

Methods for architectural, structural, thermal 3D data acquisition of existing buildings

Deliverable report 1.1



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BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

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Methods for architectural, structural, thermal 3D data acquisition of existing buildings

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Publishable executive summary

A solid base for defining an optimized refurbishment strategy is to know exactly the as-is situation of the building. In general, as-is documentation of buildings, which have to be refurbished, are not sufficient to serve as a design base. Therefore, additional data has to be collected on site. Nowadays, technology has reached a state where a lot of information can be gathered in a short time, providing a very clear picture of the building. What sounds at first like a very good starting point, might turn out to be a hard challenge. Figure 1 shows the main challenges addressed by BIM-Speed project.

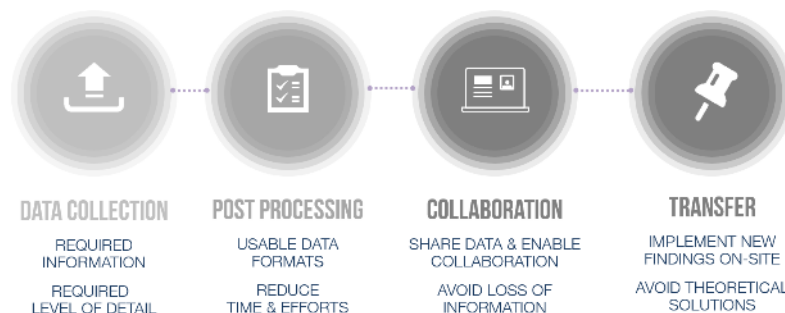


Figure 1 - Industry Challenges during Data Collection for refurbishment projects

It is a common procedure of refurbishment projects to collect many gigabytes of data to get a solid design base of a project. Unfortunately, managing this amount of information often turns out to be a very hard challenge. The raw data has to be post-processed to become usable for further process steps, identification of the data which is really required needs a lot of time and storing those amounts of information might become very expensive.

This deliverable approached the need for gathering data in another way. Based on definition of BIM use cases, the required information to apply these use cases on a refurbishment project should be derived. Work Package 1 developed a Use Case methodology toolkit, which enables the users to specify their main goal of the refurbishment project to identify the related business processes, use cases, methods and finally software, tools and devices to be used to collect specific data.

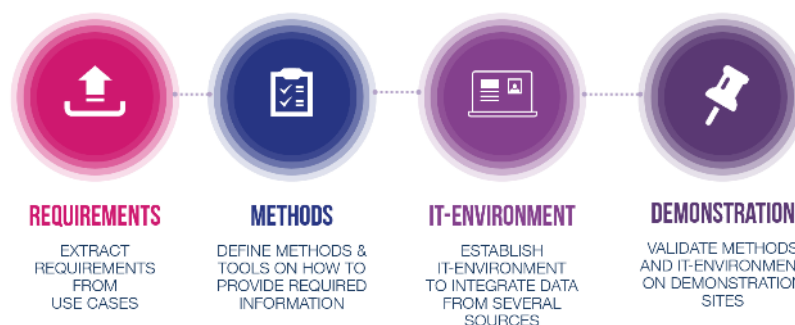


Figure 2 - BIM-SPEED approaches to address those challenges



Based on identified required information, methods to collect data will be defined and the process of post-processing can be optimized (as illustrated by the developed 3DASH-tool, which automatically creates basic objects out of laser-scans).

Defining a common Project Breakdown Structure (PBS) to structure data and to enable attaching information to 3D objects will provide the option to transfer the gathered data into an IT environment and to transfer these optimized approaches onto demonstration sites for further validation. Figure 2 shows BIM-Speed's approaches to address the named challenges.

AIM of Deliverable

The main objective of Work Package 1 is to reduce time, cost and complexity in the deployment of tools, techniques (methods/procedures/protocols) for BIM data acquisition in EEB residential renovation projects. In this context Task 1.1 focused on data acquisition and diagnostics for architectural, structural and thermal 3D data. The way how to do this, which methods and tools are the most suitable ones and how they are used were key-questions to be answered in deliverable D1.1.

Since in the beginning of BIM-Speed project there were no explicitly specified use cases, which should be addressed, one of the major challenges was the identification of data to be acquired. Without knowledge about the use cases to be applied, the specific requirements to perform these use cases could not be derived and therefore, it also was not been possible to define, which and what kind of data and/or information has to be collected.

To close this gap deliverable D1.1 defined a comprehensive base BIM-Speed project and therefore, for all those tasks and work packages, which are relying on these information. In specific, deliverable D1.1 provides essential input for following tasks:

- D1.1 outlines requirements on 3D Models and its elements that have been the Input for Task T2.3 model guidelines.
- The identified requirements form input to define the model checks in Task 5.3 and design checks in Task T7.2.
- For Work Package 8 a lot of Input and especially ideas has been generated, as well as guidance on identifying possible BIM use cases for the projects.

This deliverable D1.1 creates an overall understanding to data acquisition and defined the base for other Work Packages. It provides a method for identification of required information on specific use cases. It is intended to evaluate the given information and findings on the demonstrator projects to be transferred back into the BIM-Speed methodology toolkit.



List of acronyms and abbreviations

DoA	Description of Action
BEM	Building Energy Model
BIM	Building Information Modelling
BS	BIM-SPEED
ECM	Energy Conservation Measure
EEB	Energy Efficient Buildings
EPBD	Energy Performance Buildings Directive
EPC	Energy Performance Contract
ESCO	Energy Services Company
GIS	Geographic Information System
HVAC	Heating Ventilation Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality
IPMVP	International Performance Measurement and Verification Protocol
IPR	Intellectual Property Right
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LIC	Location Identification Code
LOD	Level of Development
LOG	Level of Geometry
LOI	Level of Information
MEM	Model Element Matrix
MEP	Mechanical Electrical Plumbing
M&V	Measurement & Verification
nZEB	nearly-Zero Energy Buildings
PIC	Plant Identification Code
POE	Post Occupancy Evaluation
R&D	Research and Development
RES	Renewable Energy Source
RoI	Return on Investment

SME Small and Medium-size Enterprise
TCP Technology Commercialisation Platform
TRL Technology Readiness Level
VR/AR Virtual / Augmented Reality
UC Use Case



Definitions

Renovation goal

All renovation projects are aiming towards specific **Renovation Goals**, which pursue an improvement of the building to prolong the lifecycle of the building. Observing the whole project phase of renovation and considering the buildings improvement, the main goals are usually:

- saving and improving energy performance
- reducing run time of the renovation project
- optimizing costs for all phases (building, renovation, lifecycle)
- increasing comfort level of inhabitants

Business process

The **Business Process** describes the general task to be done in design and construction phase to reach the **Renovation Goal**, e.g. energy analysis.

BIM use case

The **BIM Use Case** complies with BIM requirements. That means the **Business Process** is broken down into detailed use cases and automated processes and/or data analysis are implemented, e.g. BIM based energy analysis.

Methods

The **Method** describes the way of working to serve the **BIM Use Case**, e.g. transfer BIM to BEM.

Framework

The **Framework** needs to be set up in the beginning of a project. It needs to satisfy organizational, technical, and legal requirements to run business processes.



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1. Approach to Architectural, Structural and Thermal 3D data acquisition

1.1 Introduction

Gathering as-built information about an existing building is often very time-consuming. On one hand, this is related to complicated procedures to collect the required information and the time-consuming procedures during the post-processing phase to provide the gathered information in a sufficient file-format. On the other hand, it is also related to the issue that the required information is not specified in detail and therefore too much data will be collected, which makes identifying the required information even more complicated. The general goal of work package 1 (WP1) is to provide guidelines for the deployment of tools and definition of techniques (methods/ procedures/ protocols) to reduce time, cost and complexity for BIM data acquisition in EEB residential renovation projects. The definition of how to collect data and which way is the most useful to interpret the data will be described in this WP.

Identification of the required data is the most important approach to reduce the amount of data and therefore also to reduce the related efforts. It is not necessary to collect all available data if the data will not be used anyway. Depending on the relevant BIM use case, only specific data must be collected. If this data fulfils the requirements of the BIM use case, it will enable the successful application of the use case and therefore serve the aimed renovation goals in a sufficient way.

Task 1.1 is generally aiming at data acquisition and diagnostics for architectural, structural, acoustic, and thermal 3D data. Recommendations on specific methods and tools are predicted on experience of project partners, coming from a widespread field of building projects.

- Key aspect for **architectural and structural** data is determining information of 3D geometry. Laser scanning and drones are commonly used as well as as-built data analysis of existing 2d drawings, etc.
- Assessing **acoustic comfort** of a building before and after renovation is the main aspect for this kind of data. One representative way to determine location of weak elements of the building envelope is using Beamforming technique for example.
- Capturing **thermal 3D data** offer a comprehensive picture for estimating the thermal transmittance of building elements. Soft-Sensing technique with IR thermal camera is one example for thermal data acquisition.



1.2 Approach

Nowadays, a commonly used approach on renovation projects is to collect as much information as possible with current available technologies. This leads in general to huge amount of data, which can only hardly be managed. And even in case it can be managed, it is most time consuming to keep track of the provided information.

Therefore, the general idea of Work Package 1 is to identify the relevant information and to focus on the required information to enable use cases, which will lead to the aimed goals of the renovation project. Following general questions must be answered to successfully pick the required information to serve specific use cases:

- Which data needs to be collected?
- In which way will they be collected?
- What is the purpose of these data?

To answer these questions in the right way, first, Use Cases need to be defined to ensure a suitable clustering of data for relevant use cases. Without understanding the purpose of data, it will not be possible to decide which data need to be collected.

1.2.1 BIM Speed Terminology

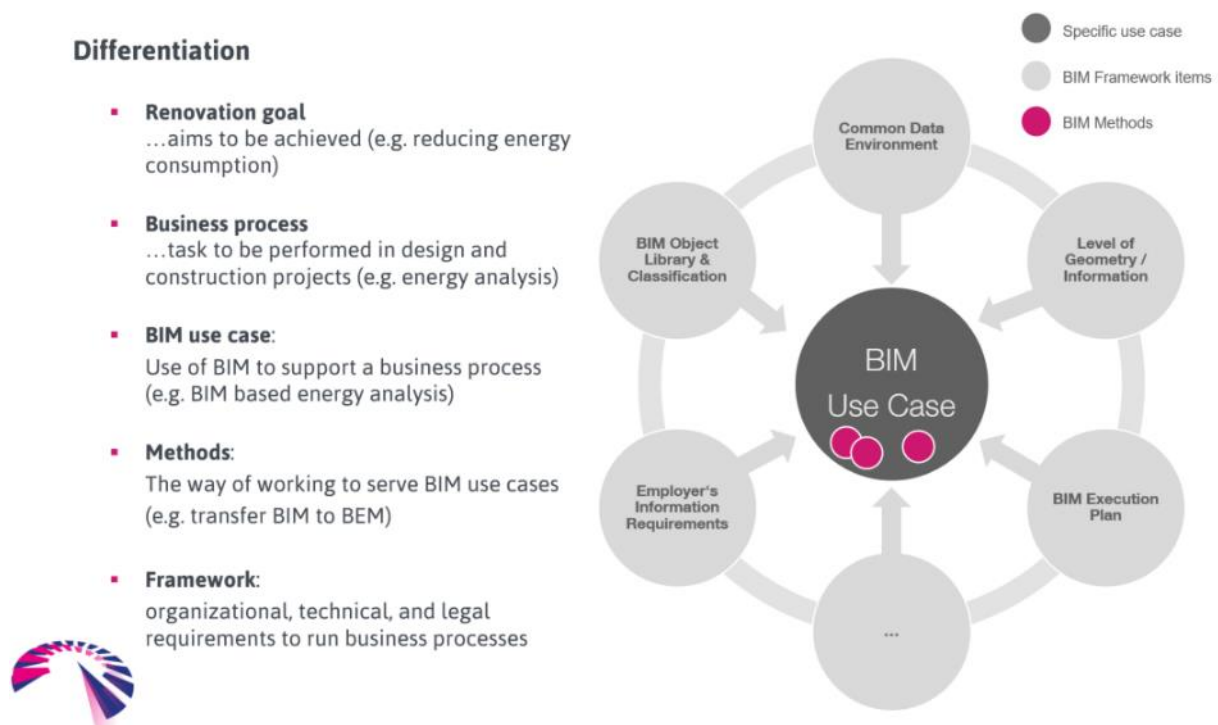


Figure 3 - Terminology

To enable definitions of relevant Use Cases, the BIM Speed Consortium decided to perform an “Use Case Workshop” to identify a specific BIM Speed Terminology (Figure 3). This was required to align the different perspectives on several terms and to create a solid base for BIM Speed use cases.

1.2.2 BIM Speed Requirements towards Data Collection

The creation of this BIM Speed Terminology enabled the possibility to define the relationship between the BIM Readiness Level of a company (to be defined in Work Package 2) and the choice of aimed use cases for a specific renovation project (Figure 4). By the identification of the aimed use cases, Work Package 1 will be enabled to derive the required data to be collected.

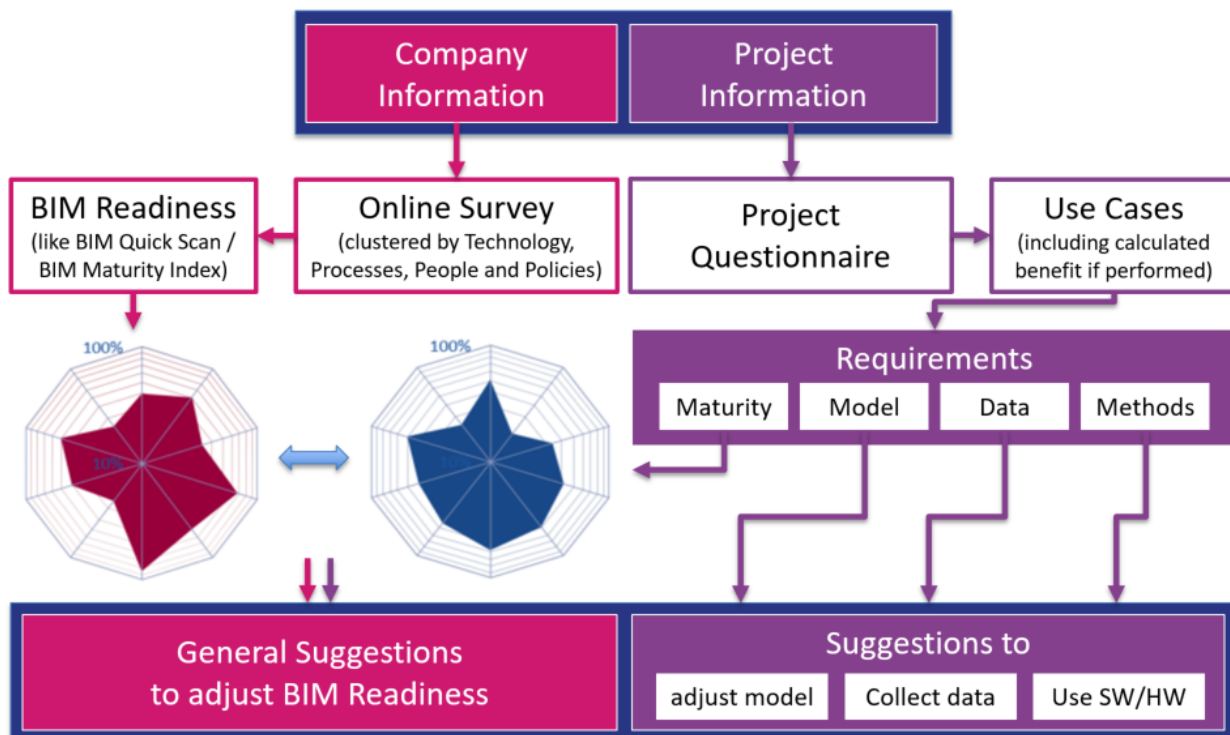


Figure 4 – Relation between aimed Use Case and required data to be collected

1.2.3 BIM Speed’s Tree View approach

To derive the required data for the BIM Use Cases, a general structure and relationship between Project Goals and Software/Tools/Devices has been defined. This so called “Tree View approach” translates the BIM Speed terminology to more specific use case examples and their definitions. In general, the Tree View is an Excel Sheet (Figure 5), where in the left column all possible renovation goals are listed. Depending on these goals in the next column all Business Processes are listed, which serve these goals. By enhancing this relation-branches with more dependencies between Business Processes, Use Cases, methods and tools, an information tree has been established to identify hardware and software to be used to perform specific methods and to enable the application of specified BIM Use Cases.





TREE VIEW

Requirements Approach

Top-Down-Approach

What are the requirements to reach a specified goal?

Renovation goal	Business process	BIM use case	Methods	Tools/Software/Devices
Goal: reducing energy consumption  60% ENERGY SAVING	Business Process: Energy performance prediction	BIM Use Case: predict energy performance on base of BIM	Method: Building Information Model (BIM) to Building Energy Model (BEM)	Tool: BIM to BIM Converter
		BIM Use Case: provide decision base for different refurbishment strategies on base of BIM	Method: Performing 3D Energy Simulation	Tool: Simulation #
	Business Process: Lightning concept development	BIM Use Case: ...	Method: Multi-Criteria Decision-making (MCDM)?	Tool: ...
		BIM Use Case: ...	Method: ...	Tool: ...
	Business Process: Sustainability analysis	BIM Use Case: Integrate sustainability into the energy efficiency analysis	Method: ...	Tool: ...
		BIM Use Case: ...	Method: ...	Tool: ...
Goal: Speed up renovation process  30 % TIME REDUCTION	Business Process: Coordinate constructable Design	BIM Use Case: BIM based Design coordination	Method: Gather geometrical information about as-is situation	Device: Lector Scan Station P30
		BIM Use Case: ...	Method: Verify As-Built Model against Point Cloud / Deviation Analysis	Device: Lector CAM2
	Business Process: ...	BIM Use Case: ...	Method: Clash Detection / Geometrical verification	Device: Holoport 400
		BIM Use Case: ...	Method: ...	Software: Lector Cyclone
	Business Process: ...	BIM Use Case: ...	Method: ...	Software: Hologon 3D Reshaper
		BIM Use Case: ...	Method: ...	Software: Autodesk Navis Works Manage
BIM Use Case: ...	Method: ...	Tool: ...	Software: Capvision Design MS	

Feasibility Approach

What can be achieved with available tools and data?

Bottom-Up-Approach

Figure 5 – Tree View Table Approach

This Tree View approach enables two procedures to align renovation goals and available tools, devices and software packages:

Requirements Approach (Top-Down-Approach)

The requirement approach, which means a top-down approach, will answer the question to what is required to reach a specific goal. Starting from the general Renovation Goal for the renovation project, it will go down to relevant business process, aimed BIM use case, pertinent methods and then resulting in mandatory tools, software and/or devices.

Feasibility Approach (Bottom-Up-Approach)

On the other hand, there is the feasibility approach which is examined the other way round and will answer the question what can be achieved with available tools and data.

According to this approach, business processes has been clustered by the general goals of saving energy, cost, or time and by increasing the comfort level. Additionally, to get an overview on required data in specific renovation phase, the tree view table has been enhanced by the BIM-SPEED Renovation Phases and related RIBA Stages listed (Figure 6).

This enables the user to choose either to start with definition of the specific project phase to identify the relevant use cases, or to start by pointing out to the most relevant goal to be achieved.



BIM-SPEED Renovation Phase	RIBA Stage	Energy	Time	Cost	Comfort	Business process
1. Existing building Data collection	S0. Strategic definition	-	-	-	Comfort	Assessment: Thermal Comfort
1. Existing building Data collection	S0. Strategic definition	-	-	-	Comfort	Assessment: Acoustic Comfort
1. Existing building Data collection	S0. Strategic definition	-	-	-	Comfort	Assessment: Indoor Air Quality
1. Existing building Data collection	S0. Strategic definition	Energy	-	-	-	Assessment: Energy Performance
1. Existing building Data collection	S0. Strategic definition	-	Time	-	-	Assessment: Asset Information
1. Existing building Data collection	S0. Strategic definition	-	Time	-	-	Assessment: Asset Information

Figure 6 – Tree View Table Input

1.2.4 BIM Speed Use Case Definitions

To get a list of the required information to be collected in order to perform specific use cases and, therefore, to serve specific renovation goals, the next step was to list the relevant BIM use cases for each business process.

Work package 4 (task 4.1) evaluated several use cases for renovation projects and provided a starting point to fill in the Tree View table. These use cases do not match exactly with BIM use cases according to the BIM Speed terminology, but are relevant to operate renovation projects and to identify the required information to be collected (Figure 7).

M	N	O	P	Q	R	S	T	U
Data Input	Cluster/Family	Unit	Data Type	Measurement frequency	Requested info	Data flow	Data to be collected	
1	Final energy for energy carrier i	Energy Network [kWh]	Real	Monthly	Building	Platform	Survey/monitored data	Final energy for energy carrier i / location (IFCsite)
2	Energy exported for energy carrier i	Energy Network [kWh]	Real	Monthly	Building	Platform	Survey/monitored data	Energy exported for energy carrier i / location (IFCsite)
3	Primary energy factor (PEF) for final energy carrier i	Energy Network [-]	Real	-	-	Platform	Survey/geo-clustering	Primary energy factor (PEF) for final energy carrier i / location (IFCsite)
4	Primary energy factor (PEF) for exported energy carrier i	Energy Network [-]	Real	-	-	Platform	Survey/geo-clustering	Primary energy factor (PEF) for exported energy carrier i / location (IFCsite)
5	Net floor area	Building Lyaaout [m²]	Real	-	Building	IFC file	-	Measurements of building elements
6	Final energy for energy carrier i	Energy Network [kWh]	Real	Monthly	Unit	IDF file (energy model)	-	Simulated data
7	Energy exported for energy carrier i	Energy Network [kWh]	Real	Monthly	Building	IDF file (energy model)	-	Simulated data
8	Primary energy factor (PEF) for final energy carrier i	Energy Network [-]	Real	-	-	Platform	Survey/geo-clustering	Primary energy factor (PEF) for final energy carrier i / location (IFCsite)
9	Primary energy factor (PEF) for exported energy carrier i	Energy Network [-]	Real	-	-	Platform	Survey/geo-clustering	Primary energy factor (PEF) for exported energy carrier i / location (IFCsite)
10	Net floor area	Building Lyaaout [m²]	Real	-	Building	IFC file	-	Measurements of building elements
11	Weather Data File	Environmental D	-	-	Building	epw, twt	-	data from Energy Plus database
12	Conductivity of materials	Materials [W/m]	Real	-	Material	Platform	Survey	Conductivity of materials
13	Thermal resistance of materials	Materials [(m²K)]	Real	-	Material	Platform	Survey	Thermal resistance of materials
14	Thickness of materials	Building Lyaaout [m]	Real	-	Material	Platform	Survey	Measurements of material thickness
15	Density of materials	Materials [kg/m³]	Real	-	Material	Platform	Survey	Density of materials
16	Specific Heat of materials	Materials [J/kgK]	Real	-	Material	Platform	Survey	Specific Heat of materials
17	Solar, thermal and visible absorptance of materials	Materials	-	-	Material	Platform	Survey	Solar, thermal and visible absorptance of materials
18	Heat transfer of transparent elements	Materials [W/m²K]	Real	-	Material	Platform	Survey	Heat transfer of transparent elements
19	Air tightness	Materials [m³/h]	Real	-	Room	Platform	Survey	Air tightness
20	Solar factor of transparent elements	Materials [-]	Real	-	Material	Platform	Survey	Solar factor of transparent elements
21	Heating setpoint temperatures of building zones	Surveys/inhabita [°C]	Real	-	Building	Platform	Survey	Heating setpoint temperatures of building zones
22	Cooling setpoint temperatures of building zones	Surveys/inhabita [°C]	Real	-	Building	Platform	Survey	Cooling setpoint temperatures of building zones
23	Thermal bridges	Building Lyaaout [m]	-	-	Room	IFC file	Calculated with Open B	-
24	Occupancy profile	Surveys/inhabita [-]	Real	-	Room	Platform	Survey	Occupancy profile
25	Floor area	Building Lyaaout [m²]	Real	-	Room	IFC file	Survey	Measurements of building elements
26	Room internal height	Building Lyaaout [m]	Real	-	Room	IFC file	Survey	Measurements of building elements
27	Volume	Building Lyaaout [m³]	Real	-	Room	IFC file	Survey	Measurements of building elements
28	Weather Data File	Environmental D	-	-	Building	epw, twt	-	data from Energy Plus database
29	Conductivity of materials	Materials [W/m]	Real	-	Material	Platform	Survey	Conductivity of materials
30	Thermal resistance of materials	Materials [(m²K)]	Real	-	Material	Platform	Survey	Thermal resistance of materials
31	Thickness of materials	Materials [m]	Real	-	Material	Platform	Survey	Thickness of materials
32	Density of materials	Materials [kg/m³]	Real	-	Material	Platform	Survey	Density of materials
33	Specific Heat of materials	Materials [J/kgK]	Real	-	Material	Platform	Survey	Specific Heat of materials
34	Thermal bridges	Building Lyaaout [m]	-	-	Room	IFC file	Calculated with Open B	-
35	Heating setpoint temperatures	Surveys/inhabita [°C]	Real	-	Room	Platform	Survey	Heating setpoint temperatures

Figure 7 – Analysing Data Flow to identify required data to be collected



Additionally, WP4 created a list to examine the Workflow from WP1 to WP4 (Figure 8). For each KPI there is a definition and an Output Use Case. Work Package 1 set each of these defined use cases into relation to the relevant BIM use case. The output of this list is an overview of the required data (in defined format, sequence, from which source to which result) based on WP4 use cases for realizing the BIM use cases defined by WP1.

A	B	C	D	E	F	G	H	
KPI ID	Definition	Unit	Color/ Responsibility	Use Case	Output in Use Case	In Use	BIM use case	
1	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X
2	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X
3	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X
4	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X
5	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X
6	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X
7	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
8	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
9	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
10	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
11	BS.OPED Operational Primary Energy Demand	[kWh/m ² /year]	CARTIF	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
12	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
13	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
14	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
15	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
16	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
17	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
18	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
19	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
20	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
21	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
22	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
23	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
24	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
25	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
26	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
27	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
28	BS.TED Total Energy Demand	[kWh/m ² /year]	CYPE	UC2	UC2 (Assessing the Energy Performance of buildings with simulated data)	-	Energy Performance Prediction	X
29	BS.TEC Total Energy Consumption	[kWh/m ² /year]	CYPE	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X
30	BS.TEC Total Energy Consumption	[kWh/m ² /year]	CYPE	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X
31	BS.TEC Total Energy Consumption	[kWh/m ² /year]	CYPE	UC1	UC1 (Assessing the Energy Performance of buildings with measured data)	-	Energy Performance Assessment	X

Figure 8 – Work package 1-4 Workflow

While WP4 was focusing on energy efficiency, WP7 provided information about use cases related to best renovation strategies and WP7’s multi criteria decision making system. Therefore, close collaboration with WP4 and WP7 has been conducted to result in definition of relevant BIM use cases for renovation projects.

