, Deliverable "*D2.5 List of owners' and inhabitants' needs and requirements for BIM-based renovation processes*", version 1.0, 28/06/2019.

[D3.5, 2019] BIM4EEB project, Deliverable "*D3.5 Measurement and Verification protocol*", version 1.0, 20/12/2019.

[D4.1, 2019] BIM4EEB project, Deliverable "*D4.1 Technical specifications for the design of a BIM management system*", version 1.0, 20/12/2019.

[D5.2, 2019] BIM4EEB project, Deliverable "*D5.2 Report of Output from Metering Devices and Their Translation in BIM Models*", version 1.0, 13/12/2019.

[D5.3, 2020] BIM4EEB project, Deliverable "*D5.3 Augmented Reality Tool*", version 1.0, 30/06/2020.

[D6.3. 2020] BIM4EEB project, Deliverable "*D6.3 Tool for constraint checking BAC-topologies VS building codes -including D6.4 Tool for connecting BIM and BAC and D6.5 Database Management system*", V1.0. 30/03/2020

[D6.6, 2020] BIM4EEB project, Deliverable "*D6.6 Decision support tool*", version 1.0, 20/06/2020.

[D6.7, 2020] BIM4EEB project, Deliverable "*D6.7 Report on BIM4EEB Occupants' Profiling Mechanism*", version 1.0, 29/06/2020.

[D6.8, 2020] BIM4EEB project, Deliverable "*D6.8 Ambient User Interface",* version 1.0, 29/06/2020.