To complete the Tree View Table, specifying methods for each BIM use case has been listed, and additionally tools, software and/or devices have also been defined to perform these methods (Figure 9).

Time	Cost	Comfort	Business process	Business process description	BIM use case	BIM use case description	Methods	Methods description	Tools/softw	Type
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on point clouds	3D Modeling of existing asset based on point clouds	Scan to BIM	Tool
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on pictures	3D Modeling of existing asset based on pictures	Agisoft	Software
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on pictures	3D Modeling of existing asset based on pictures	ContextCapture	Software
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on 2D drawings	3D Modeling of existing asset based on 2D drawings	Autodesk Revit	Software
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on 2D drawings	3D Modeling of existing asset based on 2D drawings	Vectorworks	Software
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on 2D drawings	3D Modeling of existing asset based on 2D drawings	ArchiCAD	Software
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on 2D drawings	3D Modeling of existing asset based on 2D drawings	MicroStation	Software
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on 2D drawings	3D Modeling of existing asset based on 2D drawings	NIPLAN	Software
Time	-	-	Assessment: Asset Information	Gather information on existing asset (detailed description to be added)	Design	Create 3D design	3D Modeling based on 2D drawings	3D Modeling of existing asset based on 2D drawings	BricsCAD	Software

Figure 9 – Identifying relation between Business Process, BIM Use Case and corresponding method to be performed



1.3 Data Collection Methodology Toolkit

While gathering all those information, even more information has been provided, which were related to either the use cases (e.g. on which demonstration site this use case will be demonstrated), or the methods (e.g. in which task there are further information) or about the information itself (e.g. is this “must be – information” or “can be - information”). The amount on available excel files from several project parties was increasing rapidly.

1.3.1 Business Intelligence

To provide users all these information in a suitable format and to enable the users to manage all the different information sources, BIM Speed project intended to develop the Data Collection Methodology Toolkit (Figure 10). This toolkit should use the Business Intelligence software QlikView by the company QlikTech and should provide the possibility to link several data sources (like the above mentioned files) by defining specific keys (e.g. like a specific use case).

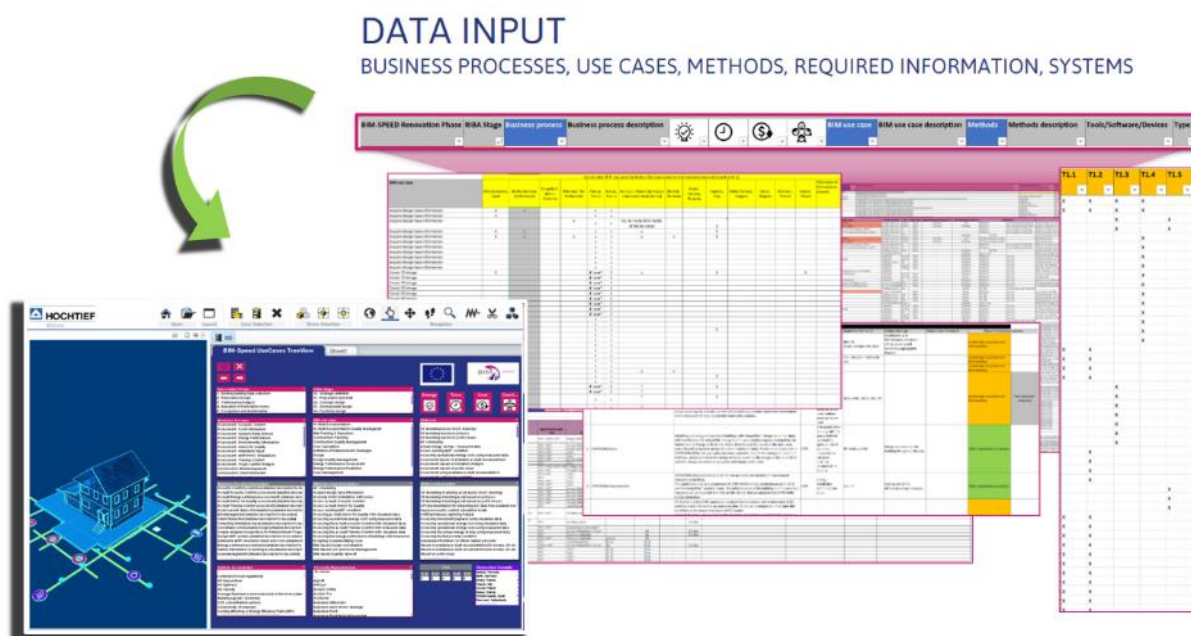


Figure 10 – BI-System for managing data

Qlikview offers versatile possibilities to combine numerous files and clustering data comprehensive. Based on this Business Intelligence Work Package 1 developed the Data Collection Methodology Toolkit, which enables the user to filter needed data for relevant BIM use cases with one click. The toolkit automatically hides those options, which are not available due to a specific filter, even if those information are provided by another information source.



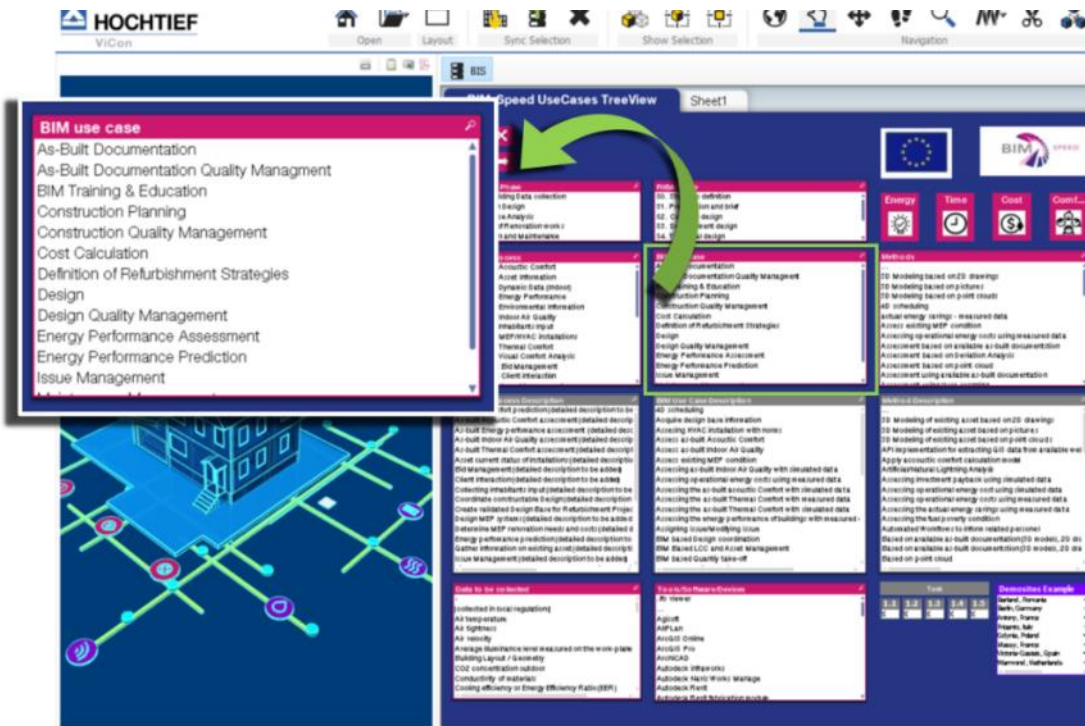


Figure 11 – Identifying relevant BIM Use case in BI System

For BIM Speed project and especially for Task T1.1, this tool offers the great opportunity to filter according to BIM use case (Figure 11) and then directly get the information on which data is required, in what kind of format and which task is responsible. Additional Information like related demo-site projects, which have interest in or already set up this specific BIM use case become also available (Figure 12).

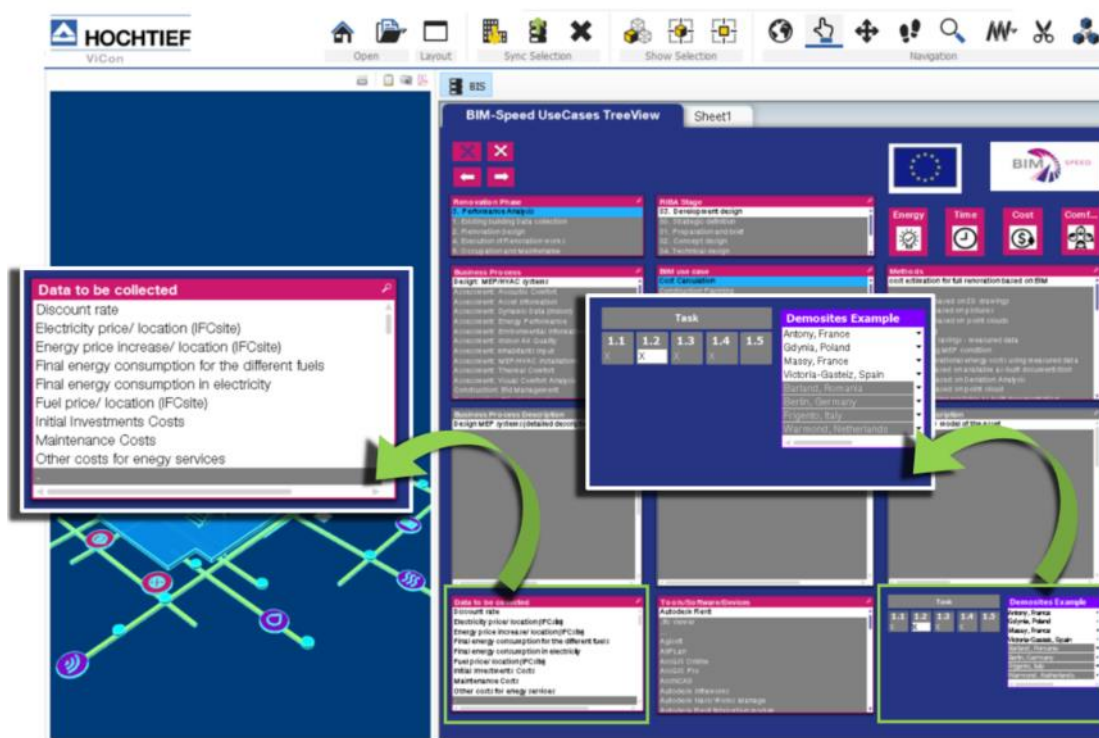


Figure 12 – Distinguish required data to be collected, involved task of WP1 and related demo-site projects



On the other hand, BIM-Speed project encountered a huge drawback that this solution is not free to use and therefore comes with licensing costs. Since BIM Speed project is looking for open solutions, which can easily be used by all participants of refurbishment projects, the system has been transferred to a nearly similar version by using Microsoft Excel with Power Pivot.

1.3.2 Microsoft Excel with Power Pivot

To avoid expensive licensing costs and additional installation needs of Qlikview software, it was intended to develop another tool to provide the methodology toolkit to all BIM-Speed project partners (and later on to refurbishment project users). As described, the methodology toolkit will help to identify:

- which data needs to be collected,
- in what kind of format and
- for what purpose.

Since all those information sources are included in several Excel Sheets, the functionalities of the above mentioned Business Intelligence tool can also be setup by activating the integrated Add-In “Power Pivot” of Microsoft Excel. This enables to setup filtering possibilities in nearly similar way as provided by QlikView, based on pivot tables. The developed BIM use cases are acting as point of connection between the different source files (excel sheets).

The methodology toolkit is available here: <https://depositonce.tu-berlin.de/handle/11303/11930>

The starting page gives user instructions on how to use this sheet (Figure 13).

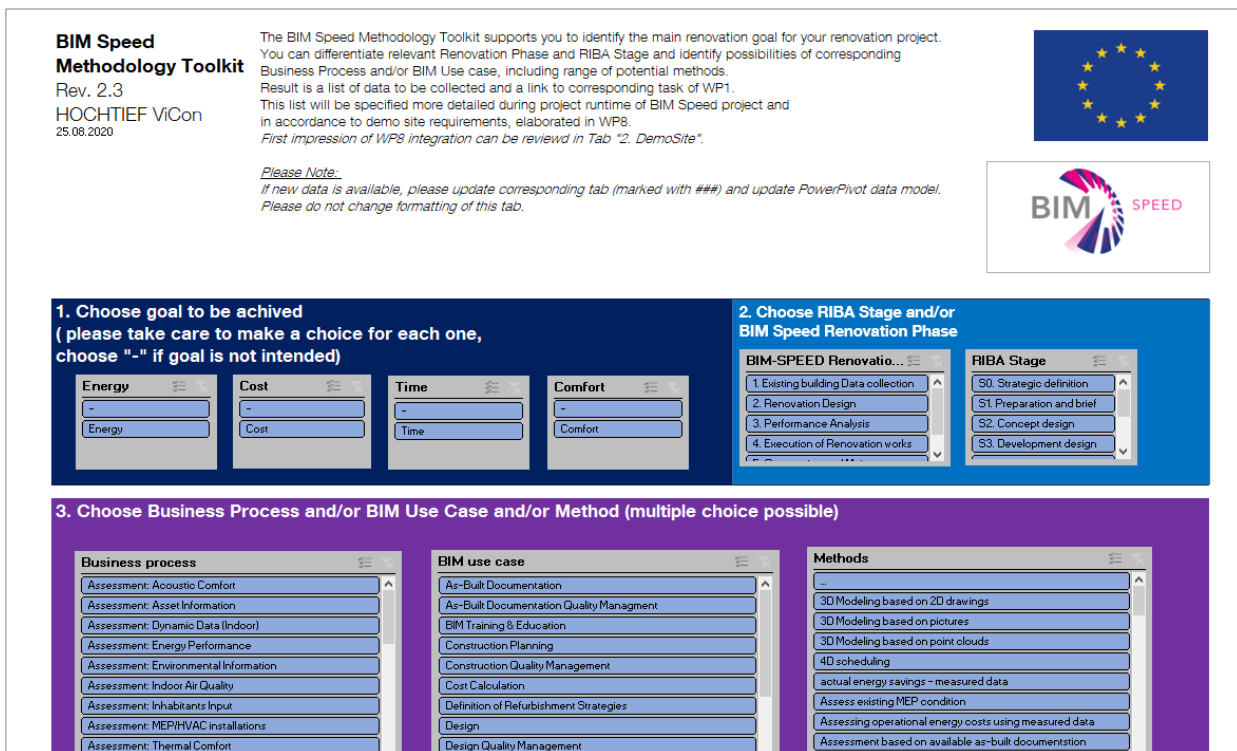
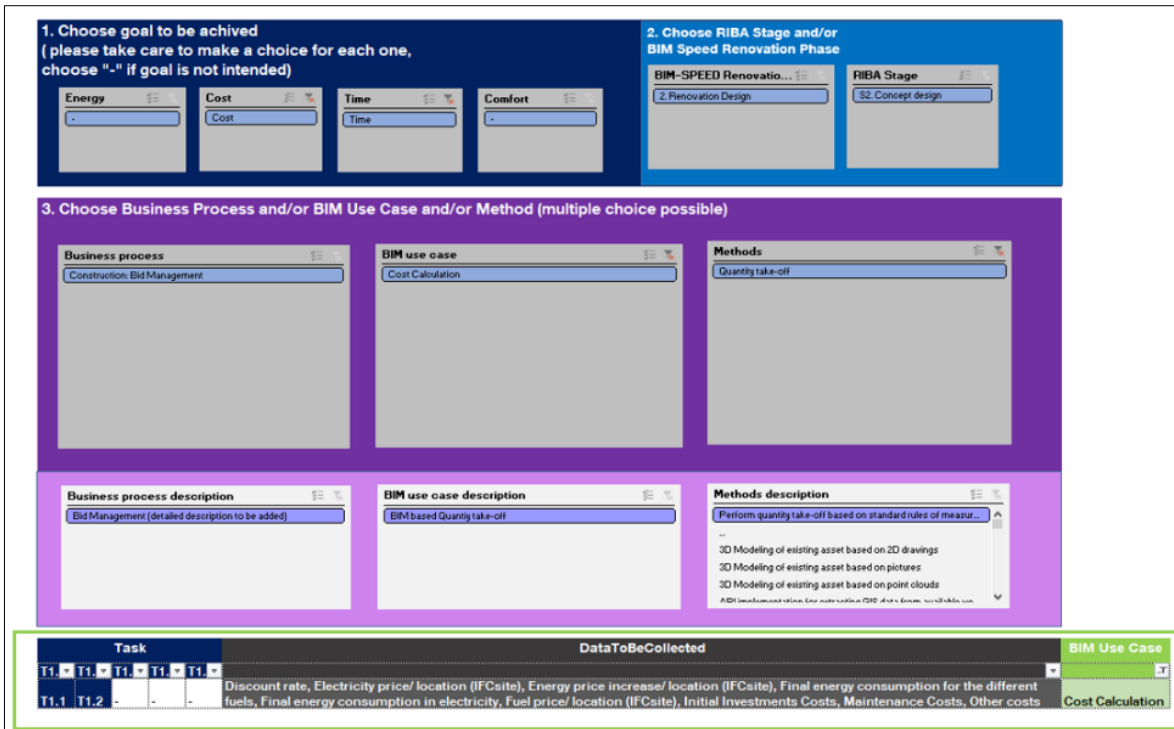


Figure 13 – Starting Page of Methodology Toolkit based on excel

Additionally, the user is led step-by-step through the toolkit (Figure 14). Starting point in this case is the main goal to be achieved within aimed renovation project. After choosing the relevant BIM-Speed Renovation Phase and/or RIBA Stage, it is possible to decide which business process and/or BIM use case and/or Method is desired. The result is a list of data to be collected and assignment to involved WP1 task.



The screenshot shows a multi-step selection interface. Step 1: 'Choose goal to be achieved' with dropdowns for Energy, Cost, Time, and Comfort. Step 2: 'Choose RIBA Stage and/or BIM Speed Renovation Phase' with dropdowns for '2. Renovation Design' and 'S2. Concept design'. Step 3: 'Choose Business Process and/or BIM Use Case and/or Method (multiple choice possible)' with dropdowns for 'Construction: Bid Management', 'Cost Calculation', and 'Quantity take-off'. Below these are text areas for descriptions. At the bottom, a table summarizes the results:

Task	DataToBeCollected	BIM Use Case
T1.1	Discount rate, Electricity price/ location (IFCsite), Energy price increase/ location (IFCsite), Final energy consumption for the different fuels, Final energy consumption in electricity, Fuel price/ location (IFCsite), Initial investments Costs, Maintenance Costs, Other costs	Cost Calculation

Figure 14 – Result: List of data to be collected, involved task and relevant BIM Use Case, based on chosen filter

Following the instructions within the excel sheet, the user will be guided to the second sheet, where an overview of all demo-sites is provided. The overview provides information about whether a specific BIM use case is already in use or is of interest to be used.



1.4 Data to be collected

Another important approach to understand, which kind of information has to be collected to support the aimed use cases, is a common understanding about what is meant by as-built information (Figure 16). In general, as-built data can be everything, not only geometrical information (e.g. coming from a 3D laser-scan). While Work Package 1 is not focusing on specific data, following data clusters have been established:

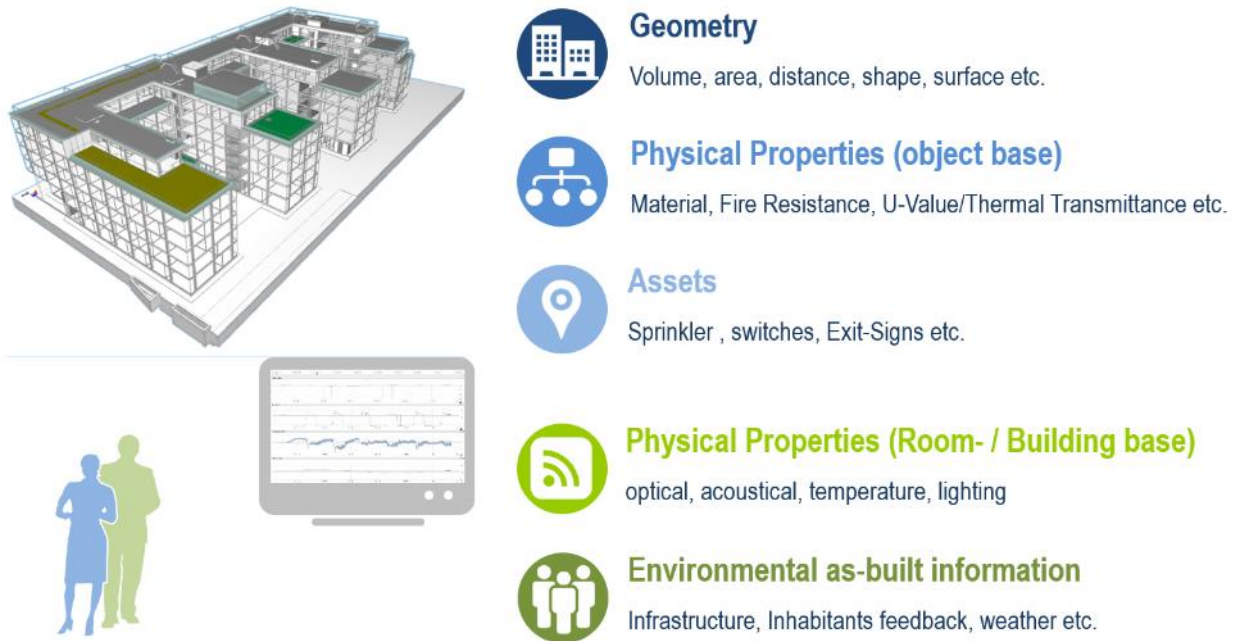


Figure 16 – Clustering of Data

BIM Speed Methodology Toolkit
Rev. 2.3
HOCHTIEF ViCon
25.01.2023

After identifying relevant Use Case(s) for your project in Tab "1 Methodology Toolkit", this tab will help you to have an overview on demo sites, where this use case has been implemented.

Please Note:
If new data is available, please update corresponding tab (marked with ###) and update PowerPlex data model.
Please do not change formatting of this tab.

Choose identified BIM Use Case, then choose possible method.
Review relevant Demo Site Project in List below.

BIM use case	Methods	Victoria Gasteiz	Berlin, Germa (Lichtenrack)	Tempelhof, Be Germany	Warmond, th Netherland	Anton Franc	Mass Franc	Warsaw II, Poland (underpass roundabout Jazdy Komnej)	Barlani, Roman	Malko Tarn, Bulgaria	Frieger, Italy	Malko Tarn, Bulgaria	Varn, Bulgai	Warsaw, Polan	Gdynia, Polan
As-Built Documentation	(User)														
BIM Training & Education	3D Modelling of existing assets based on 3D scanning														
Construction Planning	3D Modelling of existing assets based on 3D scanning														
Cost Calculation	3D Modelling of existing assets based on 3D scanning														
Determination of Performance Indicators	3D Modelling of existing assets based on 3D scanning														
Duration	API Implementation for extracting 3D data from assets														
Duration Quality Management	Application for construction comparison of the results														
Energy Performance Assessment	Apply economic comfort calculation model														
Energy Performance Pre-Action	Application for construction comparison of the results														
Usage Measurement	Recording construction progress with 3D scanning data														
Maintenance Management	Recording construction progress with 3D scanning data														

Figure 15 – Result of Step 2: List of relevant demo-site projects based on chosen BIM Use Case and Method



Since Task T1.1 is referring to „Architectural, structural, thermal 3D data acquisition & diagnostics“ (Figure 17), the relevant data clusters in this deliverable are defined as:

- “Architectural & Structural“ (1.4.1) and
- “Comfort: Thermal, Air quality, Acoustic & Air-Tightness“ (1.4.2)



Figure 17 – Task relevance for data cluster

1.4.1 Architectural & Structural

Depending on the aimed use cases, geometrical data acquisition can occur on several ways. Geometrical information might be collected via manual onsite measurements as well as by using automated devices like laser-scanners or drones using photogrammetry. The method of the choice is depending on the given circumstances and the required level of detail.

As-built drawings and documents

As basis for getting information to architectural and/or structural data, as-built drawings and documents can be taken into consideration. If not digitally available, vectorization of these drawings and documents will help to read the data for further usage. Different kind of existing documentation provide all kind of as-built data:

- 2D drawings serve for dimensions, positioning, structural information (e.g. reinforcement), materials, etc.
- Static, Thermal, Acoustic, or other calculation offer additional data to be attached
- Daily Shift Reports offering on-site data
- other

Big advantage of as-built drawings and documentation is that they are on hand at once, but it has to be considered that eventually the correctness of as-built documentation has to be verified by additional methods. Especially 2d drawings offer the big advantage of showing thickness of walls or position and dimensions of beams and columns. For other methods of measurement this means



additional effort to get this information. Of course, the distribution of all available documents in different application/systems must be incorporated. But taking all this into account, as-built data provide a good basis for architectural and structural information.

Manual and digital on-site measurement

Site measurements even with digital devices are only suitable for small areas. It is not recommended for big areas, as the effort on-site would be too high. Advantage is that dimensions of each room are available at once and can be processed as simple space model for example.

Mobile Forms

Mobile Forms offer versatile field of application: e.g. to support site inspection of the building by directly collecting information about building objects and/or MEP equipment (see also deliverable D1.2; chapter 2; subchapter 2.9.3). Mobile devices can be used to directly assign information and attach images. Mobile Forms provide possibilities to record site conditions, daily shift reports, photo documentation and even defect management as digital exploitable data. By tagging building objects and/or MEP equipment with corresponding LIC and PIC, automated processing of input data is guaranteed.

Indoor laser scanning

For indoor measurement on-site, often static laser scanners are installed. Laser scanners require a well-harmonized on-site inspection. The scanner needs to be positioned in each room that needs to be measured. This implies accessibility to all rooms and in case allowance of inhabitants or owners. Result of a scan is a point cloud and 360° images, if desired. This data can be processed directly by other systems or applications. For creation of 3D models from point clouds there are several challenges to be handled.

Point clouds provide dimension and position of building objects and MEP equipment, if accessibility is guaranteed. Hidden elements will not be measured. That means the scan process will ignore elements within wall construction or above suspended ceilings that are not visible. In addition, thickness of elements, e.g. wall thickness and materials will not be captured.

Big advantage is the fast measurement of buildings and the availability of 3D coordinates. Today's commonly used mobile laser scanner are very handy and provide a very fast "Go-Anywhere" technology for measurement.

Outdoor laser scanning

For Outdoor laser scanning the static laser scanner is not suitable and its range of operating distance is not sufficient. There are special terrestrial laser scanners that offer possibilities for scanning e.g. facades. However, the effort of positioning this static laser scanner every time is very high for big buildings. Nevertheless, this method will result in a usable point cloud file that can be processed directly.

For scanning of roofs or bigger outdoor areas, it has proved to use drones. Drones can fly across terrain and/or building and delivers a point cloud file, too. Especially the exertion of drones imply allowance of inhabitants, owners and, in case, public authorities. Big advantage here is the



availability of 3D coordinates for the whole terrain or building from outside. File size of outdoor scans have to be observed for further processing and, if needed, separated more precisely.

Photogrammetry

Primary goal to be achieved by photogrammetry is a three-dimensional reconstruction of an object. Measurement is carried out in digital way (coordinates, geometrical elements) or graphical way (images, drawings, maps). Photogrammetry is qualified for high-resolution images and/or videos. Result is a dense point cloud that can be processed directly. Like laser scanning technology, Photogrammetry does not record hidden objects.

The effort for Photogrammetry process is economically justifiable, but processing of the data is very time-consuming similar to laser scanning. To achieve good result, the illumination of objects must be assured. Measured coordinates have to be regarded with suspicion as these values are not measured as through laser scanning, but are calculated due to evaluation of the different points of measurement.

For outdoor measurement, drones will perform photogrammetry. In this case, video files as output are preferable because they ensure automated optimal covering of the video-frames, contrary to images that should be fitted manually.

1.4.2 Comfort: Thermal Characteristics, Indoor Air Quality, Acoustic & Air-Tightness

Thermal Characteristics

With a strong presence in the energy efficiency development, the thermal design of buildings (including the walls) is important for controlling the amount of energy required to ensure thermal comfort throughout the year. The role of the thermal inertia and thermal insulation of the building are the principal topics that are widely studied in the literature.

Thermal and infrared multispectral camera is useful for energy auditing of building insulation, detection of air leakages, moisture detection, thermal performance, checks plumbing and piping;

Thermography is defined as the process of detecting and measuring heat variations emitted by an object under inspection and transforming identified changes into visible imagery.

In the context of building energy performance modelling, thermography can be a robust tool in recording, analysing and reporting actual energy performance of the buildings. Thermal images captured from buildings are directly influenced by energy performance deviations caused by insulation voids or thermal bridges (construction problems related to construction errors).

- Poor manufacturing of the building components

The incorrect technical manufacturing of the envelope building components can cause defective components characterised by technical attributes differing from the expected performances.

Windows with different thermal transmittance, panel façades with incorrect external joints, varying thicknesses of the façade panels as well as inconsistent insulation with dissimilar thermal



conductivity are examples of the possible manufacturing problems that could impact building energy performance and quality.

Indoor Air Quality

- CO₂

Indoor air quality depends on a variety of sources, such as occupants, finishing materials, cleaning products, equipment and activities carried out in the spaces; these sources emit various types of pollutants that are difficult to forecast and complex to monitor. However, the presence of people inputs CO₂ from breathing, with increasing concentration in the indoor air as the occupants exhaust the available air. The assessment of CO₂ concentration in the air covers the overall air quality, as the air changes required to contain the CO₂ levels guarantee a reduction of the concentration of other, more dangerous, pollutants, increasing the quality of the indoor air and thus providing a healthier environment for the occupants. Basically, a KPI calculated on the CO₂ concentration can provide a comprehensive and straightforward way to assess and measure improvement in the building ventilation to guarantee the users' health and well-being. This approach underpins the standard EN 16798 [1], where the indoor air quality assessment methodology provides a CO₂ KPI.

Remain the fact that the mere CO₂ could not be fully representative of problems that can occur in indoor environments. Other pollutants, relevant for the human health, should be investigated too. The most recognized are:

- Formaldehyde
- VOC
- PM
- BTX (Benzene-Toluene-Xylene)

The possibility to monitor those pollutants should also be considered case-by-case so to face problems specific of the buildings and district under investigation. In fact, the CO₂ represents well the air renovation rate: thus, a poor CO₂ KPI will surely identify also bad conditions from the other pollutants. However, in some cases, there could be the internal emission or outdoor inlet of other pollutants, which cause health problems even if the CO₂ is lower than the safety threshold.

- PM

Particle pollution is a mixture of solid particles and liquid droplets. The IEQ assessment monitors the air for two categories of particle size: PM_{2.5} and PM₁₀. These particles are very small and are measured in micrometers (µm).

PM_{2.5} particles are smaller than 2.5 micrometers (0.0025 mm) in diameter. Often described as fine particles, they are up to 30 times smaller than the width of a human hair. PM_{2.5} particles are small enough to be breathed deep into the lungs. This can cause health effects. Children, people over 65, pregnant women and people with existing heart or lung conditions (including asthma) are more



sensitive to the effects of breathing in fine particles. Symptoms may include wheezing, chest tightness and breathing difficulty. PM_{2.5} particles result from the burning of fossil fuels (such as coal), organic matter (including wood and grass) and most other materials, such as rubber and plastic. Motor vehicles, power plant emissions and bushfires are all major sources of fine particles.

PM₁₀ particles (often described as coarse particles) are smaller than 10 micrometers (0.01 mm) in diameter. High levels of PM₁₀ particles in the air can irritate the eyes and throat. People with existing heart or lung conditions (including asthma) can experience an increase in symptoms, including wheezing, chest tightness and breathing difficulty. Common sources of PM₁₀ particles include sea salt, pollen and combustion activities such as motor vehicles and industrial processes. Dust from unsealed roads is a major source of PM₁₀ particles.

Acoustics

A building's envelope has the primary scope to protect an indoor environment from the external one. One of the environmental influences is protection from noise through walls, roofs, windows and doors. There are several planning measures that minimize exposure to external noise: accurate selection of materials, thickness and construction systems of building elements, such as envelope mass and continuity; double-leaf construction, etc. Thus, façade sound insulation requires a lot of attention both during design stages and during renovation interventions. At the same time, to allow the correct planning of building envelope insulation and guarantee indoor noise protection, the evaluation of the environmental noise level is necessary. The transmission of noise across indoor environments is not considered since the renovation process regards only the building envelope.

Air-tightness

Air leakages are air infiltrations through the building envelope, which can be prevented if the building is sufficiently airtight (Figure 18). In this case, special attention needs to be paid to the junctions between the walls and other walls and floors, junction between windows frames and walls. If the joints are too wide, air leakage will occur, which negatively influences the energy performance. The design of the connections of the different elements is decisively important, as well as the survey to identify and quantify any installation errors or air infiltrations due to the deterioration of the sealants or joints. Especially in the renovation phase of an existing building it is important to carry out a survey before the renovation to detect where it is necessary to improve the airtightness and after the renovation to verify the new performance of the building.



Apart from infiltration, air also enters the building through ‘regular’ ventilation systems that are necessary to guarantee a comfortable and healthy indoor environment.

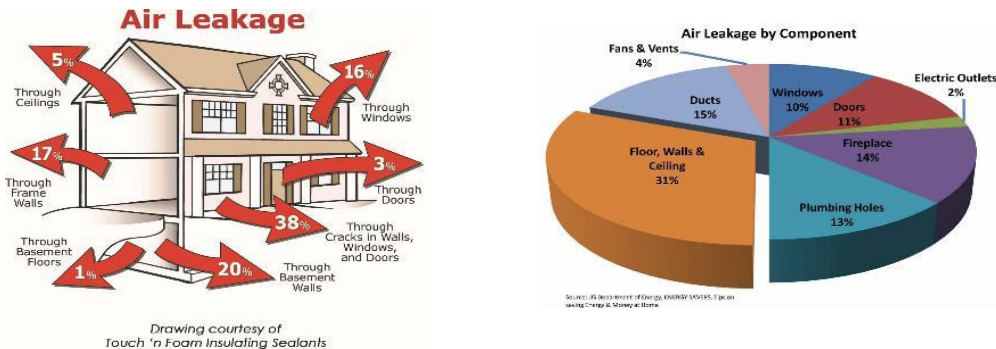


Figure 18 - Air Leakage representation (please note that the percentage estimated in the graphic depends by the methods adopted and by the Country)



2. Methods for Data Acquisition

This chapter describes methods for data acquisition and outlines recommended use and guidance to deal with.

2.1 Building/Architectural Layout

When it comes to acquiring geometrical information of renovation projects, the first thought is nowadays to collect data via laser scanning. On one hand this technique provides the most accurate input, on the other hand it is related to more complicated procedures than traditional measurement techniques. Depending on the aimed use case, one has to choose the right data acquisition method. It has to keep in mind that the post-processing effort of handling point-clouds is much too complicated in case the aimed use case is just requiring the functional spaces of the project. Therefore, it has also to be considered, whether available as-built drawings might lead to sufficient BIM models for a specific use case or if the efforts of transferring most exact information from a laser scan to an accurate BIM model will create even a greater benefit.

Beside these thoughts, the following chapter focusses on the more complex processes of transferring information from a laser scan towards a BIM model. But using available as-built drawings should be considered as well.

2.1.1 Generals on laser scanning

Laser-scanning is a methodology for data acquisition leading to obtain a final product which gives the user a series of information regarding the object under investigation. The laser-scanning product is a “Points cloud”, which provides a representation of the object under investigation in a 3D reference system. Nevertheless, the rough data from the laser-scanning data acquisition are not sufficient to guarantee the direct output of the object representation. Indeed, the data from the point clouds are difficult to interpret and, therefore, a correct analysis of the acquired data is needed to obtain one or more products able to meet the user needs. According to aimed results from laser-scanning methodology, different procedures for data treatment and elaboration can be performed and need to be planned before the data acquisition. Moreover, results need to be controlled during the use. Planning the stages of the laser data elaboration is crucial because the final product depends on these operations. Indeed, if the data treatment is incorrect, the final product could be inconsistent with reality. Therefore, planning the correct laser data treatment leads to obtain a valuable final product and to control the procedure step-by-step.

The laserscanner data treatment is a set of operations leading to a file which could be used for extracting relevant information, such as 3D colored model, solid image, precise orthophoto, photo plan, and others. It is based on the acquisition of one or more the point clouds. This set of operation can be defined by two different stages: i) treatment of laser scanner data; ii) creation of the final product.



2.1.2 Planning of data acquisition activities

As abovementioned, planning the data acquisition activities with laser scanning technology is crucial for having, as result, a satisfying product, with high precision and representation completeness. The selection of adequate tools and workflows, the study of the object(s) and the area(s) to be analyzed and the study of the tool itself are all important steps to analyze.

The success of the laser scanning data acquisition methodology is influenced by some variables, such as:

- Divergence issues

The signal emitted by the scanner is not perfectly coherent and arrives on the surface to be acquired with a finite area. The “spot size” dimension is around 1,5cm considering 10-20m distance. Since the emitted signal tends to diverge, its dimension increases with increasing distance. Therefore, it is useless to acquire data with scanning rate smaller than the dimension of the spot laser on the object. If the spot size dimension is small, the tool can acquire small details.
- Characteristics of surface

Sometimes, systematic errors occur due to the material and reflections of the analyzed surface. In some cases, these errors have been quite high compared to the tool measurement precision depending on used technology. Moreover, big disadvantages for data acquisition occur when acquisition is made for very reflective surfaces, specifically when the acquisition is in perpendicular direction, or in case the tool is backlight oriented. Since in both cases the points could be not acquired or could present big errors, it is important to adequately plan the scanning sequence for building facade surveys.
- Weather conditions

The laser scanner can work in different weather conditions. Nevertheless, it should be noticed that the data acquisition could not be performed in extreme conditions. As an example, too different temperature values (which may occur if the acquisition is made in two different moments) could modify the distance measurement due to a different air density. Moreover, it is not recommended to perform a laser scan if humidity is high; indeed, water droplets in the air or on the objects to be acquired could reflect the laser, leading to an unforeseeable measurement artifacts.

The activities need to be planned also analyzing:

- 1) The goal and the scope of the survey
- 2) The product/output format
- 3) The type of the object to be analysed (an area, a building, an infrastructure, a sculpture, ...)
- 4) The site, the external space or the environment hosting the object
- 5) The most adequate type of laser scanner
- 6) The timing for final product delivery
- 7) The availability of authorizations for accessing the area/site/environment hosting the object to be analysed
- 8) The weather conditions, in case of outdoor surveys.



Before planning and starting the data acquisition activities, it is recommended to do a preliminary inspection on the site where the survey will happen. The inspections aim to have a more complete and detailed survey campaign, also using cartographies and photos, which help in identifying barriers, non-accessible areas and poor survey capacities. Moreover, it is considered best practice to realize sketches which represent a schematic configuration of the area under investigation, the prediction of the scanner localizations, the extension of single object acquisitions, the position and the typology and name of targets. All this preliminary work helps in planning the activities correctly and in having a better estimation of the execution timing of the survey campaign.

Regarding the acquisition schemes, the catching conditions which can be adopted in case of external and internal areas are shown in the following Figure 19.

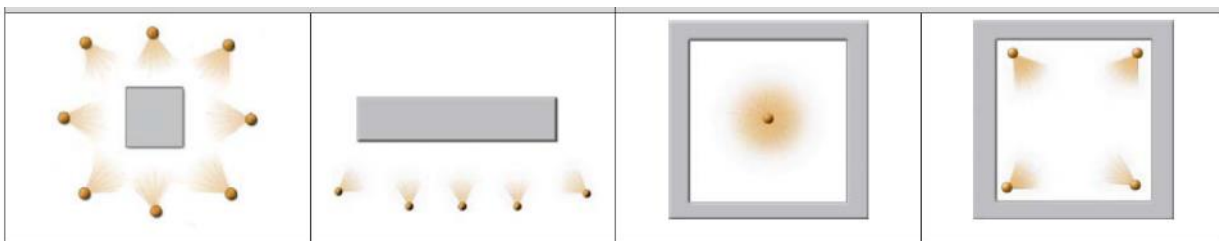


Figure 19 - Acquisition schemes for external and internal areas

Moreover, the complete documentation should include acquisitions from different altitudes, compatibly with the poor handling of scanning tools and the stability required for a correct measurement. Finally, it is evident that, for planning the data acquisition geometry, the scanner characteristics (such as the optimal distance from the surface) should be taken in count, together with the handling options around the object. In case the object is not acquired completely, it is necessary to perform other scans, which need to be aligned through algorithms of surface marching and/or through artificial targets. In case algorithms of surface marching are used, two adjacent scans must have points in common, and generally 30% of overlapping is considered (Source: S. Huang, Z. Gojcic, M. Usvyatsov, A. Wieser, K. Schindler - Predator: registration of 3d point clouds with low overlap arXiv preprint arXiv:201113005 (2020)). Each scan has its own reference system which, generally, matches with the center of the tool.

2.1.3 Laser scanner measurement and setting

The procedure for measure and setting the laser scanner includes the following operations:

- 1) Verification of obstacles absence on the path to be cover with the scanner

Before assembling the scanner, it is worth to verify that no barriers occur during the planning stage. This helps in avoiding that survey operations are interrupted or “contaminated” by the presence of obstacles, such as people moving, and also that the survey cannot be performed at all.



2) Arrangement of targets along the planned path

Once the absence of possible obstacles is verified, it is possible to place the reference targets, following the schemes defined in the planning stage. The target placement is crucial for the success of the survey campaign. Indeed, they are responsible of the correct scanning alignment. In case correct geo-referenced anchorage points are missing (total station, GPS points ...), the target is the only solution which allows two consecutive scans to be recognized by the elaboration software. Indeed, the laser scanning operator places the targets to guarantee that two consecutive scans have at least 4 targets in common. Targets can be spheres, cylinders or reflective plan elements; nevertheless, software prefer three-dimensional targets.

3) Assembly of the scanner

Systems are assembled on site, preferably next to the first acquisition place. The assembly procedure needs to guarantee the correct adhesion of the tool to the tripod, and the correct connection to the batteries (when they are not integrated in the tool) and to the external equipment (Reflex cameras). During laser scanner assembly, it could be necessary to locate a portable PC near it, with a LAN or WIFI connection, for the simultaneous storage of data on the PC and the preliminary result verification.

4) Positioning of the scanner in the initial reference point

The tool is located in the indicated position, ready for the data acquisition.

5) Verification of the boundary safety conditions

Before starting the data acquisition, it is important to verify that the tool does not obstruct the passage of vehicles and people and that operators respect the safety indications. Moreover, it is important to verify that the tool does not get in touch with water or fluids and that it is stable on the tripod and does not swing or slip, in order to guarantee a correct acquisition.

6) Starter and setting of the survey project

Once the laser scanner is switched on, some verifications on the devices and on the connection with other external systems, including the PC, are needed. In case storage systems do not work properly, the data could not be stored. After this verification, the survey project is set through the scans labelling, according to the planned codification.

7) Setting of the acquisition parameters

The parameters setting depends on the aims of the survey campaign, on the output typology required by the client and on the object under investigation.



Systems setting:

- Laser scanner FARO
 - Selection of a preset for interiors and exterior surveys
 - Customization of the parameters made by the operator, such as the scans resolution and the quality (accuracy, data precision in mm/distance)
- Laser scanner RIEGLE
 - Overview with default setting, resolution of 0,08 deg for the preview generation;
 - setting of an accurate resolution and reference distance;
 - setting of the field of vision
 - setting of the number of photo shoots for the generation of colors.
- Laser scanner GeoSLAM
 - Acquisition parameters are set as described by the tool manual, depending on the scanning area (exteriors or interiors). In case the scans are made for interiors, a distinction should be made between ordinary rooms and rooms which are geometrically particular (very tight spaces or tight and tall)
 - In case tight spaces are present, the default bonding box of the laser scanner should be modified
 - In case areas to be scanned do not present particular features, the window size of the tool should be increased.

8) Scan initialization

Scan is launched, ones no one is in the action radius of the tool.

9) Control of the result preview

The acquisition results can be controlled by looking at the display placed on the tool, or directly to the connected PC. If needed, targets can be identified and scans can be refined.

10) Completion of the survey campaign

All the scans are realized by placing the tool in the following identified positions. Moreover targets are placed along the path. The path is planned in a matter that the last and the first scans have a portion of the object under investigation in common. This helps in avoiding alignment and roto-translation errors between scans.

11) Archiving of acquired data

Once the data acquisition is concluded, data can be copied on the portable PC connected to the laser scanner, or on an external hard disk.



12) Disassembly of the scanner

The laser scanner is disassembled with care and placed in the bags.

13) Editing of daily written documentation

A synthetic report has to be written at the end of each survey day, till the survey is completed. The report has to include the acquisition date and a brief description of the parts/areas surveyed.

2.1.4 Treatment of Laser scanner data

In this stage, the following operations should be done:

1) Scanning alignment and record

To work on a complete three-dimensional model, it is necessary that, during the acquisition stage, the scans have the same reference system. The alignment stage is very important because it binds the precision levels and the accuracy of the final model. This is a semi-automatic procedure, depending on the operator work. In order to connect more scans, different methodologies can be used and it should be reminded that, in order to roto-translate the point clouds, minimum three targets in common among two scans or three targets to be referred to the topographic coordinates are required. Once the alignment stage is completed, the scans are linked together to provide a unique geo-referred point cloud. This operation can be performed manually by the operator, who chooses a minimum of three points in common between the fixed and the moved scans, guaranteeing an overlapping of minimum 40% between two consecutive scans. Alignment stage can be performed also automatically, with the use of targets which automatically orient the scans according to their spatial position.

2) Cloud coloring

After alignment, the cloud coloring can be performed by providing the RGB value to the points. Cloud coloring helps for the characterization of the cloud data and for a better visualization.

3) Cleaning, simplification, and filtering of the point clouds

Based on scans features, the data cleaning process can be performed also before the registration stage, especially in case the point quantity is high and it creates difficulties in the alignment stage. This helps in a better accuracy. Cleaning is the removal of the points which do not provide useful information and could generate data noise. Once the cleaning stage is concluded, some filters are applied on the registered point cloud. When a point cloud is filtered, the features of each point are modified, leading to a lighter cloud density. This is helpful for the trilateration stage.



4) Trilateration and generation of the mesh

Creating a triangulated model means converting the points cloud into meshes made of triangles. Trilateration provides a more intuitive visualization and helps in modifying the final model. This operation is also called “meshing”. Therefore, starting from the point clouds, a grid of connected polygons is creating, where the vertices are the points cloud. For this stage, it is important to consider the geometry of the point clouds, i.e. if the cloud is structured or non-structured. A structured cloud, which is typical of the triangulation laser systems, is made of points on a bi-dimensional grid on a logic order; in this case, the triangulation is simple and does not create problems during the editing stage. A non-structured cloud, typical of the time-of-flight (TOF) systems, is made of points, which are not tri-dimensionally organized; the points do not have a precise logic since they follow the movement of the laser generating them and the triangulation is quite complicated. Therefore, in this case, the Delauny algorithm needs to be used.

2.1.5 Creation of the final product

The products/outputs generated by the laser scanning process can be:

- Cartographies
- DTM (digital terrain model) models
- 2D representations (plans, prospectus, sections, ...)
- Degradation and disruption mappings
- Orth photos and referred photo plans
- Panoramic photos for 360° navigation
- 3D modelling, axonometries, perspectives, axonometry projections, ...
- 3D BIM modellings
- Navigations of 3D models in virtual and augmented reality

2.1.6 Existing as built drawings

Renovation projects in general cover older buildings. Often these buildings are not registered digitally in any kind of way. When they have been built, there was no CAD software available. That’s why often the corresponding construction drawings are non-digital. Range of drawings can be from manual made on paper up to digital *.dwg files. Especially the manual ones often are a real challenge to handle. Dimension or text are hard or not readable, texts are missing, etc. Scanning these drawings may also cause deformation.

2.2 Thermal characteristics

2.2.1 Thermograph

Thermographic surveys are realized with the use of infrared cameras, called “thermal cameras”, which aim at visualizing and measuring the thermal energy emitted by an object, as shown in the following Figure 20.

BIM-SPEED D1.1 – Methods for architectural, structural, thermal 3D data acquisition of existing buildings



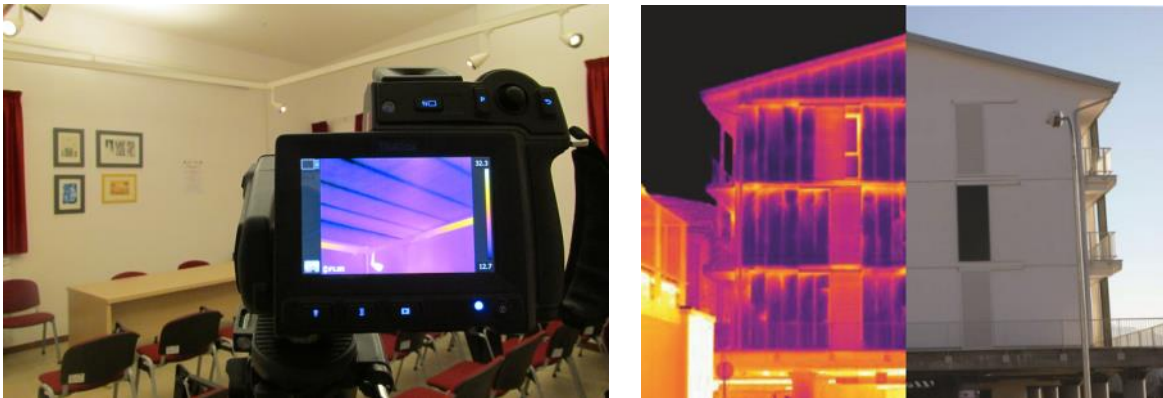


Figure 20 - Thermograph for building applications

Thermal energy emits light at a very large wavelength which cannot be seen by the human eye and can be perceived as heat.

All elements having a temperature higher than the absolute zero emit heat and radiations in the infrared field. This statement can be verified by the Planck law (i.e. the higher the object temperature is, the higher number of infrared beams it emits).

With the use of the thermal camera, non-destructive and non-invasive surveys can be performed. Thermal cameras detect the radiation in the infrared field of the electromagnetic spectrum and make measures related with the radiations emissions. This tool can detect the temperatures of the analyzed objects through the measurement of the intensity of the infrared radiation emitted by the object and allows visualizing absolute values and temperature variations of the objects.

The amount of the radiations emitted by the object increases with the increase of its absolute temperature, with the following equation [1] from Stefan-Boltzmann:

$$q = \varepsilon \cdot \sigma \cdot T^4 \quad [1]$$

Where:

σ is the Stefan-Boltzmann constant, equal to $5,6703 \cdot 10^{-8} \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$;

ε is the emissivity of the emitting surface (ranging from 0 and 1);

T is the absolute temperature (K).

Thermograph aims at identifying the thermal anomalies of the energy emission.

The results of the thermographic surveys are strictly related to the environmental and climatic conditions of the site. The temperature, the humidity and the wind velocity influence the results quality because they modify the conditions of the heat exchange among the materials and the environment.



For building data acquisition, thermographs aim at obtaining the following results:

- Detect the morphology of the plastered masonry
- Identify cavities
- Identify the presence of different materials
- Highlight the structure and reveal anomalies or inconsistencies
- Verify the presence of humidity.

2.2.2 Setup

When taking a thermal image, attention should be paid at the right field of view and at the correctly focus of the thermal image on the area. As with normal digital photography, neither the field of view nor the image can be changed, once the thermal image has been saved. To obtain a perfect thermal image, the following changes can be made in the thermal imager and in the analysis software (FLIR Tool +):

- Modify the setting of the emissivity and the compensation of the reflected temperature (RTC). This can also be done point by point or by sections with professional analysis software such as Flir Tool +;
- Choose a suitable color palette (e.g. iron, rainbow, etc.) in order to have a thermal image with high contrast and easy to interpret;
- Manually adjust the temperature scale, which helps in improving the temperature or the color gradation of the thermal image.

Moreover, the followings tips are provided to take a high-quality thermal image:

- consider, prevent or shield all sources of interference;
- the surface of the measuring object should be free of optical and thermal sources of interference; therefore remove covers and objects that cause interferences;
- Change position when measuring to identify any reflection. The reflections move, while the thermal characteristics of the measuring object remain in the same place, even if the inclination changes;
- the measurement area should not be larger than the measurement object;
- keep the measuring distance as small as possible;
- use an appropriate lens for the type of measurement;
- for an exact measurement of the details, it is recommended to use a tripod;
- the design of the measurement object must be known, in order to correctly identify the thermal characteristics;
- use an integrated digital camera in addition to the thermal imager; in this way, it is possible to use real images for analysis at a later time;
- Write down all the environmental conditions, measure and document them where necessary for subsequent analysis of the thermal images.



2.2.3 Measurement

In the construction sector, infrared thermography is used for non-destructive investigations that aim to detect the following three pathologies:

- detachments of plaster;
- thermal bridges;
- Infiltration of humidity.
- Heat transfer

Plaster detachment

Thermography allows an in-depth assessment of the state of conservation of the building coatings, facilitating the preventive assessment of times, costs and methods of intervention. Thermographic investigation techniques exploit the objects' emission of electromagnetic energy, in infrared band, detected by cameras, which are sensitive to this wavelength. Thermal images are obtained by converting infrared thermal energy into electrical signals, which return video images in false color scales (each color corresponds to a detected thermal level).

The radiant energy of an object is a function of its surface temperature, and with appropriate calibrations, the thermographic image offers an indirect measurement of the temperatures on the building surface. Thermal behavior of a material is conditioned by thermal conductivity and specific heat: differences between the values of these two parameters bring the component materials of a wall to assume different temperatures, if subjected to one identical thermal stress.

The detachment of the plaster from the wall is a pathology not always visible to the naked eye, since it is not said that the detachment is accompanied by the fall of the material. It often happens to notice swellings in the walls of the buildings, which are symptoms of an ongoing detachment. With thermography, it is possible to search for the detachments of the plaster in the whole wall, quickly and without any invasive intervention.

The detachment of the plaster is detected during the wall heating phase (generally during the first sunshine), because the air present between the masonry and the swollen plaster acts as an insulator and makes the outer surface warmer in that area. The remaining portion of the wall, on the other hand, is colder because the heat does not find insulating barriers, it penetrates the wall and the external surface makes more time to get warm.

This phenomenon is clearly visible with low plaster thicknesses and adequate wall heating. The latter, especially for the relief of detachments of plaster from internal walls, can be artificially created through the help of heat generators.

Being an external inspection, it is very important to consider the weather and climatic conditions, the atmospheric conditions, the temperatures involved and, above all, the orientation of the building with respect to the cardinal points.



The technique offers the possibility of making high-distance measurements without using scaffoldings and the possibility to obtain real-time data, which are immediately reproducible in digital format.

The fundamental use of the thermographic technique is in monitoring the state of health of the plaster (also historical) and wall paintings, with evaluation of adhesion to the substrate and interlayer (discontinuity, risk of detachment and loss of matter).

The investigation is based on the principle that the temperatures of the tiles that adhere well to the masonry will have trends similar to those of the masonry itself, while the detached ones will warm up and / or cool with a different timing.

Based on this principle, inspections should be carried out after the sun has irradiated the surfaces, that is, when tiles return the accumulated heat to the surrounding atmosphere. The methodology is to investigate the walls facing East during the morning, the walls facing South during the afternoon and the walls facing West at sunset. The best time of the year to investigate is from mid-April to mid-October; indeed, during winter, the presence of thermal bridges hides any detachments.

Thermographic investigations are highly reliable if performed in compliance with some simple rules, which are:

- surfaces irradiated by the sun during the cooling phase are analyzed;
- the period for carrying out the analyzes is from April to November and, in any case, with the heating off;
- The surfaces facing East are analyzed in the middle of the morning, those facing South in the mid-afternoon and those facing West at sunset.

This technique also highlights surfaces of the wall covering where restoration works have been carried out, because the filler materials have different emissivity than the original ones.

Thermal bridge

A thermal bridge is an area with less insulation due to construction features, such as metal fasteners, beams, slabs, concrete columns. The heat runs along the path with less resistance, i.e. from the heated space to outward. Very often, the heat "takes the shortcut" by going through an element, that has a much higher conductivity than that of the surrounding material: this phenomenon can be described as a "thermal bridge".

Typical effects of thermal bridges:

- decreased temperatures of the internal surface; in the worst cases this can lead to condensation problems, especially in the corners;
- much greater heat losses;
- Cold areas in buildings.

Stable environmental conditions are especially important for infrared measurement. This means that the climate and objects in the measurement site, as well as any other influence, should not change during the measurement. This it is the only way to evaluate possible sources of interference and document them for subsequent analysis. For outdoor measurements, the weather conditions must



be stable and the sky cloudy to shield the measurement object from direct sunlight and from "cold diffuse celestial radiation".

It should also be borne in mind that the measuring objects can still be hot because of the previous exposure to sunlight due to their ability to store heat. The ideal measurement conditions are:

- stable weather conditions;
- cloudy sky before and during the measurement (for outdoor measurements);
- absence of direct sunlight before and during the measurement;
- absence of rainfall;
- dry and free of thermal sources of interference object surface;
- absence of wind or air flows;
- absence of sources of interference in the measurement environment or in the transmission path;
- High and known emissivity of the surface of the measuring object.

For the determination of thermal bridges, a difference of at least 15°C between the external temperature and the internal one is recommended.

Moisture infiltration

Damages caused by humidity are the most common form of building deterioration. Air leaks can cause condensation inside the walls, floors, or ceilings. Wet insulation requires long time to dry and becomes the privileged place for the growth of mold and fungi. Scanning with a thermal camera aims at detecting humidity in areas that the human eye may never see. The sense of smell could signal its presence but not provide indications on where it is forming. A thermographic inspection will determine where the humid areas are located, which encourage the growth of molds, which are potentially harmful, and which cause health problems.

Humidity can be difficult to spot and the trick is to change the temperature of the building. The materials with humidity tend to be clearly visible since they change temperature much more slowly than dry materials.

The thermal mapping of the humidity is often clear and evident, especially if the right conditions are present for evaporation of the wet surface. In this case, the surface will appear cold. The moistened building materials are more conductive and, during a thermal transition, have a large thermal capacity compared to dry ones. In this situation, thermal mappings are not always clear or evident. Great care should be taken in the verification that there are the right conditions to identify humidity, if present.

Thermal transmittance

There are different standards [2], [3], [4] for thermal transmittance assessment, as shown in Figure 21, related to different kind of test cases (calculation, laboratory test, in situ test).

The calculation method is based on the appropriate design thermal conductivities or design thermal resistances of the materials and products for the application concerned.



The method applies to components and elements consisting of thermally homogeneous layers (which can include air layers). Of course, to apply this method the stratigraphy of the component must be known.

Regarding the laboratory test, procedures described in the standard EN 8990 [3], the U Value of the component should be evaluated by monitoring the electrical power needed to keep the temperature difference between the different sides of the wall at least at 20°C. The guarded hotbox comprises a guard chamber (commonly referred to as the hot chamber) with an inner metering box, and an environmental chamber (commonly referred to as the cold chamber) separated by a central mask wall. An opening provided in the mask wall accommodates the component to characterize.

Of course, only method that can be applied on an existing building is the third described in the ISO 9869-1 [4] standard (Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance. Part 1: heat flow meter method). According to this standard, the U Value is estimated based on heat flux and temperature measurements by means of heat flux meters and thermocouples. The main issue in in-situ measurements is the temperature fluctuations inside and outside the building, causing a fluctuation of the heat stored in the building component, a wall for instance. The fluctuation of the stored wall heat, which depends on the thermal mass of the wall itself, influences the U Value calculation. That influence can be neglected only if the measurement is performed during a long period since the averaging process allows reaching the actual U Value of the wall. The monitoring period required by the standard is of at least 72h. The U Value calculation is based on a progressive average approach, as shown in the following equation [2].

$$U = \frac{\sum_{j=1}^n q_j}{\sum_{j=1}^n (T_{ij} - T_{ej})} \quad [W/(m^2K)] \quad [2]$$



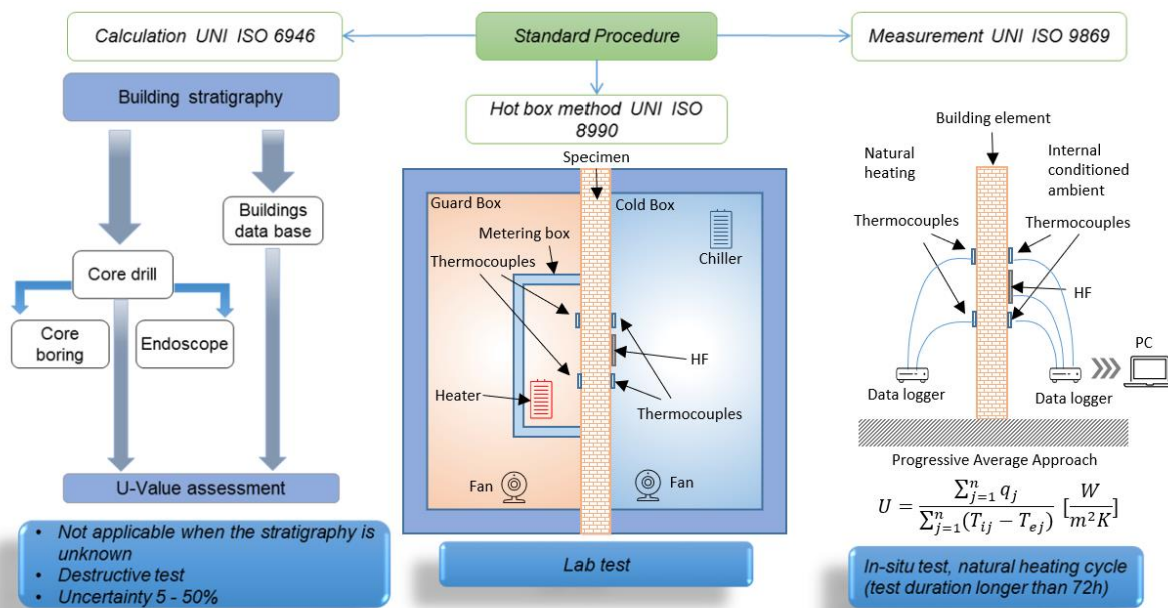


Figure 21 – Overview of the current standards for thermal transmittance assessment

Where q_j is the value of the flux through the component measured with the heat flux transducer. T_{ij} and T_{ej} are respectively the value of the internal and external temperature at the opposite sides of the monitored component.

The methods described so far make use of contact sensors (thermocouples and heat flow meters) that limit the evaluation of the thermal transmittance to punctual values in the space. Consequently, the eventual presence of a thermal bridge in the wall under test cannot be taken into consideration thus introducing an underestimation of the thermal transmittance. For this reason, in the last years the research has been focused on the use of IR sensors for thermal transmittance assessment [5]. IR sensors practically exploited in thermal cameras allow framing large portions of building envelopes and identifying areas with anomalous thermal behavior (local thermal bridges, areas with high moisture ...) which can be rejected from the analysis. The main limitation of this approach is related to the low value of accuracy, up to 20%, related to the strong dependency of the IR sensor on the environmental conditions (external radiation, wind) [6], that causes a low repeatability index for light walls and super-insulated structures. To reduce this limitation, some works have proposed to use thermal camera for the estimation of the thermal transmittance by measuring the heat flow and the surface temperature while the wall under test was in steady-state conditions ([7], [8]) or quasi steady-state conditions [9].

2.2.4 Results

In the construction field, for the relief of the three main pathologies (detachment of plaster, thermal bridges and humidity) "qualitative" thermographic investigations can be performed, which are aimed at determining the presence or absence of a problem and at establishing its extension;



therefore the results produced can be represented by graphic images that are appropriately evaluated and commented.

Survey of plaster detachment

With reference to the evaluation of the state of conservation of the wall coverings, this method allows to obtain excellent results with considerable time and costs savings. In fact, for this technique, no preventive assembly of scaffolds is necessary since the surveys are performed remotely also using the "telephoto" lens. This system allows remote detection of the surface temperature of the wall covering. Surfaces subject to detachment or poor adhesion, thanks to the solar heating or through forced ventilation of hot air, overheat (temperature difference of the order of 2 - 3 ° C), since they do not have possibility of transmitting heat inside the masonry.

This thermal increase is detected and highlighted in the thermogram and the results can be emphasized by appropriate color palette provided by the Flir Tool + software. In this way, with a scan of all surfaces, it is possible to monitor the overall conservation status of the building. Figure 22 shows the areas with higher temperature, which identify the detached plaster.



Figure 22 – areas with higher temperature, which identify the detached plaster



Survey of Thermal bridges

The thermal bridges in the thermogram appear as "hot" areas compared to other portions of the building, because they are preferential ways for dispersing heat to the outside of the building. In Figure 23 the identification of thermal bridges are shown as warmer areas.

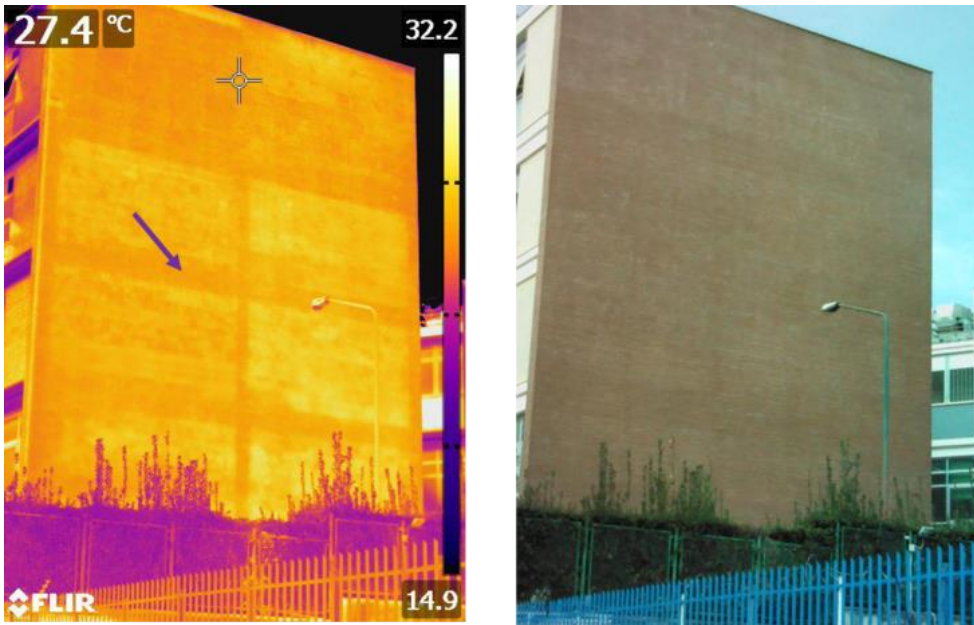


Figure 23 – identification of thermal bridges are shown as warmer areas

The method presented in [11] introduces a parameter able to express the thermal bridge effect on the building element thermal transmittance. According to the standards, a thermal bridge is individuated by its linear thermal transmittance which influences the direct heat transfer coefficient of a building element, H_D , given by the following equation [4]:

$$H_D = \sum_i A_i U_i + \sum_k l_k \Psi_k + \sum_j \chi_j \quad [W] \quad [4]$$

where A_i is the area of the i -th element of the envelope, U_i the thermal transmittance of the i -th element, l_k the length of the linear thermal bridge k , Ψ_k the linear thermal transmittance of the linear thermal bridge k and χ_j the point thermal transmittance of the point thermal bridge j .

In other words, the linear thermal transmittance of a thermal bridge represents the transmittance of an area where the thermal properties are significantly different from the rest of the element. Consequently, the temperature in this area, when a thermal gradient exists between the two surfaces of the element, differs with respect to the sound area and an IR thermal camera can appreciate this difference. In terms of heat flux across the building element, it can be stated that in stationary conditions the heat flux through the sound area is one-dimensional and the temperature is a function of the thickness and thermal conductivity of the layers that constitute the wall. The 1D heat flux across the sound area, Q_{1D} , is given by the following equation [5]:



$$Q_{1D} = h_{1D,i} * A_{1D} * (T_i - T_{1D,is}) \quad [W] \quad [5]$$

where $h_{1D,i}$ is the convective coefficient, A_{1D} the extension of the sound area, T_i the indoor air temperature and $T_{1D,is}$ the wall internal surface temperature.

In presence of a thermal bridge the heat flux (Q_{tb}) is not anymore 1D, because the temperature is not constant through the whole surface of the wall. Nevertheless, an IR thermal camera is able to measure the temperature of the entire wall surface and, at each pixel of the camera, a temperature level, $T_{pixel,is}$, can be associated. The equation [6] can be rewritten as following:

$$Q_{tb} = h_{tb,i} * A_{pixel} * \sum_{p=1}^N (T_i - T_{pixel,is}) \quad [W] \quad [6]$$

where $h_{tb,i}$ is the convective coefficient and A_{pixel} is the area of the single pixel (depending on IR camera spatial resolution).

At this point a parameter assessing the incidence of the thermal bridge on the global wall thermal transmittance can be introduced. The incidence factor of the thermal bridge I_{tb} is defined as the ratio between the heat flowing in real conditions, when a thermal bridge exists in the wall, and the heat flowing in absence of the thermal bridge.

$$I_{tb} = \frac{Q_{tb}}{Q_{1D}} = \frac{h_{tb,i} * A_{pixel} * \sum_{p=1}^N (T_i - T_{pixel,is})}{h_{1D,i} * A_{1D} * (T_i - T_{1D,is})} \quad [7]$$

Introducing equations [5] and [6] in [7] under the hypothesis of constant laminar flow, i.e. $h_{1D,i}=h_{tb,i}$ and being $A_{1D}=N*A_{pixel}$ the incidence factor of the thermal bridge can be written as:

$$I_{tb} = \frac{A_{pixel} * \sum_{p=1}^N (T_i - T_{pixel,is})}{N * A_{pixel} * (T_i - T_{1D,is})} = \frac{\sum_{p=1}^N (T_i - T_{pixel,is})}{N * (T_i - T_{1D,is})} \quad [8]$$

Survey of humidity

A building's issues related to humidity and water infiltration may only appear after the surface has been exposed to a heat source, such as sunlight.



The presence of water changes the conductivity and thermal mass of the building material. It can also modify the surface temperature of the material due to evaporative cooling. Thermal conductivity is the ability of a material to conduct heat, while thermal mass is its ability to store heat; therefore the presence of humidity is shown in the thermogram as "cold" areas, as identified in Figure 24.

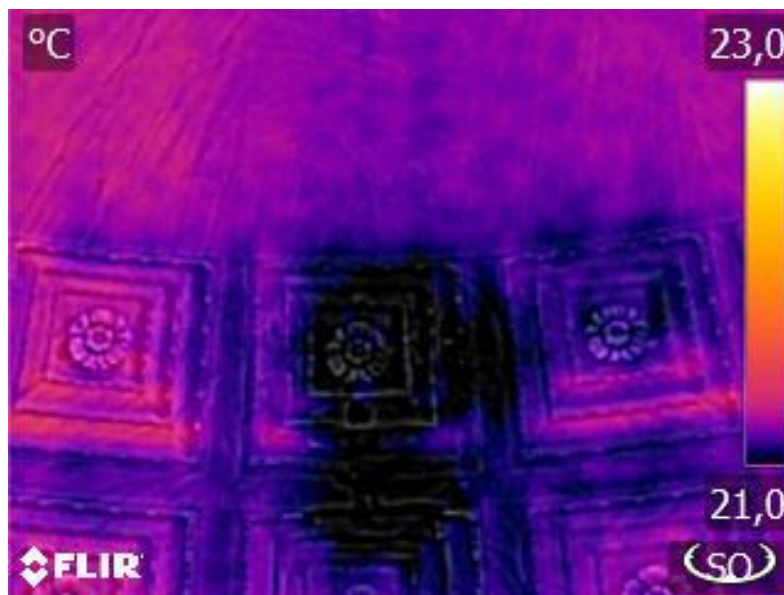


Figure 24 – Identification of humid areas

Thermal transmittance

The use of thermography for building thermal transmittance estimation has been regulated by the standard ISO 9869-2-2018 [10]. The U Value calculation is based on the following equation [3]:

$$U = h_{in} \frac{1 \sum_{i=1}^{j+n-1} (T_{ij} - T_{sij})}{n \sum_{j=1}^{j+n-1} (T_{ij} - T_{ej})} \quad [W/(m^2K)] \quad [3]$$

where T_{ej} is the outdoor temperature, T_{ij} the indoor temperature, T_{sj} the plane radiant temperature and h_{in} the heat transfer coefficient.

The ISO 9869-2 also introduces a method for the in-situ estimation of the heat transfer coefficient (h_{in}) that is considered critical in real conditions. The heat transfer coefficient is determined using a thermal camera and an active heat flux sensor.



To estimate the thermal transmittance the standard suggests performing the measurement at night for at least three consecutive days; in alternative the measurement stops when the thermal transmittance, calculated by the moving average method, converge to a steady value whose variation is within 10%.

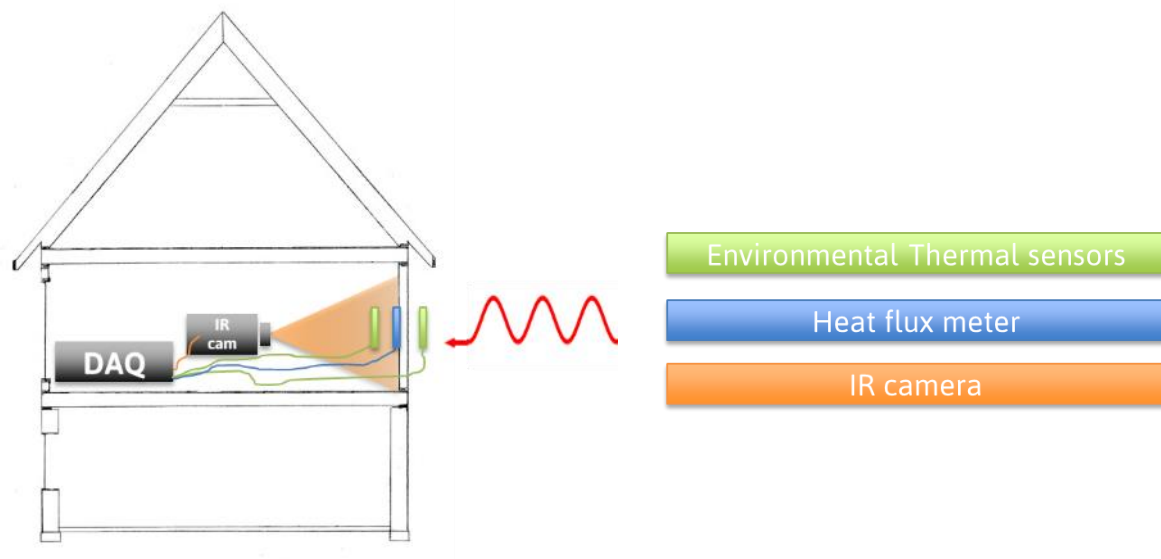


Figure 25 – Thermal transmittance measurement setup according to the standard ISO 9869-2

Soft sensing technique with IR thermal camera

To improve accuracy of building element transmittance estimation based on thermal data measured by an IR camera and to reduce the amount of experimental data needed for an accurate estimation of the thermal transmittance from the building element surface temperature measured by the IR camera, the thermal parameters as the conductivity of the building component can be take in consideration by optimizing the heat flow balance.

This method is based on the integration between experimental data, measured by an IR camera, and numerical data estimated by an analytical model, and therefore it can be called a hybrid method or else “Soft Sensing” (sensor output combined with software model). The Soft Sensing method is based on a mono-dimensional model of the building element under test implemented in Matlab. The mechanical and thermal characteristics of the element (density, ρ , conductivity, k , specific heat, c_p) are guessed in the first loop. The boundary conditions are uniform heating on a wall of the element with a variable thermal load (sinusoidal in Figure 26) and free convection at both the walls. The air and wall temperature on the side of the thermal load are the inputs for the model that calculates the heat flux across the building element and the air and wall temperature on the opposite side with respect to the thermal load on the basis of that inputs and boundary conditions. Because the wall temperature and the heat flux are measured experimentally, the optimization tool minimize the difference between the measured temperature/heat flux and the calculated ones by varying the mechanical and thermal characteristics of the element (density, ρ , conductivity, k , specific heat, c_p). When this difference is minimal, the optimization tool



closes the loop and gives the real conductivity of the element from which the thermal transmittance can be easily calculated.

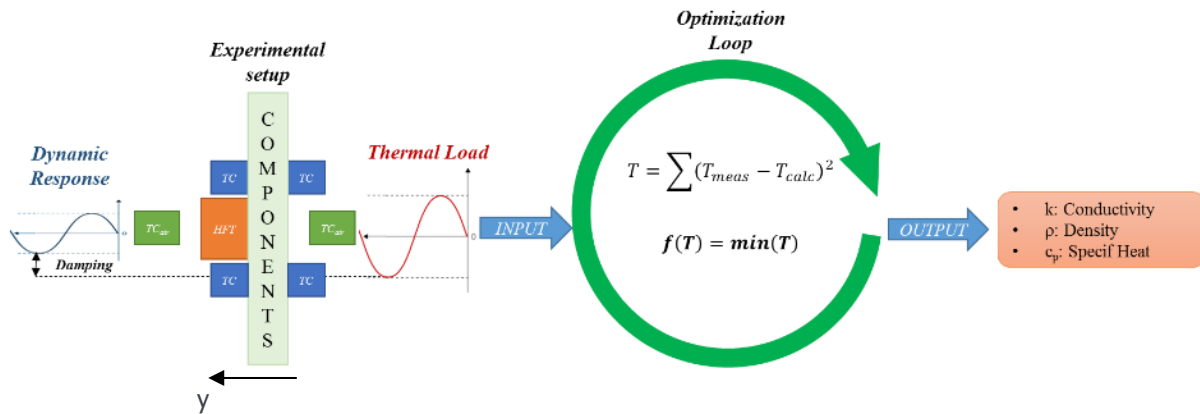


Figure 26 – Overview of the Soft-Sensing approach

2.2.5 Data management

The management of the data acquired by the FLIR T640bx camera is performed using the FLIR Tool+ software that allows exporting the results directly to .pdf files, or by using the appropriate tool in word allowing the management of thermograms and the creation of easily manageable technical reports.

2.2.6 Record storage

Since there are no specific regulatory requirements that report the duration of the records storage, the reports can be saved on pc, external HD and/or on cloud platforms.



2.3 Acoustic Data

2.3.1 General on indoor acoustic comfort

It is demonstrated that the acoustic comfort is one of the most influential factors on human perception and behavior, which significantly contributes towards the regulation of their physical and psychological well-being. The acoustic comfort is related to the noise that is a pollutant that, in the building sector is defined as “unwanted, unexpected and unpleasant sound” that penetrates external walls, party walls and separating floor structure, and cause of concern of the inhabitants and users of the buildings (WHO [25]). In addition, the WHO identified a considerable number of effects of excessive noise levels into living environments, including annoyance, sleep-disturbance and irritability, and long-term health effects such as cardiovascular disease, heart illness, hypertension and psychiatric problems.

The evaluation of indoor acoustic comfort is related to the measurement of the indoor sound pressure level and to the assessment of the sound insulation of facades and partitions. Since the acoustic insulation of the façade is the main building characteristic that can block the noise to get into the building, this indicator, that the standards call Sound Reduction Index, is the most suitable to define the acoustic performance of the building itself. Unfortunately, the sound insulation index is a global indicator characterizing the whole façade, partition or element of them. In order to identify loss in insulation within the building fabric or in the connection of building elements spatial sampling of the acoustic field is required. This can be performed by using a set of sound pressure sensors (microphones) able to measure the acoustic sound pressure level distribution all over the building façade and to identify insulation loss where the level of sound pressure is higher with respect to the surrounding areas.

2.3.2 Sound Pressure Level measurement (microphones, sound level meters, and sound intensity probes)

The standard EN ISO 16283 –Part 3 [12] indicates the procedure to measure the façade sound insulation in field. Sound pressure level, called L_{Aeq} , must be measured inside and outside the building. The A weighting indicates that the value was filtered to focus on the frequencies to which the human ear is sensitive. The outdoor measurement must be performed at a distance of 2 m from the building facades (or 1 m in the case of the balcony). Real external noise can be assumed as sound excitation for the measurements or it is possible to use a calibration directional sound source. The sound pressure levels are measured in the frequency range between 20 Hz and 10 kHz.



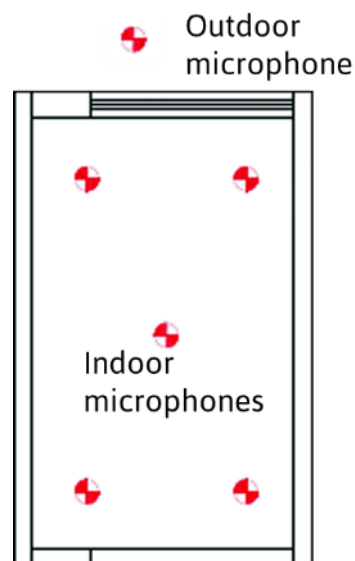


Figure 27 Microphone positions for façade insulation measurement [12]

Noise levels measurements can be performed with ¼” condenser free-field measurement microphones (Sensitivity 20 ± 2 dB, ref 1V/Pa).

A minimum of five microphone positions shall be used in each room. These shall be distributed within the maximum permitted space throughout each room. No two microphone positions shall lie in the same plane relative to the room boundaries and the positions shall not be in a regular grid (Figure 27).

Fixed microphones may be used without an operator in the room by using a microphone fixed on a tripod. Alternatively the operator can be present in the room with the microphone fixed on a tripod, or with the operator using a manually-held microphone at a fixed position; in both cases the trunk of the operator’s body shall remain at a distance at least an arm’s length from the microphone. Averaging times shall satisfy at least 6 s in the frequency range of 100 Hz to 400 Hz. For 500 Hz to 5 000 Hz, it is permissible to decrease the time to not less than 4 s. For 50 Hz to 80 Hz, the averaging time at each individual microphone position shall be at least 15 s.

2.3.3 Beamforming technique

A map of the sound pressure level at the surface of a wall gives an insight on the regions where the insulation performance is low. This may arise because of a defect in the fabrication of the panel or from leakages at the junctions between components, e.g. at window frames. The apparatus retained for the sound pressure mapping is a microphone array, made of five ½” microphones moved sequential at different position in order to have a global array of at least 20 sampling positions. Such kind of method can be applied only under the hypothesis of stationary external noise. The sound pressure mapping is performed by a process called beamforming, which has numerous formulations, even though the most conventional is the delay and sum one [13].



It is worth noting that the mapping of the sound pressure level can be performed using most commercially available microphone arrays. MEMS array can also be found in the market with the advantage of being cost-effective and of requiring a minor number of steps for performing a measurement.

2.3.4 Determination of the location of weak elements of the building envelope to be dealt in the renovation design

Acoustic weak points in building facades and partitions can be localized by performing measurement of sound pressure level or acoustic intensity with a sufficient high spatial resolution. Those kind of measurement can be realized by a set of microphones, whose number depends on the spatial resolution and frequency range required, and applying an acoustic beamforming procedure or by using a sound intensity probe scanning sequentially or continuously different positions in space.

Acoustic Beamforming is a method of spatial filtering or localization of the specific sound source from a miscellany of other insignificant sources based on the direction of arrival. The source localization is governed by the time difference in which the sound reaches the microphone array.

A beam former scans over the predefined region where the sound source is located at all possible positions. The point giving the maximum beamforming output is the location of the source or of the weak element, in the specific case of building walls.

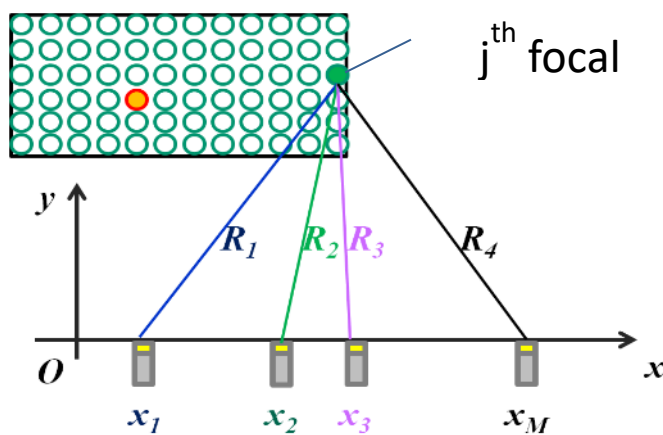


Figure 28 – Beamforming scan concept, where x_1, \dots, x_M are the microphone positions, the green dots are the focal points located on the wall under test where the beamforming is calculated and the red dot is the possible hot spot (leakage and/or missing insulation)



The acoustic results are identified to produce visual noise maps where the colors depict the sound pressure level drops and peaks.

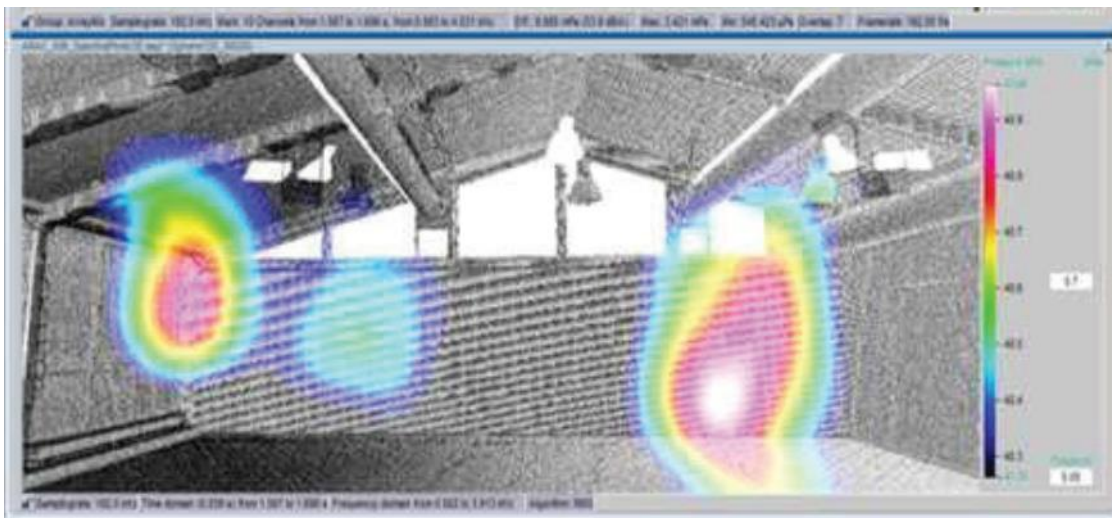


Figure 29 – Beamforming map of a partition wall in a building

Sound intensity scanning can be used instead of beamforming for acoustic leaks localization. It makes use of a sound intensity probe consisting of two microphones and based upon the measurements of the sound field of two closely spaced positions in space. From the sound pressure measured by the two microphones, the sound intensity can be estimated. Sound intensity estimation is essentially a phase estimation of the sound field. Sound intensity enables source ranking by calculation of how much sound energy or sound power is radiated from the various parts of a sound source. One of the advantages of using sound intensity is that it gives directional information, because sound intensity is a vector quantity.

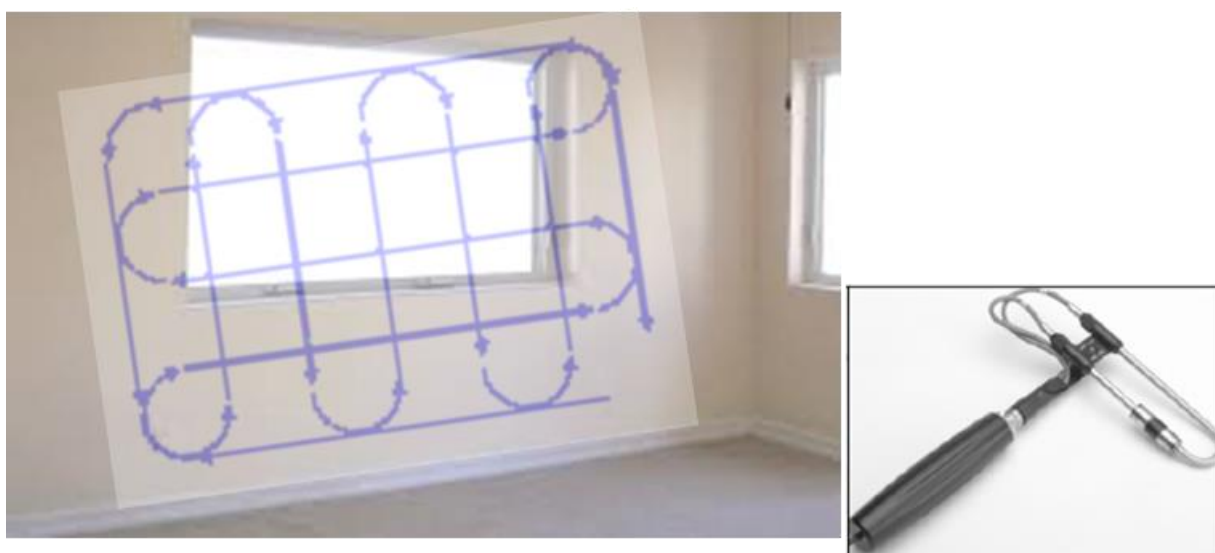


Figure 30 – Sound intensity probe, on the right and typical continuous scan all over a building external wall



2.4 Air-tightness

2.4.1 General on room air-tightness

An important key performance indicator of a building is the air-tightness of the facades and their elements. Air tightness can be measured by performing different type of tests which can be categorized in air pressure or air leakage methods.

The standard method is based on the measurement of the air permeability of a building or part of it while it is subjected to pressurization and depressurization and it is defined in the standard ISO 9972:2015 Thermal performance of buildings — Determination of air permeability of buildings — Fan pressurization method [14]. It gives a quantitative measurement of the air flow rate through the room partition tested over a range of indoor-outdoor static pressure differences. Typically, an air permeability test consists in the pressurization of the room by means of an air moving equipment as a large fan or blower mounted on a window or a door and for that reason it is called blower door test. The standard experimental set-up is reported in Figure 31. The experimental procedure is the following: the blower pumps in or draws off from the room a known air flow so that the pressure gradient between the exterior and the interior of the room is kept at a fixed value which is conventionally 50 Pa.

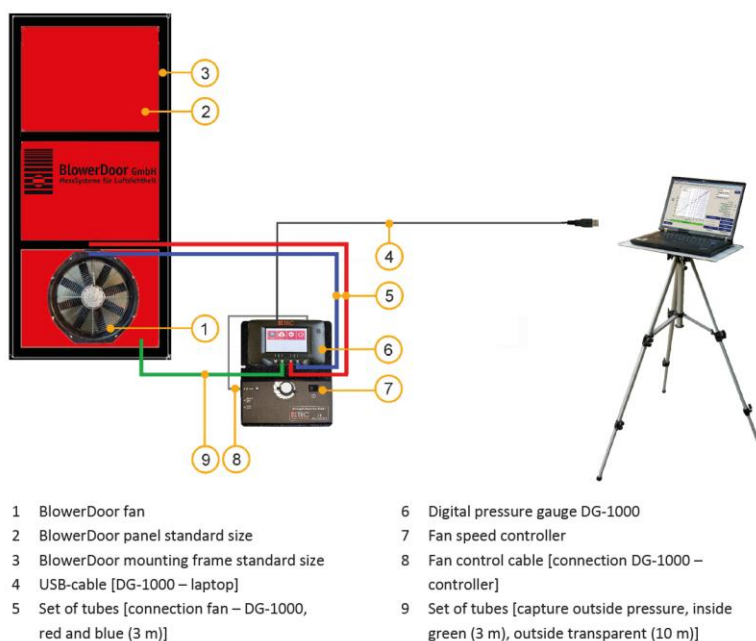


Figure 31 Blower door test set-up

The blower door (Figure 31) test gives thus a quantitative measurement of the air leakages through the building fabric but, it being a global measurement of the air flowing from the interior of the room to the exterior or vice versa, depending on the pressure gradient, it is not able to identify where the leakage is localized.



For that reason, other tests are employed to spatially pinpoint air leaks across the building façade and on the connections between building elements. The most conventional methods are based on ultrasonic testing and they are described in detail in the following section.

2.4.2 Ultrasound sensors

Ultrasound technology is an efficient system for leak detection in the sector of pipelines and transmission lines, see [14]-[17]. The most typical applications include:

- bearing inspection
- testing gears/gearboxes, pumps, motors
- steam trap inspection
- valve testing
- detection/trending of cavitation
- Leak detection in pressure and vacuum systems.

All operating equipment produces a broad range of sound, but leakage produces noise concentrated in the high-frequency range, mainly ultrasonic, and therefore it is easy to discriminate it from the background noise. Beside this, a shortwave signal tends to be fairly directional. Therefore, it is relatively easy to detect its exact location by separating these signals from background plant and operating equipment noises. The ultrasound intensity variation allows applying this technique also in condition monitoring in the three basic categories: mechanical inspection, leak detection and electrical inspection [17].

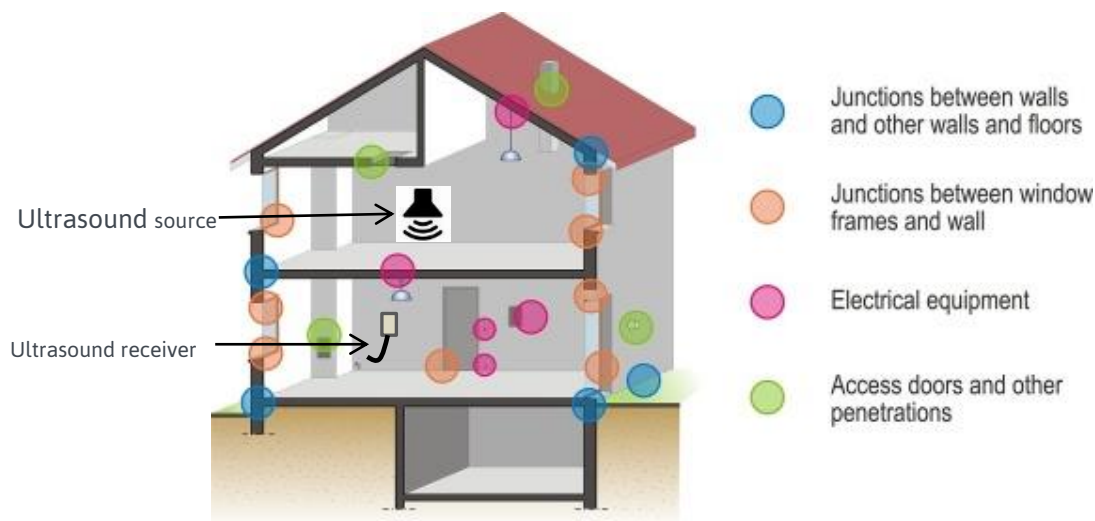
In the building the current standard (UNI EN 13829) [18] for airtightness evaluation establishes the use of Blower-door tests, which requires the application of a pressure gradient between the interior and the exterior of the envelope. Usually, air-moving equipment is mounted on a window, door, or vent opening in the room to generate a pressure difference of 50 Pa. The air flow induced by this gradient is registered and compared with standard value for similar building, to assess if the airtightness is acceptable. The instrumentation set-up and measurements results could be very different in function of the building design and boundary conditions.

This method allows establishing if there is a leakage or not, but it does not let to localise the leakage. For the identification of the leakage position additional techniques must be applied like smoke tests, anemometry, or thermography.

The use of ultrasound system would make the measurement more flexible and reduce costs of course this technique does not replace of blower-door tests in the quantitative estimation of the air flow, but it allows to detect the local leak to solve local problem.

In order to identify a leak between two walls of a building envelope, ultrasonic waves have to be generated from the inside and detected by a receiver located outside (see Figure 32). An ultrasound source must be designed in function of the building structure (wall material), size of the defects, and volume of the envelope to be inspected.





It is

Figure 32 – Potential points of air leakage on the building envelope

known that the difference in acoustic impedance between two materials does not allow the complete transmission of the ultrasonic waves and the ones transmitted experience an attenuation whose level increases with increasing frequency. These two effects compromise the intensity of the wave that passing through the material. At low frequency (audio band, until some kHz) the wavelength in air is in the order of 10 cm. In this case the dissipation on the material is low but the wavelength is too large in comparison to the defect dimension (in order of the mm) and therefore there is not possibility to identify it. For frequency above 100 kHz, the attenuation is more than 3 dB/m, so the risk is that the wave is completely dissipated before to arrive at the detector. The optimal frequency range for the ultrasound leak detection is between 20 kHz and 100 kHz, where the wavelength is in the order of some mm compatible with the potential aperture that generates leakages. When the wave arrives on the wall, it will be reflected by the rigid surface and dissipated. On the aperture the wave will pass through it and will be captured by the ultrasonic detector. Most of the ultrasound detectors available in the market for air leakage detection have a working frequency range centered at 40 kHz.

Calibration procedure

- Before performing a measurement, a calibration procedure must be followed for setting the correct sensitivity of the ultrasonic detector. The calibration can be summarized in the following steps:
- Identification of the output range of the ultrasound acquisition system (ex. Ultrasonic Detector SDT 150, 0-200 mV or 0-100 dB).
- Installation of the ultrasound source at the center of the room or on the appropriate position.
- Activation of the ultrasonic detector at low level of amplification.
- Positioning of the ultrasonic detector outside the room.
- Moving the detector around the inspection area to verify the level of the signal received is good.
- If no signal is received even with windows and door opened, increase of the ultrasound source.
- Setting the amplifier to have a signal level just under the saturation.



Measurements procedures

The measurement procedure consists of a scanning over the area under test with the ultrasonic detector which won't receive any signal if the envelop is completely sealed, while will detect the ultrasonic wave passing through the crack if a defect is present in the ultrasonic wave path. The procedures can differ in function of the automation level:

- 1) The operator scans the area freely and listens to the noise level on headphones; the ultrasound is converted in audible sound by the detection system. In proximity of a leak the operator hears a higher level of noise.
- 2) The operator scans a grid of points defined before starting the measurements and register on an acquisition system the signal detected by the ultrasonic receiver. The spatial grid resolution must be smaller than the defect size, to appreciate the defect with sufficient accuracy. A post processing software allows to plot the RMS of the signals received at every acquisition point on a 2D map to visualize the defect position within the scanned region.

If the objective is a flexible measurement, an easy data store, a map visualization and leak extension estimation a tracking system connect to the ultrasonic detector. It is possible to use one camera and one track point (a LED). While moving the detector, the ultrasound level is continuously measured and the position calculated. By moving the detector up and down over the measurement region, we can build an averaged ultrasound intensity level on a grid defined by the region traced by the microphone. This averaging will reduce measurement error caused by small variations in detector distance and orientation. A measurement can easily be improved by making several passes (in different directions) over the object.



3. Hardware and software tools for data acquisition

3.1 Hardware

As hardware-devices are evolving more and more and even in shorter iterations, there is no specific recommendation for specific devices in general. This chapter provides an overview of hardware, which can be used for data acquisition. It has to be mentioned that this overview provides some examples, which are successfully used by the BIM Speed consortium.

3.1.1 Examples for Laser scanners

The following chapter provides an overview of following three laser scanners:

- 1) Laser scanner FARO
- 2) Laser Scanner RIEGL
- 3) Laser Scanner ZEB HORIZON

These three tools have different operating principles. Each of them is particularly suitable for a specific application area.

Laser scanner FARO and RIEGL mainly differ for the operational mode: FARO is a Phase Shift (PS) system, whilst RIEGL is a Time of Flight (TOF) system. Both of them evaluate the distance between the tool center and the first point the laser meets; the distance, together with the radius emission angles, allows determining the position of the points in polar coordinates. These kinds of laser scanners are similar to the total station, since they evaluate the position of a point in the space through its polar coordinates (one angle on the horizontal plane, one angle on the vertical plane and a distance on the space), which are lately converted in Cartesian coordinates. Nevertheless, in case a total station is used, the first measured point is chosen by the operator; whilst in case laser scanner is used, the space is surveyed in a dense but acritical way.

The laser scanners using the phase shift system, such as FARO, generally acquire a larger number of points and with higher acquisition speeds, around 1 million points/seconds; they are compact and handy. They are equipped with an integrated camera for coloring mapping of the points cloud. The Laser Focus 3D s120 by FARO operates in a range from 0,6 meters to around 70 meters, in indoors and outdoors, with an accuracy around 5-6 mm for acquisitions till 10 meters and around 1 cm for higher distances. The acquisition approach of this laser scanner is to acquire every particular with the same resolution, and lately to reduce the number of the points during the post-processing stage. Moreover, the high resolution allows comparing the results to a panoramic photo image. In the next Figure 33, an application of FARO for the laser scanning process of Naples Metro line is shown.



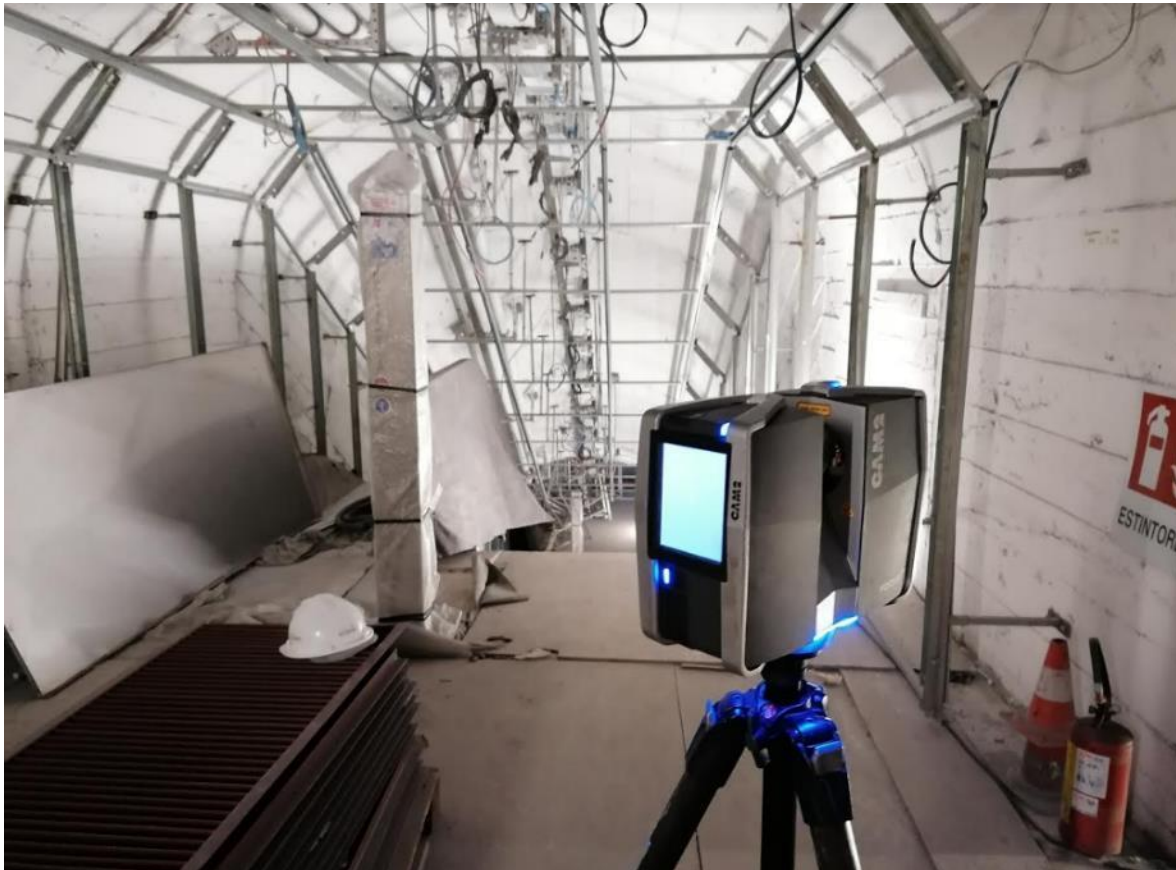


Figure 33 – Laser scanning of the Naples Metro Line with the use of FARO

The TOF scanners, such as RIEGL (Figure 34), are generally made of: a laser (usually a semi-conductor laser), emitting infrared light impulses, addressed to an emission lens; a system of rotating mirrors, necessary to deflect the radius; a receiving lens, capturing the part of the laser radius reflected by the impact surface of the object; a receiving diode called “valanche”, producing an electric receiving signal; a stabilized quartz watch, measuring the timeline between the emitted and reflected signal. The measure of the flight time provides the distance (d) among the center of the tool and the point, through a simple operation:

$$d = c \cdot \tau / 2 \quad [9]$$

where: c is the light speed in vacuum, τ is the time of flight.

These laser scanners have generally a lower acquisition speed, when compared to the phase shift scanners, i.e. around 250.000 points/second, but the acquired data is more precise and clean, leading to a minor impact on the post processing stage. The RIEGL VZ-400 scanner is a long-range scanner able to detect points at more than 400 meters distant, with 5mm accuracy. It is not equipped with an intern camera, but calibrated photographic tools can be installed externally for the color mapping; it is equipped with a NIKON D800 reflex camera, with 14mm – 50mm – 85mm NIKKOR lens. The RIEGL VZ-400 can storage data on an internal hard disk of 32GB; it also has a GPS L1 antenna for locate the scans in global coordinates and an integrated technology, called 3D Multiple Target, able to enrich the received data with the



“unpacking” of the laser impulse, which is useful for archeological and environmental surveys in case of dense vegetation.



Figure 34 – Laser scanning of Frigento Demo Case with the use of RIEGLE

In Figure 34, an application of the Riegle for the laserscanning process of Frigento Demo Case is shown. Both the laser scanners have a display for visualizing the data previews and for the scanner setting and can be used for different applications (architectural, infrastructural and environmental surveys). The third laser scanner above listed is a mobile mapping laser scanner using the SLAM (Simultaneous Localization and Mapping) technology. The SLAM technology uses an automatic system, moving in an unknown area, which can build up the map of that area and can locate itself inside it. Therefore, this system can make a device able to determine its position while it is simultaneously scanning an unknown environment. This system allows to rapidly obtain a large number of data, in form of points cloud, with a small use of energy and resources; it is very handy (light and compact) and versatile, since it can be used also for other purposes. This system allows providing accurate scans also in hard conditions, such as for objects, which cannot be surveyed from the external view, or for underground and/or dark areas.

The SLAM technology has an algorithm, which uses the geometrical features of the scanned environment and works on the survey path and the global registration. The path is analyzed by an algorithm using the translation and rotation functions, considering the spent time. The device scans continuous segments, which are progressively put in a three-dimensional reconstruction. During the data acquisition, the tool continuously registers the environment with a declared precision and minimizing the errors. Therefore, while moving in an unknown place, it simultaneously builds up a map of it and locate itself inside it. This means that, differently from the terrestrial scans, which cannot be moved during the acquisition stage, this system works perfectly when it is necessary to move. It is therefore very useful in case a fixed scan should be frequently moved to catch the needed information. Moreover, this technology



allows having just one scan, which includes the point cloud of more spaces, already connected. The system is very quick and make very accurate measurement; nevertheless, some errors and uncertainties can occur. The typical errors occurring during a laser scanning procedure with SLAM technology are the “drift errors”: when a device captures highly accurate individual measurements, chaining them will result in an accumulation of noise and tiny measurement uncertainties. Over time, the estimated motion will start to deviate from the true motion, generating the drift error, which can be sometimes observed when small flexions occur. These errors can be corrected e.g. realizing a closed path. The Laser Scanner ZEB HORIZON, by GeoSLAM, operates until 100 meters in indoors and outdoors, with a relative accuracy from 1 to 3 cm and a scanning speed equal to 300.000 points/sec. The following Figure 35 show the use of GeoSLAM and the data processing for the survey at Capodimonte Museum, in Napoli.

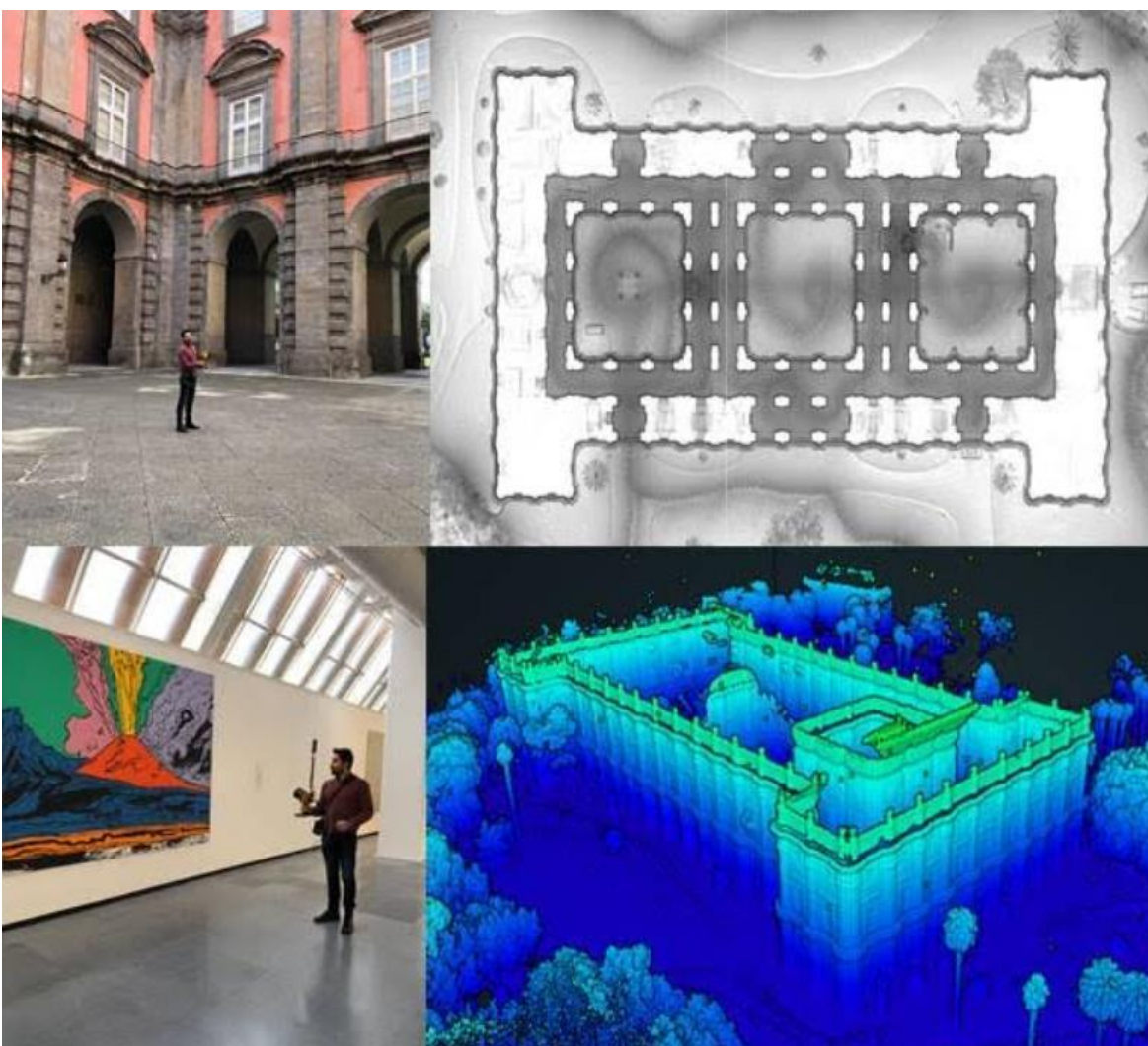



Figure 35 – Survey at Capodimonte Museum , Napoli (IT) with the use of GeoSLAM




In the following tables, an overview of the main features of these laser scanners are shown and some additional information on equipment and accessories are listed.

Phase Shift Laser scanner									
Brand	Model	Picture	Laser Class	Range	Field of application	Nominal distance	Accuracy at 25m		Divergence
FARO	FOCUS 3D S120		3R	0,6-120m	Architecture; Archeology; Cultural Heritage	70m	10% ref 2,20mm	90% ref 0,95mm	0,19mrad

Equipment / accessories:

- Bag
- Batteries
- Tripod
- SD 32GB for data storage
- Glasses for eye protection
- Machine certificates
- 2D/3D targets


Time of Flight Laser scanner								
Brand	Model	Picture	Laser Class	Range	Field of application	Nominal distance	Accuracy at 100m	Divergence
RIEGL	VZ-400		1	1,5-400m	Architecture; Archeology; Cultural Heritage; Environment; Infrastructure	350m	5mm	0,35mrad

Equipment / accessories:

- Bag
- External batteries YUASA
- Tripod
- LAN cable for internet connection and cable for external battery charger
- Portable PC
- Reflex camera Nikon d800 – external
- SD 64GB for data storage
- Glasses for eye protection



- Machine certificates
- 2D/3D targets

Time of Flight Laser scanner								
Brand	Model	Picture	Laser Class	Max Range	Field of application	Scan rate	Field of view	Scan range noise
GeoSL	ZEB		Class 1	100m	Architecture;	300.000	360° x 270°	±30mm
AM	HORIZON		Eye-safe for IEC 60825- 1:2007 & 2014		Archeology; Cultural Heritage; Environment; Infrastructure	points/s 160 lines/s		

Equipment / accessories:

- ZEB-HORIZON laser scanner
- ZEB-HORIZON data logger and shoulder strap
- ZEB-HORIZON connection cable
- USB 32GB for data storage
- Spare battery and charger
- Backpack
- ZEB-PANO camera

3.1.2 Example for thermal camera

The thermal imaging camera used is the FLIR T640bx model, as shown in the following Figure 36.



Figure 36 – FLIR T640bx model Thermocamera



The main technical characteristics of the thermal imaging cameras are the following:

- Uncooled 4th generation 640x480pixel Microbolometric sensor
- Sensitivity: <math><0.035^{\circ}\text{C}</math> at + 30°C
- Standard optic FOV / Min. Fire Dist .: 25° x19° / 0.25m
- UltraMax function
- MSX function
- Spatial resolution: 0.68 mrad
- Automatic and manual focusing
- Thermal Fusion function (range, above, below)
- PiP (Picture in Picture) function, sizable and mobile
- LCD touchscreen display with 800x480 pixels
- Automatic alignment by laser pointer
- Temperature range measurable from -40 ° C to + 650 ° C
- Accuracy: $\pm 1^{\circ}\text{C}$ or $\pm 1\%$ of reading
- Measurement functions: Spot (10), Area with automatic search for Max/Min/Average temperature, Isotherm, top / bottom temperature alarm, Delta T, T Ref., Adjustable emissivity
- Inserting text comments from predefined lists
- Insertion of voice comments lasting 60 sec. on each thermography
- Removable SD card for storing images
- Digital Video Outputs (HDMI compatible)
- Integrated 5 Mpixels visible digital camera

Additional optics

- FLIR T198065 IR Lens 6.5 mm (80 °) Wide angle lens (Figure 37), $f = 6.5\text{mm}$ (80°)
- FLIR T198166 IR Lens 88.9 mm (7 °) Telephoto lens (Figure 38), $f = 88.9\text{mm}$ (7°)



Figure 37 – Wide angle lens



Figure 38 – Telephoto lens



Minimum detectable spatial size for the available lenses

When an infrared camera is used, it is essential to know the size of the minimum area that can be framed, given the characteristic spatial resolution of the instrument and with respect to a reference distance (1 meter)

1. FOV - Field of View:

It represents the entire area that the instrument manages to frame at the conventional distance of 1 meter, for a determined optical opening angle of the instrument.

2. Optical opening angle:

This is the value of the optical aperture of the instrument. Generally, the opening is expressed by the horizontal angle and the vertical angle. These values depend on the type of lens and its convexity.

3. IFOV - Instantaneous Field of view:

Within the visual field, the minimum identifiable area (IFOV) is defined. This represents the projection of the "instrument" area onto the surface of the visual field.

Lens	FOV	Angle	IFOV (horiz)	Minimum detectable object (at 1m distance)
Wide angle	1.396	80°	2.18mm	6.54mm
Standard	0.436	25°	0.68mm	2.04mm
Telephoto	0.122	7°	0.19mm	0.57mm



3.2 Software

Scan to BIM is a practice of creating a digital representation of existing structures with its physical and functional characteristics.

It captures a 3D scan and then converts it into a 3D BIM model. The scan to BIM workflow presented in Figure 39 is based on the tools and options that Revit software and ReCap software can provide to help the process.

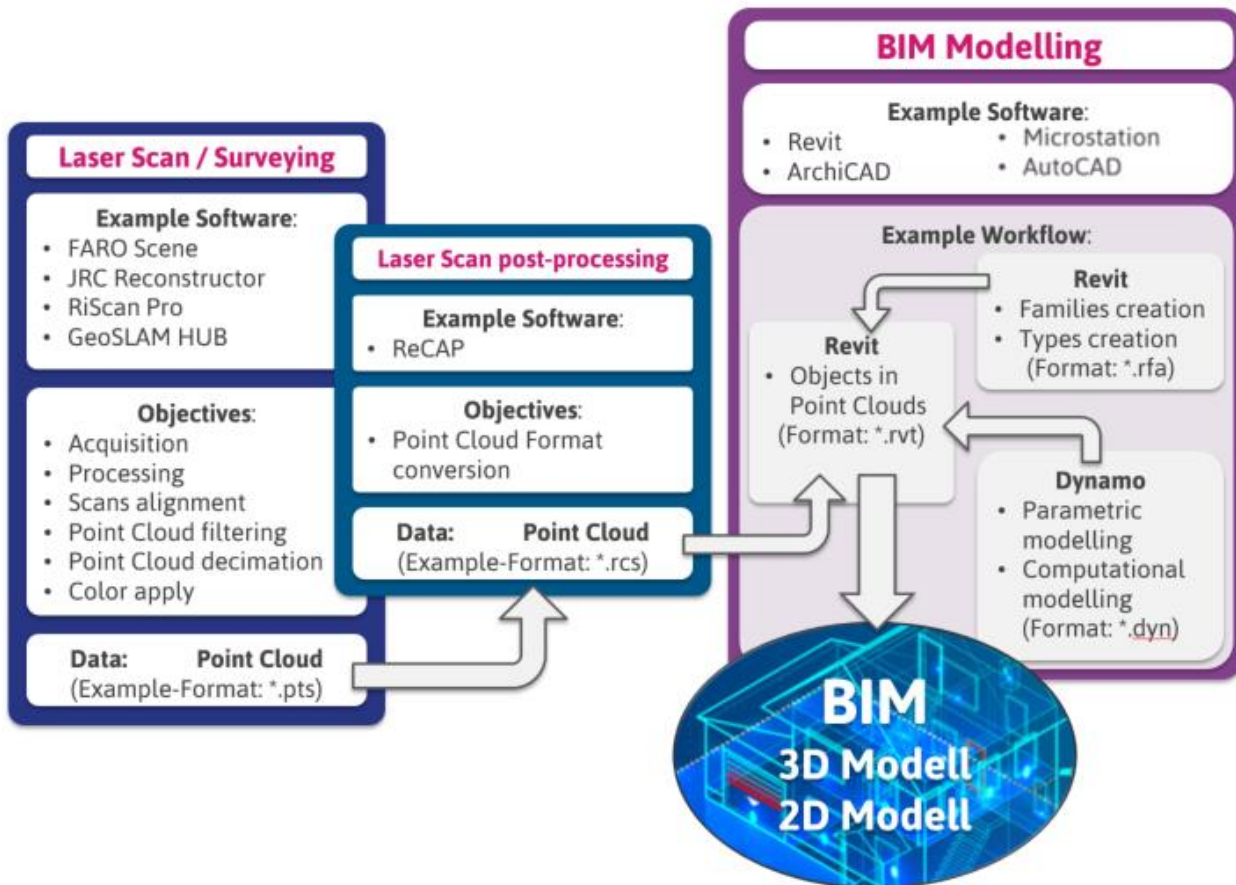


Figure 39 – Scan to BIM workflow

The first step of the workflow involves several software applications related to the different laser scanner used in the survey phase.



FARO SCENE

SCENE software is specifically designed for all Focus laser scanners, and it allows to process and manage scan data efficiently and easily by automatic object recognition, scan registration, and positioning. In addition SCENE allows to generate high-quality data in full color quickly and conveniently by incorporating images from automated target less and target-based scan positioning. Users can begin the evaluation and processing immediately by performing simple measurements, creating stunning 3D visualizations or exporting to various point cloud and CAD formats once SCENE has prepared the scan data. Share and collaborate worldwide anytime, anywhere with SCENE WebShare Cloud – a hosted web-based service from FARO for easy and secure sharing of scan project data (Figure 40).



Figure 40 – WEB_SCENE application. FS Railway Station, Napoli (IT)

RISCAN PRO

RISCAN PRO (Figure 41) is the companion software for RIEGL Terrestrial 3D Laser Scanner Systems. RiSCAN PRO is project orientated, i.e., the entire data acquired during a measurement campaign are organized and stored in RiSCAN PRO's project structure. These data include scans, fine scans, digital images, GPS data, and coordinates of control points and tie points, and all transformation matrices necessary to transform the data of multiple scans into a common well-defined coordinate system. The software is designed to optimize the acquisition workflow in the field and provides the tools for visual inspection of overall completeness of data coverage in 3D right after acquisition. In addition to data acquisition, it provides a variety of functions for data processing.





Figure 41 – RISCAN PRO application. Palazzo Testa Cipriano, Frigento, AV (IT) – Demo Case

GEOSLAM HUB

GeoSLAM Hub (Figure 42) brings together industry-leading SLAM (Simultaneous Localization And Mapping) technology with powerful post processing functionality to deliver complete end-to-end solutions.

The software provides the SLAM processing to generate accurate 3D point clouds from survey data. In addition, it allows to import, view and interrogate data captured from all GeoSLAM devices and to control the datasets through geo-referencing tool.

GeoSLAM Hub includes the module GeoSLAM Draw that provides tools for quickly extracting floor plans and sections from point cloud data and tool for export data for use in third party CAD and BIM software packages.

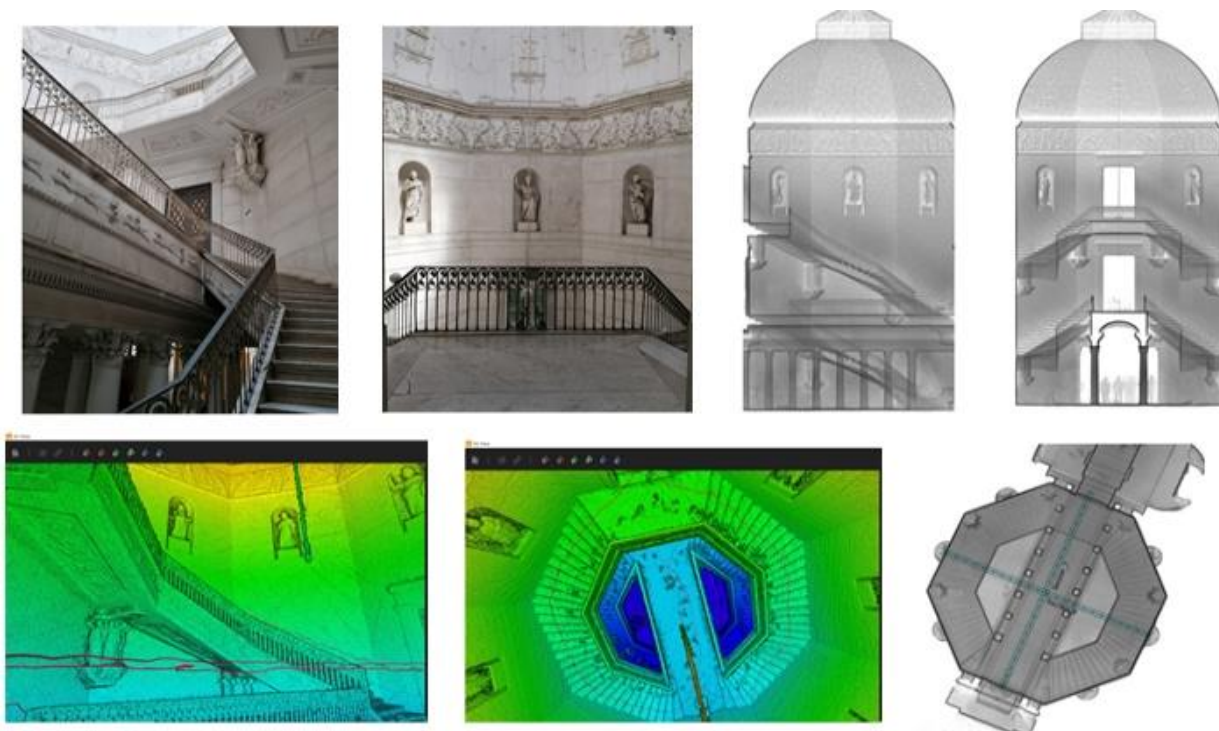
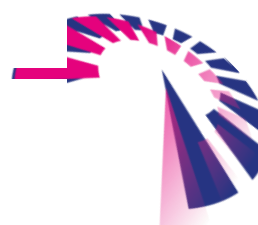


Figure 42 – GeoSLAM HUB and DRAW results. Private Building located in Via Chiaia 202, Napoli (IT)



JRC 3D RECONSTRUCTOR

JRC 3D Reconstructor (Figure 43) is the well-known multi-platform and multi-resolution software to manage point clouds and images coming from different LiDAR and imaging platforms. It is a suitable tool to combine LiDAR data coming from terrestrial, mobile and airborne sensors, with UAV and 3D imaging data. It allows advanced filtering, ICP automatic alignment and bundle adjustment, georeferencing and different post-processing, analysis and output export.



Figure 43 – JRC 3D RECONSTRUCTOR results from FARO survey. Convento Sant’Angelo d’Ocre, L’Aquila (IT)

AUTODESK SUITE

The available Architecture, Engineering & Construction Collection integrates BIM tools for building design, civil infrastructure, and construction. In particular RECAP and REVIT software packages enable by a comprehensive set of services to deliver a powerful Scan to BIM workflow.

ReCap software allows to quickly get reality data into Autodesk design and construction tools from imported photographs and point clouds. The ReCap reality capture data can be export into Revit to create 3D building models.



Autodesk Revit

Revit (Figure 44) is one of the most used software in creating 3D BIM Models. Software allows the modeling of architectural, structural and MEP systems in a friendly and easy to use environment. Revit allows collaborative design, either working with central models on local drives or uploading and working from a cloud platform. The file extension of a project is .rvt. Besides creating 3D object, it allows the creation of all

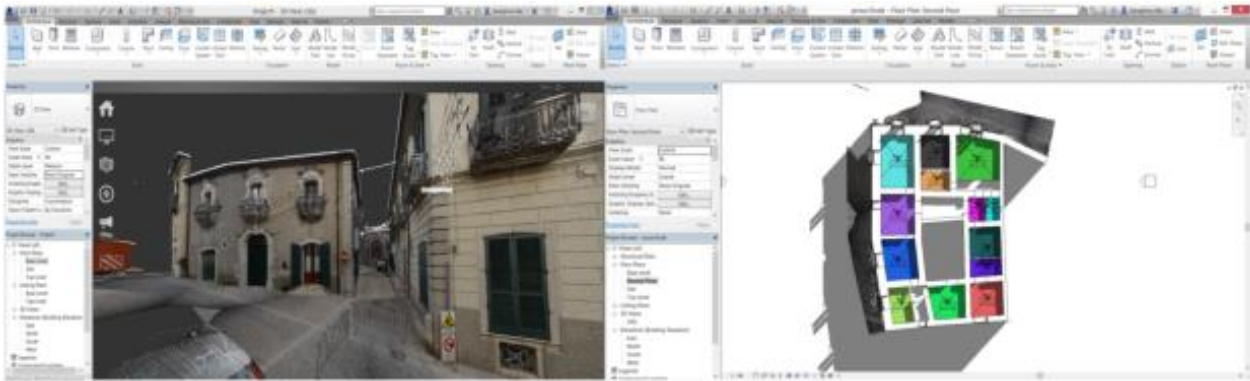


Figure 44 – Point Cloud and 3D MODEL of “Testa Cipriano” demo site, Frigento (Italy).

types of 2D plans (section, façade views, floor plans, P&ID schematics).

Advantages in using Revit:

- Allow the creation of parametric 3D object.
 - Can created complicated curves using the Dynamo add-in. Dynamo allow the users to use/create script that can automate process during modeling work, thus cutting valuable time from repetitive actions
 - 3D objects can be place in libraries and used for multiple projects.
 - Allows the user numerous graphical overrides of elements, offering the user countless possibilities to present as clear as possible the design.
 - Visual templates can be created and reuses across multiple projects.
 - Allows the import of numerous files as design base, e.g. .dwg, .pdf, point cloud files, .ifc.
- Models can be rendered inside the software, with good results.

As any software, Revit has also some disadvantages:

- More of a modeling tool than an engineering tool. Although it gives the possibility to make calculations inside the software, these are mainly oriented towards US norms.
- IFC exporting causes errors and it takes a lot of time preparing the model for an export. Sometimes, information can be missing from the .ifc file.
- Cannot downgrade versions.



Autodesk Navisworks

Navisworks comes in three variants: Freedom, Manage and Simulate. With Freedom, users can view .nwd files or 3D .dwg files. It is a free viewer and allows users the possibility to see the reports made within Manage version. Manage is the version used to review the 3D models. It allows the import of a significant number of types of files (around 60 depending on the versions used), including .rvt, .ifc, .sat, .fbx, .dgn, etc. The clash detection is done using set of rules that can be easily tailored to the requirements expressed in the B.E.P. Besides clash detection, Navisworks can be a good communication line between modelers and designers, allowing for mark-ups and tracking the changes inside the model. Navisworks Manage has also other benefits, such as using the Navisworks model to create a timeline or extract quantities. IT can be used to create fast renderings or presentation videos but without any outstanding graphics. Simulate version is somewhere in between Manage and Freedom. The difference between Manage and Simulate is the fact that the last cannot perform clash detection and interference checking.

Autodesk RECAP PRO

Recap is Autodesk’s response for creating point clouds files from laser scans or photographs. Recap supports Revit in the sense that the output of Recap is a .rcp file that can be imported very easily in Revit. Recap supports laser scans done with Leica, Faro, Topcon, LIDAR, Riegl and Zoller & Frolich 3D scanners. In Recap, the created point cloud can also be manipulated, in the way that it can be cleared, divided in smaller parts, adjusting its colors. This makes the import of the point cloud in a BIM 3D model much easier. Recap is also a good photogrammetry software that allows the creation of 3D Meshes from photographs (Figure 45).



Figure 45 – 3D Mesh



Bentley OpenBuildings Designer

OpenBuilding Designer is the BIM response of Bentley to its client's request for BIM modeling solution. OpenBuilding is a multidisciplinary software integrating all three main disciplines related to building design: architectural, structural engineer and building services. It allows the possibility to design and model in the same environment. OpenBuilding Designer allows to simulate and evaluate the performance of the building in order to have the best design possible. It offers data regarding energy analysis that provides peak loads, annual energy calculations, energy consumptions, carbon emissions, and fuel costs.

OpenBuildings allows for collaborative design in a common design environment using streamlined workflows. It has a clash detection build-in features that allows for check-ups without using other software. For MEP modeling, it allows the creation of parametrical objects and incorporates features that allow lighting, power and fire-detection subsystems design.

Bentley ContextCapture

ContextCapture is a reality modeling software providing 3D meshes composed of unique elements that can be georeferenced. ContextCapture allows users to generate spatially classified and engineering-ready reality meshes at any desired level of accuracy and scale, including an entire city. ContextCapture is compressed from 3 modules: ContextCapture, ContextCapture Cloud processing service and ContextCapture Center. ContextCapture Cloud Processing Services can be used for all the projects, but the other two versions depend on the amount of points in the point cloud or gigapixels for imagery.

Software Flir Tool +

FLIR Tools+ is a powerful software solution that allows the user to quickly import, edit, and analyze thermal images. FLIR Tools+ provides an expanded set of cutting-edge controls for generating more comprehensive thermal imaging inspection and research reports. Moreover, the software aims at realizing playback radiometric video files and time/temperature plots, and at providing advanced analysis data and more detailed thermal imagery in impressive PDF documents that show anomalies, trends, and results with greater precision.

The key characteristics of the software are:

- Image import from camera to PC
- Filter application in image search
- Search in all texts, in images and text annotations
- Memorization of the last five search criteria
- Arrangement, movement and resizing of the measuring instruments for all thermal images
- Mosaic of images
- Creation of image collections in PDF format with images of your choice
- Adding headers, footers and logos to image collections
- Creation of reports in PDF and .doc formats with images of your choice
- Adding headers, footers and logos to reports



- Report editor (report page preview and grid alignment)
- Sorting function (by date, groups sorted by route and groups sorted by date)

Clear Edge 3D - EdgeWise

EdgeWise is a Scan-to-BIM software used for detecting and automatic placement of pipes, walls, round ducts, structural elements, from a point cloud into a Revit 3D model (Figure 46). The Revit families are placed automatically in the correct position, depending on the quality of the point cloud. While the software



Figure 46 – Point Cloud and 3D MODEL

reduces a lot the need of manual modelling of the elements described (during tests, 1000 elements were found and placed in about 1 hour), after the process is complete, a checking needs to be done, because certain elements may not be placed. Including the check, it still saves a great amount of time. For architectural elements and structural elements, walls may not be placed correctly if there are a lot of object surrounding them. Still, like in the case of piping, a check is required. Complex architectural walls are not recognized.

Agisoft Metashape

Agisoft Metashape is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales.

Wisely implemented digital photogrammetry technique enforced with computer vision methods results in smart automated processing system that, on the one hand, can be managed by a newcomer in the field of photogrammetry, yet, on the other hand, has a lot to offer to a specialist who can adjust the workflow to numerous specific tasks and different types of data. Throughout various case studies, Metashape proves to produce quality and accurate results.



MeshLab

MeshLab is an open source system that can be used to process and edit 3D triangular meshes. It provides a set of tools for editing, cleaning, healing, inspecting, rendering, texturing and converting meshes. It offers features for processing raw data produced by 3D digitization tools/devices and for preparing models for 3D printing.

3.3 Overview Table

The above mention hardware devices and software application are summarized in this overview table. It provides a brief overview of examples to be used for architectural, structural, thermal 3D data acquisition of existing buildings.

No	SW/HW	Device	Type	Name	Description/Key Facts	Result
1	Hardware	Lasercanner	Lasercanner	FARO	Phase Shift, fast data acquisition, compact and handy	Poincloud file
2	Hardware	Lasercanner	Lasercanner	RIEGL	Time of Flight (TOF) system, lower acquisition speed, more precise and clean	Poincloud file
3	Hardware	Lasercanner	Lasercanner	ZEB	SLAM technology, During the data acquisition, the tool continuously registers the environment with a declared precision and minimizing the errors.	Poincloud file
4	Hardware	Thermal Camera	Thermal Camera	FLIR T640bx	Uncooled 4th generation 640x480pixel Microbolometric sensor, Thermal Fusion function (range, above, below)	Thermal Images
5	Software	PC	Tool	Scan2BIM	captures a 3D scan and then converts it into a 3D BIM model	3D BIM Model
6	Software	PC	Tool	FARO Scene	automatic object recognition, scan registration, and positioning for FARO scanners	3D Visualization
7	Software	PC	Tool	RISCAN Pro	processes scans, fine scans, digital images, GPS data, and coordinates of control points and tie points, and all transformation matrices necessary to transform the data	3D Visualization
8	Software	PC	Tool	Geoslam Hub	SLAM processing to generate accurate 3D point clouds from survey data	Poincloud file
9	Software	PC	Tool	JRC 3D Reconstructor	combine LiDAR data coming from terrestrial, mobile and airborne sensors, with UAV and 3D imaging data.	Poincloud file
10	Software	PC	Tool	Autodesk Revit	Revit is one of the most used software in creating 3D BIM Models.	3D BIM Model
11	Software	PC	Tool	Autodesk Navisworks	Clash Detection, Mark-Ups, Timeline, Extracting Quantities.	Divers
12	Software	PC	Tool	Autodesk Recap Pro	Recap is Autodesk's response for creating point clouds files from laser scans or photographs.	Poincloud file
13	Software	PC	Tool	Bentley OpenBuilding Designer	OpenBuilding is a multidisciplinary software integrating all three main disciplines related to building design: architectural, structural engineer and building services.	3D BIM Model
14	Software	PC	Tool	Bentley Context Capture	ContextCapture is a reality modeling software providing 3D meshes composed of unique elements that can be georeferenced.	3D Meshes
15	Software	PC	Tool	Software Flir Tool +	FLIR Tools+ is a powerful software solution that allows the user to quickly import, edit, and analyze thermal images.	Thermal Images
16	Software	PC	Tool	Clear Edge 3D - EdgeWise	EdgeWise is a Scan-to-BIM software used for detecting and automatic placement of pipes, walls, round ducts, structural elements, from a point cloud into a Revit 3D model	3D BIM Model
17	Software	PC	Tool	Agisoft Metshape	stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications.	3D Spatial Data
18	Software	PC	Tool	Mesh Lab	MeshLab is an open source system that can be used to process and edit 3D triangular meshes.	3D Meshes

Figure 47 - brief overview of examples to be used for architectural, structural, thermal 3D data acquisition



4. Understanding the acquired data of existing building

4.1 IT architecture to couple acquired data to BIM

A general definition of an overall IT architecture for renovation projects cannot be standardized in general. Data for setting up a renovation project is coming from many different sources and in many different formats and this individual for each project. But standardization of the IT architecture is not even necessary. More important is the structuring of data and elements, independent where it comes from.

Project Breakdown Structure

Irrespective of source or format, all data must be structured in the same way. It is recommended to generate an overall Project Breakdown Structure (PBS) before setting up a renovation project. This PBS defines the location for elements and/or data in conjunction to the aimed project. Starting from general information to the project, going on to more detailing like parts of project up to detailed element information covers the structuring overall.

Summarizing this means that the PBS is used to split the project into manageable subdivisions. An example is shown in Figure 48.

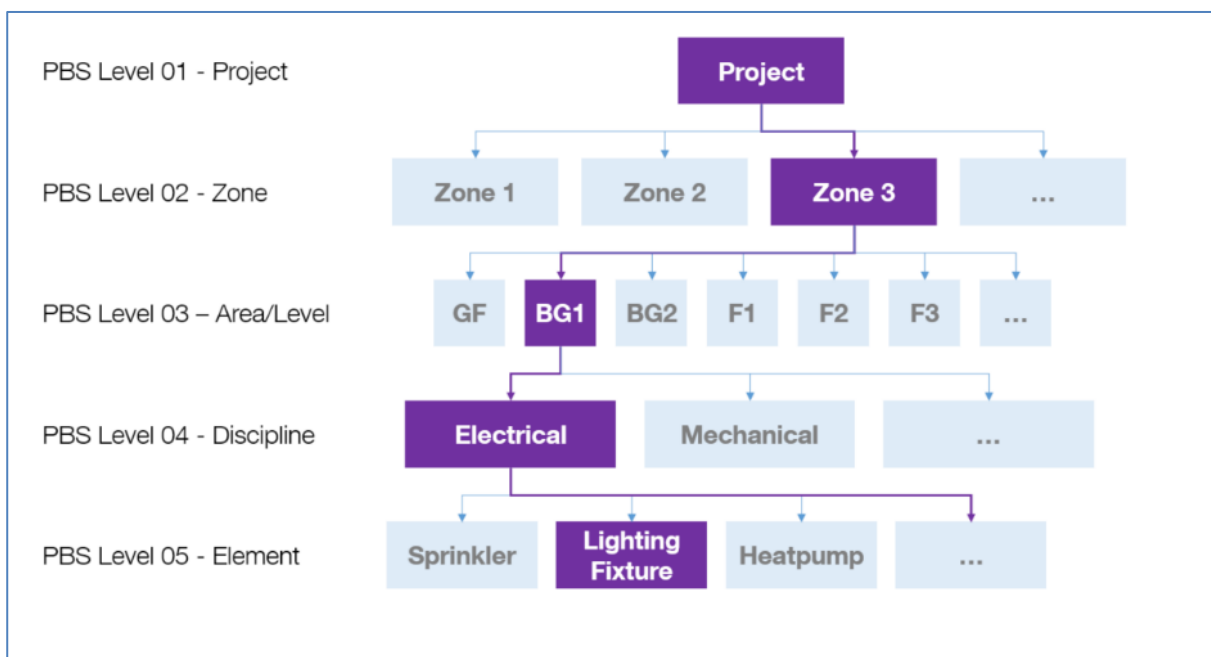


Figure 48 – Project Breakdown Structure

For each new project, this PBS must be setup individual to match the projects requirements. It must be considered how much detailing is necessary. By implementing the PBS for a project, localization of data and elements regarding project structure is clearly defined. Compliance with the PBS is the key to perform BIM.



Location Identification Code (LIC) and Plant Identification Code (PIC)

After defining the refurbishment strategy for the aimed project, relevant BIM use cases are stated more precisely. The Methodology Toolkit will help to decide which BIM use case is reasonable.

Independent of which and how many BIM use cases will be transposed, it will be obligatory to locate data and elements more specific. The PBS is great to identify the location within the project, but to really tag data or elements, additional information is needed. BIM-Speed suggests to implement a Location Identification Code (LIC) for data and corresponding model elements and a Plant Identification Code (PIC) for asset elements.

The LIC relates data and 3D elements to the room, where they are in real life (Figure 49). Assigning the LIC to each file and element outlines the on-site position. Elements with same LIC are in the same room.

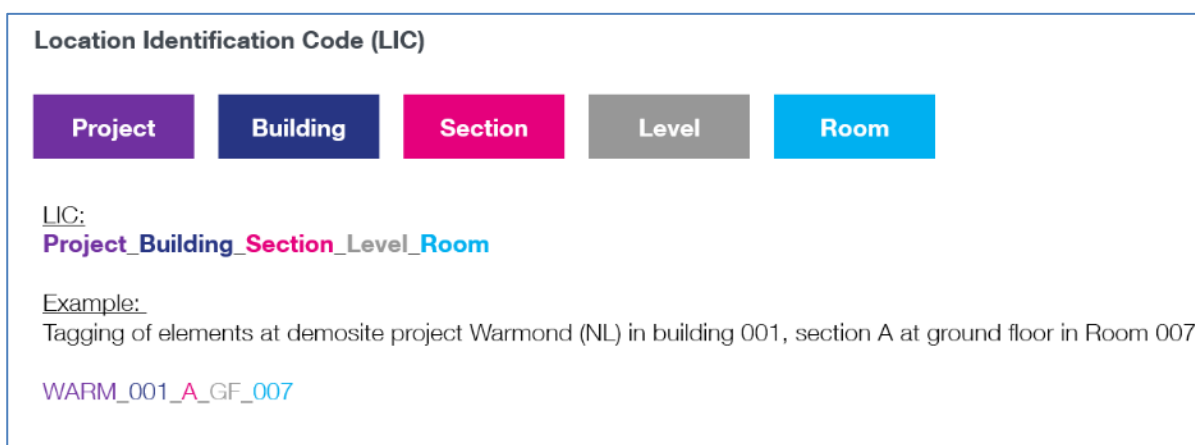


Figure 49 – Location Identification Code LIC

Same procedure works for equipment of mechanical, electrical and piping type. By integrating the PIC (Figure 50), these MEP elements will also be assigned to the room, they are located in on-site but additionally a distinct identification is added. For MEP elements, the related system information is needed, as well as naming of equipment itself and an additional number in case there are more than one of the same equipment within the same room. The PIC for each equipment is unambiguous. Documents and other data, which belong to this equipment, also get the PIC tagging.



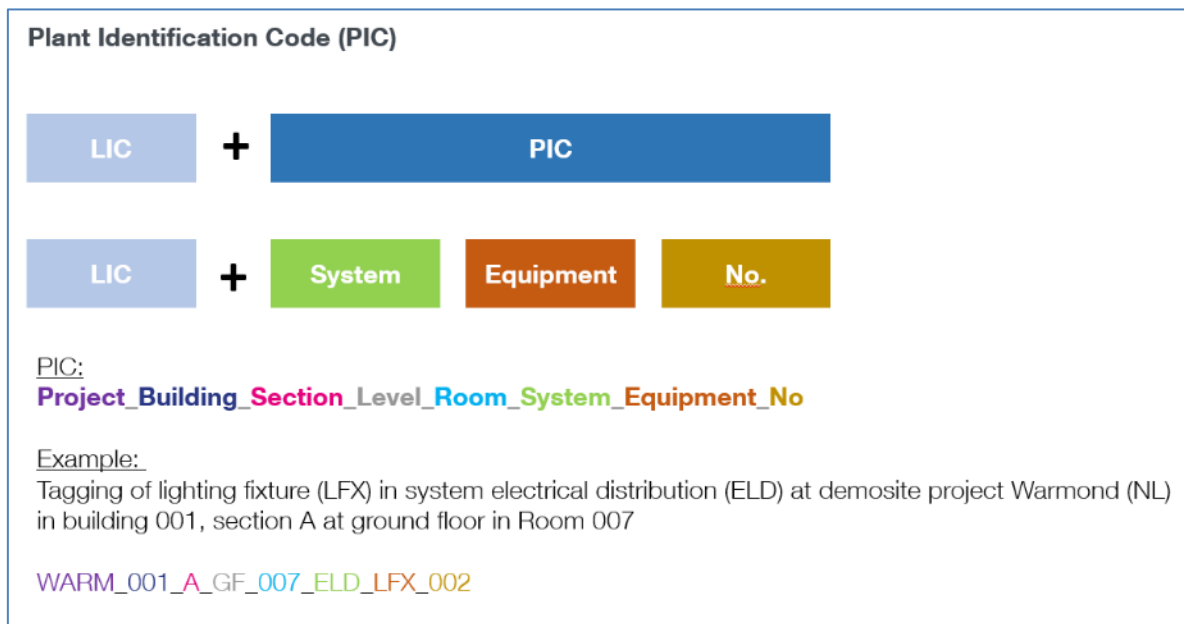


Figure 50 – Plant Identification Code PIC

Inauguration of the LIC and PIC makes it possible to link 3D model elements, documents and additional information with each other (Figure 51). Integrating the LIC and PIC into all connected systems and applications empowers automating of digital data workflows. It could be said that realizing the integration of LIC and PIC enables project partners to proceed working with their own IT application, as-built documentations, etc. It is no need to change everything, but to add the LIC and PIC. BIM Speed project evaluates possibilities to integrate this approach in the BIM Speed platform to simplify the setup of renovation projects.

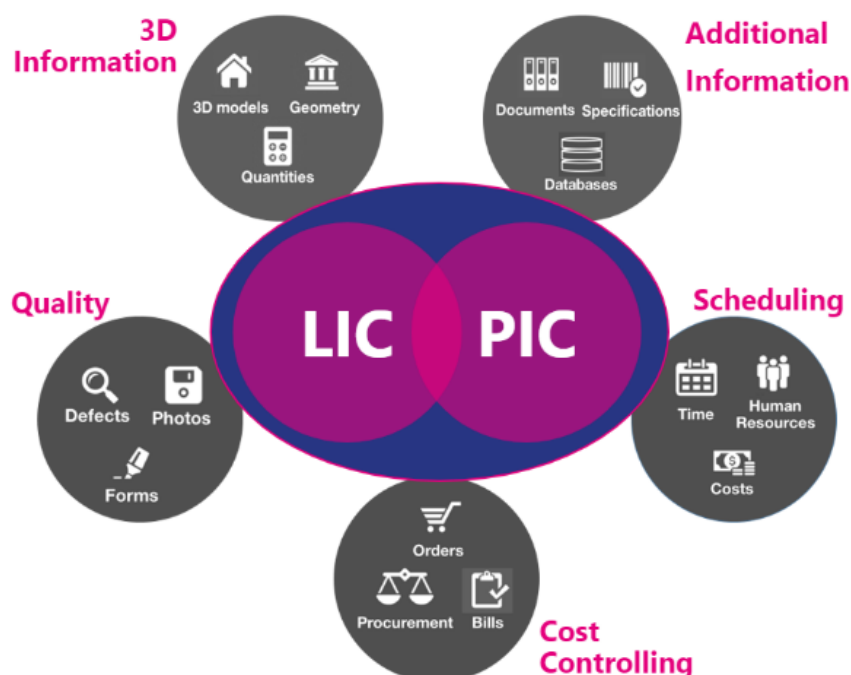


Figure 51 – Key Element LIC and PIC



4.2 BIM Model definition

3D Modelling for renovation projects can be done in several kind of ways and especially in several kind of Level of Detail (LoD). To define a standard definition for generating a 3D model and its attached data, it is compulsory to consider the intended purpose of these. Assessment of as-built data requires different LoD in comparison to design for new construction. To minimize the effort for model generation, it is recommended to contemplate Level of Geometry independently from Level of Information.

4.2.1 Level of Development (LoD)

Crucial to define the Level of Development for generating a 3D model is the intended purpose for using the model. Depending on designated BIM use cases, the exertion of a 3D model can be different. In most cases and especially for renovation projects, a detailing for the geometry to the last detail is not necessary. More important is the information attached to the model elements.

The Level of Geometry (LoG) shall be described based on model elements and, therefore, needs to be considered separately from the Level of Information (LoI) attached to the element. Both values can vary for the same model element, depending on the aimed purpose to use this element.

The combination of LoG and LoI form the degree of completion for each element is the so-called Level of Development (LoD). It has approved to define a Model Element Matrix (MEM) before starting the modelling process (Figure 52). The MEM outlines required 3D model elements and describes definitions of LoG and LoD for each element. The following picture shows an example for modelling and detailing of an architectural room.

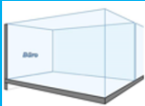




		LoD Definiton	LoD 100	LoD 200
LoG (Geometry)	Definition for Geometry of an element: geometrical presentation of model element with general information like - Position - Dimension - Shape	- Space - Walls - Floors		- LoG100+ - Windows - Doors 
LoI (Information)	Definition for Information attached to an element: attributes and additional datat, e.g. Naming, related zones, FireProtectionClass, etc.	- LJK - Space Naming - Space No. - Area - Volume		- LoI 100+ - Door No. - Window No.
		LoD 300	LoD 400	LoD 500
LoG (Geometry)	- LoG 200+ - detailed windows - detailed doors - Materials - suspended ceilings - floor construction 	- LoG 300+ - detailed suspended ceiling - detailed floor construction - detailed wall construction 	- similar to LoG 400, plus any additional detail, if needed 	
LoI (Information)	- LoI 200+ - additional information (number of) elements within room, e.g. light switches, outlets, etc. - Fire Protection Indication - Noise Protection Specification - ...	- LoI 300+ - detailed materials - small ironworks - fitting assemblies - manufacturers information - ...	- LoI 400+ - cost units - link to product data sheets - link to maintenance documents - additional links - ...	

Figure 52 – Model Element Matrix MEM



4.2.2 Model Definition

For renovation projects, it is recommended to keep the level of geometry at a very low level. Often it may be enough to generate an as-built model containing only room elements. For each aimed BIM use case, it has to be considered which elements really are required.

Mostly the following recommendation will be sufficient:

- Architectural and structural 3D models: only spatial elements like Walls, Floors, Ceilings, Windows, Doors, etc. In fact, everything that forms a room plus an additional space element for each room.
- MEP 3D models: simplified model element (e.g. box/cylinder) for main plant components and placeholder model elements for relevant system equipment (e.g. only one smoke detector for each room, a box for cable harness and not each cable, etc.)

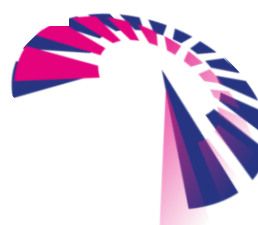
By regarding this, the LoG is set to a level of 200-300.

Contrary to the LoG, the Lol shall be set to a much higher level, depending on the aimed use case. The range of data, included to each model element should be specified following the rule “As much information as required but not as much as possible”. This helps to reducing file size and minimizes performance issues while observing 3D views. Attached information regarding assessment of building data comprise manual recorded data as well as automated data based on e.g. input from sensors or laser-scanners, etc. Of course, also relevant documents like product data sheets, maintenance descriptions, related 2D drawings, etc. should be appended to the 3D model elements.

To define the mandatory attributes for each element it has proved to set up an additional attribute list for each model element:

Lol Definition Example	Attribute																													
	Name	Type	Unit	Example	Name	Type	Unit	Example	Name	Type	Unit	Example	Name	Type	Unit	Example	Name	Type	Unit	Example										
	LIK	string		WE1226_004_A_01_0012	RoomName	string	Living Room	RoomNo	string	4	Area	integer	m	26.75	Construction	string	3inch xxxx, 5inch XXV, etc.	Material	string	carpet	Manufacturer	string	Company	ProductDataSheet	link	Link to Homepage	MaintenanceDocument	link	Link to Device	
3D Model element	Lol 100	Lol 200	Lol 300	Lol 400	Lol 500	Lol 100	Lol 200	Lol 300	Lol 400	Lol 500	Lol 100	Lol 200	Lol 300	Lol 400	Lol 500	Lol 100	Lol 200	Lol 300	Lol 400	Lol 500	Lol 100	Lol 200	Lol 300	Lol 400	Lol 500	Lol 100	Lol 200	Lol 300	Lol 400	Lol 500
Architecture																														
Space	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										
Wall	x	x	x	x	x	x	x	x	x	x																				
Window	x	x	x	x	x	x	x	x	x	x																				
Door	x	x	x	x	x	x	x	x	x	x																				
...																														

Figure 53 – List of required attributes



4.3 Facilitating BIM modelling from point clouds: Automatic detection of architectonic features from point clouds

4.3.1 State of the art

There are some commercial plug-ins for efficiently using as-built point cloud data captured by laser scanners directly within *REVIT* to ease the BIM modelling of existing buildings. These plug-ins are conceived to let users get all the advantages of a high-performance point cloud application directly within *REVIT*, but restricted to specific point cloud formats according to brand and model of the laser scanner. *LEICA CloudWorx*¹ is a representative example, providing tools for accurate fitting of steel, flange, automatic pipe, and 2D lines mainly oriented to retrofit design and lifecycle asset management of the building. It also provides a virtual visit within *REVIT* with a complete view of the captured reality. In any case, such kind of plug-ins are generic, so they do not expressly meet related needs to this project.

4.3.2 Specific tailored software tool (plug-in) developed for BIM-SPEED project: 3DASH tool

A novel tool has been developed to automatically detect a useful basic set of architectonic features from a given point cloud. The detected features are intended to be a common workspace where more complex and detailed objects can be added in a later stage of the digital reconstruction process for buildings. The tool is further handled into the *REVIT* well-known BIM package to ensure functionality and actual usability by means of a specific tailored software tool (plug-in).

Suitable digital information sources are mainly 3D point clouds acquired by laser scanning or photogrammetry systems. The 3D data, which is made up of geometry (XYZ coordinates) and color (RGB coordinates: real appearance), can be directly handled by the tool. The raw 3D point cloud of the building

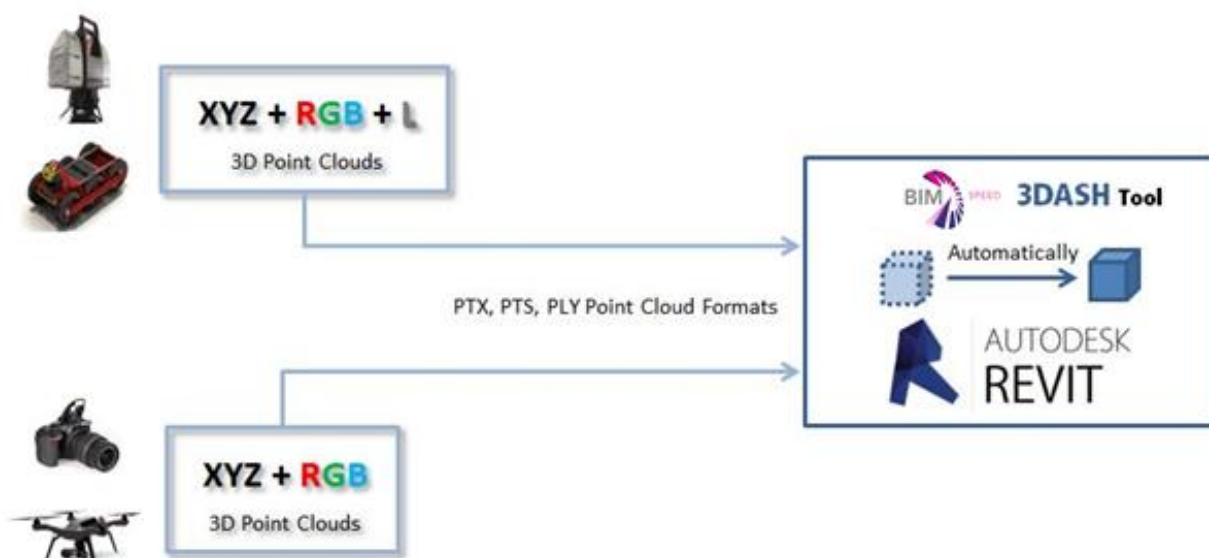


Figure 54 – Process for automatic shaping into REVIT through the 3DASH tool

¹ LEICA CloudWorx for REVIT:

<https://leica-geosystems.com/products/laser-scanners/software/leica-cloudworx/leica-cloudworx-revit>



can be imported into PTX, PTS, PLY formats to be accurately managed into *REVIT* as BIM worldwide representative software by means of a specific tailored plug-in, so called “**3DASH tool**” (3D Automatic Surfaces Handling). Figure 54 describes the process. The 3DASH tool, developed by CARTIF, has been adapted from a previous development carried out by CARTIF as part of the EU H2020 **INCEPTION** project (GA 665220) which was focused on a heritage field, adapting it in the BIM-SPEED project to the field of civil construction. For this purpose, the methodology and the processed algorithms of the tool have been modified.

This specifically tailored plug-in for *REVIT* is programmed in C++ and supported by the *Point Cloud Library* (PCL) as standalone, large scale, open software project for image and point cloud processing. 3DASH is able to precisely display the detected features in a unique working project (RVT/RFA).

The *Point Cloud Library* has a wide range of statistical algorithms to detect geometrical primitives such as planes, cylinders, spheres or cones. The vast majority of the architectural geometries making up the existing buildings can be modelled by means of these primitives. Theoretically, a point cloud can be completely processed with the proposed library.

REVIT has a vast and complex API which, in some cases, highly delays the software development cycle. In order to put the efforts into a practical example, the 3DASH plug-in has been focused on the existing primitives at the Arcaya5 Spanish demo case. Thus, planes are automatically detected on the corresponding point cloud. However, the detection of a different set of basic features can be added upon request.

Note: The 3DASH Tool shown in this deliverable is a result of developments carried out in task 1.1- Architectural, structural, thermal 3D data acquisition and diagnostics in the BIM-SPEED project and is currently in a prototype phase. The validation status of the tool is TRL6 and has been demonstrated using two BIM-SPEED cases, as shown in this deliverable. The tool is available to download directly through the BIM-SPEED platform for the consortium, Project Officer (PO) and Project Technical Advisor.

The commercial exploitation of the 3DASH tool is currently explored at the time of writing this report, considering the following options of commercialisation plan:

- Freemium version of the tool with visualization of features (walls) detected (but not walls generation into *REVIT*), but paying for:
 - Extended version of the tool – visualization of the detected features (walls) and walls generation
 - Extension of the tool/plug-in to detect other features different than walls.

A more detailed description of the exploitation of the tool will be described in WP9-Communicating, disseminating, exploiting innovations of the BIM-SPEED project.



4.4 Thermal characteristics

4.4.1 Thermal comfort

While optimizing the heating/cooling systems is crucial to reduce the energy consumption, the comfort of users must be considered and guaranteed for most of the operative hours of the systems. Several parameters affect user comfort, and the PMV (Predicted Mean Vote) methodology allows to consider through a single parameter both building- and system-related aspects such as the air and mean radiant temperature, the air speed and humidity, and user-related aspects such as clothing and activity types.

The PMV is calculated based on 4 environmental parameters: air temperature, mean radiant temperature, air velocity, relative humidity and 2 parameters relating to the subject: clothing insulation and metabolic rate.

$$PMV = f(T_a, T_r, V_a, RH, I_{cl}, M) \quad [10]$$

As the predicted quality of the indoor thermal environment increases, the PMV value gets closer to 0 (neutral thermal environment). The PMV model and its application for comfort measurement and verification is defined by the ISO 7730 [19] and ISO 7726 [20].

The personal parameters M and I_{cl} are assumed to be constants during the entire monitoring phase and their values are derived from ISO 7730. The air temperature and relative humidity are monitored in a single point. There are different ways to estimate the mean radiant temperature, either applying its definition and using equations to calculate it, or measuring it with particular thermometers or sensors.

Since the amount of radiant heat lost or received by human body is the algebraic sum of all radiant fluxes exchanged by its exposed parts with the surrounding sources, T_r can be calculated from the measured temperature of surrounding walls and surfaces and their positions with respect to the person.

T_r is derived for multiple positions of the subject in the room according to the angle factors algorithm, as presented in ISO 7726 [7]. T_r is computed from the weighted average of the internal surface temperatures T_i and the respective view factor in relation to a person, $F_{s \rightarrow i}$, for N surfaces.

A mathematical expression developed by Cannistraro *et al* [14] calculates the view factors between a subject and the internal surfaces. This approach, turned into an embedded algorithm, computes the coefficients which differentiate the type of surface (vertical or horizontal).

The T_r can be estimated using a **black-globe thermometer**. This thermometer actually measures the globe temperature (GT), tending towards thermal balance under the effect of convection and radiation coming from the different heat sources in the enclosure. Thanks to this principle, knowing GT allows the mean radiant temperature to be determined using equation defined in ISO7726.

This is suitable in the case of environments which are considered to be 'homogeneous', from the bioclimatical point of view, according to ISO 7726 [7], which defines an environment to be homogeneous when the ambient parameters are uniform around the subject. The same standard requires that this condition is frequently met in the cases of air temperature, velocity and humidity, but more rarely in the case of radiation. The limit conditions for the system to be applied are given by the same ISO 7726, which defines each parameter as uniform when its deviation with respect to the mean spatial



value, calculated as a mean of the locations, does not exceed the value obtained by multiplying the required accuracy by the appropriate factor X.

Among the number of modelling approaches, two main ones showed the higher accuracy and applicability: the steady-state and the adaptive models. The steady state model is an analytical method that express the thermal comfort with the PMV, a number on a 7-points scale to predict the thermal sensation of a group of persons exposed to the same thermal environment. The adaptive model is mainly based on the theory of the human body's adapting to its outdoor and indoor climate. Thus, it is a regression model, gathered from observations, that indicates which would be the optimal indoor temperature according to the outdoor temperature. Both approaches have pros and cons because of their accuracy under a set of limited conditions. In general, it can be said that the PMV model is more suitable for conditioned buildings with high level of expectation and where low adaptation actions can be performed (especially for the cooling season), while adaptive models are more suitable for free running buildings with low variation of the personal factors, especially the activity. The adaptive model does not allow it to be applied where the running mean outdoor temperature is less than 10 ° C. For the summer, it is advisable to use the PMV method for buildings with air conditioning systems and the adaptive method for buildings without air conditioning. For this reason, the thermal comfort module includes a set of comfort models guaranteeing the applicability to all the possible cases. In the case of performance assessment of a building before and after renovation, considering both the winter and summer seasons, it is advisable to use the PMV model

Assessment Methodology for PMV methodology

The hourly PMV values have to be evaluated against a set limit to identify the number of occupied hours outside an acceptable comfort range, and the room values are aggregated through a floor-area weighted average.

Note: as the KPI aggregates the values at building level to provide an overall value, it can hide localized discomfort conditions. It is thus recommended to analyse all room values to identify critical issues.

Data requirement

Parameter	Unit
PMV value	-
Start of Monitoring period	dd/mm/yy hh:mm
End of Monitoring period	dd/mm/yy hh:mm
Occupied hours	h
Room useful floor area	m ²
Number of rooms	-

Table 1 - General Data Requirements



Calculation method

The parameters for calculating the PMV must be measured in a single point that is characteristic of the environment, not influenced by sources of disturbance (eg. direct radiation, air currents),

1. For every room in the building, calculate the hourly PMV $PMV_{h,i}$ [-] according to the EN ISO 7730 [19].
2. Define the PMV limit PMV_{lim} as follows:
 - Category I. Spaces with special requirements (sensitive and fragile persons, e.g. sick people, very young children, elderly adults): $PMV_{lim} = \pm 0.2$
 - Category II. New buildings and renovations: $PMV_{lim} = \pm 0.5$
 - Category III. Existing buildings: $PMV_{lim} = \pm 0.7$
 - Category IV. Acceptability for a limited part of the year: $PMV_{lim} = \pm 1$
3. For every room in the building, calculate the number of occupied hours outside range $h_{or,i}$ as the number of hours when $|PMV_{h,i}| \geq |PMV_{lim}|$ and occupancy is above 0;
4. For every room, calculate the percentage of occupied hours outside range POR_i [%] as in equation [11]:

$$POR_i = \frac{h_{or,i}}{h_{tot}} * 100 \text{ [%]} \quad [11]$$

where: h_{tot} = total occupied hours during the heating season [h]

5. Calculate the average building percentage of occupied hours outside range POR as in equation [12]:

$$\Delta T = \frac{\sum_{i=1}^n POR_i * S_i}{\sum_{i=1}^n S_i} \text{ [%]} \quad [12]$$

where:

- n = total number of rooms in the building [-]
- S_i = floor area of i -th room in the building [m^2]

Note: only consider main rooms that are occupied for several hours (e.g. bedrooms, offices, classrooms). Do not consider short-term occupancy and transit areas (e.g. bathrooms, corridors, small storage areas).

Benchmarks

According to EN 16798 [1], an acceptable amount of deviation is 6% of occupied hours a year. The best performance is achieved when there are no deviations outside the PMV range.

To define an assessment scale, a linear interpolation between the minimum (6%) and best performance (0%) is recommended.

Adaptive model

The main outputs of the adaptive models are different relations for the evaluation of the “comfort temperature”, which is the air temperature that allows the thermal neutrality ($PMV = 0$). In fact, the influence of the subjective conditions brings to a translation of the thermal balance, so that in some cases the real zero condition of the PMV is different from the zero measured with the traditional method (e.g. a microclimate station).



One of the key findings from various field studies on adaptive thermal comfort is the correlation between the indoor comfort temperature and the corresponding mean outdoor temperature for the month in question. Several studies turned out to reveal a linear relationship between those variables; so much to suggest that that the desired comfort temperature could be determined by a linear equation:

$$T_{CO} = aT_{out} + b$$

Where T_{co} is the comfort temperature (°C), T_{out} is the outdoor temperature (°C) and a, b are two constants. This is the basic equation of all the adaptive models, differing one each other only by the way of calculating the outdoor temperature and the two constants. Different models were developed with large collection of data from different building categories, such as naturally ventilated buildings (where the PMV model fails mostly) and mechanically ventilated buildings.

The thermal comfort module includes three different models, selected in literature and that are the base of the comfort standards EN 16798 and ASHRAE 55.

- *Thermal audit at building scale*

Thermal audit in buildings consists on qualitative and quantitative estimation of thermal performances. The verification of thermal performances on a qualitative basis makes use essentially of thermal scans realised via an IR thermal camera, a non-invasive and remote sensor allowing to register thermal images representing the emissivity state of the surface scanned. By performing a proper calibration, the emissivity map can be translated into a temperature map, the so called thermogram. The analysis of thermograms acquired from large areas with a sufficiently high spatial resolution (at least 640 x 480 pixels) makes it possible to localize building defects such as missing insulation and sealant in the junctions (inducing air leaks), delaminating render, condensation problems, water infiltration.

Quantitative measures for assessing the thermal performances of a building can be classified in terms of the different elements considered as responsible of the building thermal behaviour, which are:

- indoor environment
- building façade.

The key performance indicator of the indoor environment is the thermal comfort which is a function of air temperature, humidity and velocity, wall surface temperature, clothing insulation, activity level (metabolic heat).

The key performance indicator of the building façade in its entirety is the Envelope Thermal Transfer Value (ETTV) that considers the three basic components of heat gain through the external walls and windows of a building. These are:

- Heat conduction through opaque walls
- Heat conduction through glass windows
- Solar radiation through glass windows.



Once known the thermal transmittance of all the walls of the envelope, is it possible to calculate the ETTV with the following equation [21], [22]:

$$ETTV = 12 * (1 - WWR) * U_w + 3.4 * (WWR) * U_f + 211 * (WWR * CF * SC) \quad [W m^{-2}] \quad [13]$$

where:

U_w : Thermal transmittance of opaque wall ($W m^{-2} K^{-1}$)

U_f : Thermal transmittance of fenestration ($W m^{-2} K^{-1}$)

CF: correction factor for solar heat gain through fenestration

SC: shading coefficients of fenestration

WWR: window-to-wall ratio (fenestration area / gross area of exterior wall).

For the calculation it is considered that there is no external shading device installed, so the Solar Coefficient (SC) of the glazing system is calculate as follow:

$$SC = \frac{\text{Solar heat gain of the glass}}{\text{Solar heat gain through a 3mm unshaded clear glass}} \quad [14]$$

The Solar Correction Factor (CF) for the wall is taken by the standard SBCA, 2004 [---]

Once known the ETTV with and without the thermal bridges effects is it possible to evaluate the energy saving loss. The relation is:

$$\Delta E = HDH * \Delta ETTV * 1/\eta \quad [kWh/m^2y] \quad [15]$$

4.4.2 Wall thermal transmittance

Thermal transmittance is one of the main measurement aspects that have to be measured after the building envelope construction or renovation in order to verify its agreement with the value estimated at the modelling stage or to evaluate the improvement of the renovation. Thermal transmittance of building elements is represented by the parameter called U value given in $[W/m^2K]$. It can be measured by an IR thermal camera or heat flux transducer used in conjunction with temperature sensors.

4.4.3 Wall thermal bridges

Thermal bridges represent an important issue for building diagnostics because they deeply influence energy efficiency. For this reason, many studies and standards are available in literature regarding the thermal bridges affecting the building envelope and their detection. The current standards can be divided in two main groups:

Standards describing experimental procedures for the visualization of thermal bridge (qualitative evaluation by IR thermal camera), i.e. [23]

Standards defining calculation methods for quantitative assessment of the thermal bridge influence to the overall heat transfer, i.e. [24]

The main drawbacks of those procedures is that the first one allows only visualizing the thermal bridges without giving any quantitative information about their influence on the global thermal



transmittance of the building element, and the second one requires the knowledge of thermal and geometric characteristics of the complete stratigraphy of the building element, including the components constituting the thermal bridge.

It is possible to overcome the two limitations above mentioned considering that the increase of the thermal transmittance of a building element associated to a thermal bridge can be quantitatively calculated on the basis of their spatial extent measured by an IR thermal camera. The output of the inspection can be a picture with a temperature level or thermal index level that highlight the thermal bridges location and extension.

4.5 Indoor Environmental Quality

The methodology for the IEQ assessment will follow the EN 16798 approach [1]. However, given the fact that EN 16798 [1] does not cover all the IEQ aspects, for specific issues or problems, the inclusion of further parameters is evaluated case by case. The proposed methodology is based on the evaluation of KPIs and benchmarks according to the buildings' classification shown in Table 2.

Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

Table 2 - Building classification to assign performance score in relation to the operating hours of the building in each category

For each IEQ aspect, the assessment procedure makes use of the above building classification to assign a performance score in relation to the operating hours of the building in each category. The benchmark is done considering a threshold of maximum % of operating hours outside the targeted class.



The monitoring systems to be used should allow the measurement of the variables listed in the following

Table 3.

Table 3 – Variables for sufficient monitoring system

Variable	Accuracy		Comments
	Required	Desirable	
Air temperature (ta)	± 0.5°C	± 0.2°C	The air temperature sensor shall be effectively protected from any effects of the thermal radiation.
Mean Radiant Temperature (tr)	± 2°C	± 0.2°C	This shall be measured with globe-thermometer or view factor methodology (requires surfaces temperatures)
Absolute humidity expressed as partial pressure of water vapour	± 0.15 kPa	± 0.15 kPa	This variable can be measured also as relative humidity with required accuracy of ± 5 % and desirable accuracy of ± 3 %
Air velocity (va)	± (0.05+0.05va) m/s	± (0.02+0.07va) m/s	This variable becomes significant for values higher than 0.2 m/s. An indication of the mean value and standard deviation for a period of 3 min is also desirable
CO2	± 50 ppm	± 30 ppm	

4.5.1 Indoor Air Quality – CO2

The monitoring of the indoor air quality KPI according to EN 16789 will be applied and, where relevant and needed, enhanced with the monitoring of other pollutants, according to the demonstration requirements.

Assessment Methodology

Air quality of building must be evaluated in buildings where people are the main pollution source by measuring the average CO₂ concentration in the building, when building is fully occupied. This can be done either with representative samples of room air or by measuring the concentration of the exhaust air. Measurements shall be made where occupants are known to spend most of their time, preferably at head level during typical high load conditions. CO₂ measurements should preferably be made under winter conditions, as normally fresh air supply is lowest during the colder months (limited use of operable windows, partly closed facade shutters due to draught risk). In some cases, momentary measurements at ‘worst case times’ (e.g. end of the morning or end of the afternoon in for example an office or school) might be sufficient. In larger buildings, not all rooms need to be evaluated and



measurements are required in only 5 or 10% of the rooms (representatively chosen). In mechanically ventilated buildings measurement of the amount of fresh air supply is often more practical and precise than the measurement of CO₂ concentrations, also considering that several National buildings codes provides baselines in terms of volume of fresh air per person in function of the building end use. The sensor to acquire the CO₂ need to be in a position that should be representative of the room’s environmental conditions, avoiding exposures to direct solar radiation, air droughts and zones characterized by stagnant air.

Installation is done by an experienced technician. If possible, the sensor is fixed, otherwise the occupants are informed to prevent the sensor from being moved or covered.

The hourly CO₂ concentration values above outdoor are assessed against a safety threshold to identify the number of hours outside an acceptable comfort range, and the room values are aggregated through a floor-area weighted average. **Note:** as the KPI aggregates the values at building level to provide an overall value, it can hide localised discomfort conditions. It is thus recommended to analyse all room values to identify critical issues.

Data requirement

Parameter	Unit
Room CO ₂ concentration	ppm
Outdoor CO ₂ concentration	ppm
Start of monitoring period	dd/mm/yy hh:mm
End of monitoring period	dd/mm/yy hh:mm
Occupied hours	h
Room useful floor area	m ²
Number of rooms	-

Table 4 - Data Requirements for Indoor Air Quality

Calculation method

1. Define the start and end times of the analysis period (yearly, heating, cooling, custom);
2. For the selected rooms in the building, calculate the hourly average CO₂ concentration $CO_{2,indoor,i}$ [ppm] from measured samples. A minimum sample time of 10 minutes is recommended;
3. For every room and hourly value, calculate the room CO₂ concentration above outdoors $CO_{2,above,i}$ as in equation [16]. The value for $CO_{2,outdoor}$ at the time of installation it must be acquired for 10 minutes outside in order to have a reference value. If this is not possible, a value must be found on surrounding public monitoring station. It is important to have a reference value on the CO₂ concentration outside the building.

$$CO_{2,above,i} = CO_{2,indoor,i} - CO_{2,outdoor,i} \text{ [ppm]} \quad [16]$$

4. Define the CO₂ limit $CO_{2,lim}$ as follows:
 - Category I. Spaces with special requirements (sensitive and fragile persons, e.g. sick people, very young children, II elderly adults): $CO_{2,lim} = 550$ ppm
 - Category II. New buildings and renovations: $CO_{2,lim} = 800$ ppm



- Category III. Existing buildings: $CO_{2,lim} = 1350 \text{ ppm}$
 - Category IV. Acceptability for a limited part of the year: $CO_{2,lim} > 1350 \text{ ppm}$
5. For every room in the building, calculate the number of occupied hours outside range $h_{or,i}$ as the number of hours when $CO_{2,above,i} \geq CO_{2,lim}$;
 6. For every room, calculate the percentage of hours outside range POR_i [%] as in equation [11]:
 7. Calculate the average building percentage of hours outside range POR as in equation [12].

Note: only consider main rooms that are occupied for several hours (e.g. bedrooms, offices, classrooms). Do not consider short-term occupancy and transit areas (e.g. bathrooms, corridors, small storage areas).

Benchmarks

According to EN 16798 [1], an acceptable amount of deviation is 5% of occupied hours. The best performance is achieved when there are no deviations outside the design limit.

To define an assessment scale, a linear interpolation between the minimum (5%) and best performance (0%) is recommended.

4.5.2 Indoor Air Quality – PM

(Note: For further details see also D4.1: “Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation)

The PMs monitoring could be significant also considering the actual concerns about the high concentration revealed in some European Country. Moreover, measuring the PMs is useful to evaluate the impact of the renovation works because of the dust production during the construction works.

In the last decade, many low-cost monitoring sensors and sensor-networks have been used as an alternative air quality assessment method. A good part of these sensors is available and easily purchased on the electronic market at very affordable prices. Among the various devices available, the sensors dedicated to the measurement of particulate matter atmospheric have had a great commercial success, also linked to the significant media impact of this pollutant, whose concentrations exceed regulatory limits. The diffusion among the population of low-cost sensors for the measurement of atmospheric particulate matter and the frequent requests for discussion by citizens of the related data with the levels measured by the air quality monitoring stations induced to with sensors of the measurement campaigns in parallel low-cost and standard monitoring tools, meeting the specifications of the legislation of reference. These studies allow to highlight the potential of these sensors, which in their cheapness and relative ease of use, will probably be increasingly widespread and used [REF : **Potenzialità e limiti nell’utilizzo di sensori low-cost per la misura del particolato atmosferico PM10 in aria ambiente- Luca Zagolin, Giovanna Marson, Alessio De Bortoli**]



Assessment Methodology

Air quality of building has to be evaluated in buildings where people are the main pollution source by measuring the average PMs Concentration in the building, when building is fully occupied. This can be done either with representative samples of room air or by measuring the concentration of the exhaust air.

Measurements shall be made where occupants are known to spend most of their time. In some cases, momentary measurements at ‘worst case times’ might be sufficient. In larger buildings not all rooms need to be evaluated and measurements in only 5 or 10% of the rooms (representatively chosen) might be enough. There are two assessment methodologies available:

1. The hourly PMs Concentration values are assessed against a threshold value to identify the number of hours outside an acceptable comfort range, and the room values are aggregated through a floor-area weighted average. Thresholds are provided by WHO [25] and WELL [26] guidelines.

Parameter	Limit WHO	Limit WELL
PM _{2.5}	< 25 µg/m ³	< 15 µg/m ³
PM ₁₀	< 50 µg/m ³	< 50 µg/m ³

Table 5 - Thresholds provided by WHO and WELL guidelines

A maximum tolerance of 20% of the operating hours out of limits is accepted.

2. The hourly and 24-hour rolling average PMs concentration are assessed against a classification, provided the Victoria EPA institute (Australia), as actually implemented:

Category	24-hr-PM _{2.5} [µg/m ³]	1-hr PM _{2.5} [µg/m ³]
Very good	0-8.2	0-13.1
Good	8.3-16.4	13.2-26.3
Fair	16.5-25.0	26.4-39.9
Poor	25.1-37.4	40-59.9
Very poor	37.5 or greater	59.9 or greater

Table 6 - hourly and 24-hour rolling average PMs Concentration

Note: as the KPI aggregates the values at building level to provide an overall value, it can hide localized discomfort conditions. It is thus recommended to analyze all room values to identify critical issues.



Data requirement

Category	24-hr-PM10 [$\mu\text{g}/\text{m}^3$]	1-hr PM10 [$\mu\text{g}/\text{m}^3$]
Very good	0-16.4	0-26.3
Good	16.5-32.9	26.4-52.7
Fair	33-49.9	52.8-79.9
Poor	50-74.9	80-119.9
Very poor	75 or greater	120 or greater

Parameter	Unit
Room PM2.5 concentration	$\mu\text{g}/\text{m}^3$
Room PM10 concentration	$\mu\text{g}/\text{m}^3$
Start of monitoring period	dd/mm/yy hh:mm
End of monitoring period	dd/mm/yy hh:mm
Occupied hours	h
Room useful floor area	m^2
Number of rooms	-

Table 7 - Data Requirements for Indoor Air Quality - PM

Calculation method

1. Define the start and end times of the analysis period (yearly, heating, cooling, custom);
2. For the selected rooms in the building, calculate the hourly average PMs Concentration [$\mu\text{g}/\text{m}^3$] from measured samples. A minimum sample time of 15 minutes is recommended;
3. For every room in the building, calculate the number of occupied hours inside each range category shown above ($h_{ir,i}$) as the number of hours when $PM_{,lim_inf} \geq PM \geq PM_{,lim_sup}$;
4. For every room, calculate the percentage of hours inside each range POR_i [%] as in equation [11]
5. Calculate the average building percentage of hours inside each range POR as in equation [12]

Note: only consider main rooms that are occupied for several hours (e.g. bedrooms, offices, classrooms). Do not consider short-term occupancy and transit areas (e.g. bathrooms, corridors, small storage areas).

4.6 Acoustic Data

4.6.1 Acoustic parameters (Sound Pressure Level at various locations inside/outside, R')

European standard ISO 12354-3 [27] provides a calculation model to evaluate the reduction of external noise using buildings' façades (sound reduction level of façade). The calculation is based on the sound reduction index of the façade elements (walls, windows, doors and small elements). The accuracy of this calculation method depends on the accuracy of the input data, i.e. type and geometry of the elements involved, rooms and building structure. The prediction of the acoustic insulation provided



by the elements of the façade can be expressed through the weighted standardized level difference of the façade, which is calculated according to the analytical formula (Eq. 1) included in ISO 12354-3 [27]:

$$D_{2m,nT} = R'_w + \Delta L_{fs} + 10 \log \frac{V}{6 T_0 S} \quad [17]$$

where R'_w is the apparent weighted sound reduction index of the façade [measured in dB], V is the volume of the receiving room [in m^3], T_0 is the reference reverberation time [in s] (for dwellings T_0 is given as 0,5 s), S is the total area of the façade as seen from the inside [in m^2] and ΔL_{fs} is the level difference due to façade shape [in dB]. Sound transmission through building façade is established by calculating the apparent weighted sound reduction index of the façade. This is used to determine the noise difference between the outside and the inside. The apparent weighted sound reduction index is calculated according to equation [18] and requires knowledge of sound reduction index values of all the components (opaque and transparent):

$$R'_w = -10 \log \left[\sum_{i=1}^n \frac{S_i}{S} 10^{\frac{-R_{wi}}{10}} + \sum_{i=1}^n \frac{A_0}{S} 10^{\frac{-D_{n,e,wi}}{10}} \right] - K \quad [18]$$

where A_0 is the reference equivalent sound absorption area ($10 m^2$), $D_{n,e,wi}$ is the weighted normalized sound level difference of each small element [in dB], R_{wi} is the sound reduction index of each element [in dB], S is the total area of the façade as seen from the inside [in m^2], S_i is the area of each element of the façade [in m^2] and K is the correction due to the contribution of flanking sound transmission. This term is normally negligible ($K=0$ dB). However, flanking transmission reduces the global sound reduction index if rigid elements in the façade, such as concrete or bricks, are connected to other rigid elements, such as floor, inside the receiving room. In this case, setting $K=2$ dB is normally sufficient to account flanking transmission. The equations above do not depend on frequency and can therefore be applied to different frequency ranges [28]. Sound reduction index of elements should be analyzed in frequency domain to effectively reduce human exposure to annoyance, because external sources have different frequency emissions. Nevertheless, the weighted sound reduction index of elements, R_w , is used to evaluate and quickly compare many different solutions [29].

4.6.2 Acoustic comfort assessment before renovation for intervention definition and modelling the upgraded performance and performance verification after renovation

Indoor acoustic comfort is assessed on the basis of the measured or simulated indoor A-weighted sound pressure level [measured in dB(A)] within the living environment transmitted through the building façades and due to the external noise surrounding the building.

In-field measurements of the indoor sound pressure level [in dB(A)] can be carried out using different equipment, according to the accuracy desired and budget available. Since the sound level difference is referred to a position of 2 meters in front of the façade, the external sound pressure level must be measured or predicted at that point.

The sound pressure is here denoted as “p” and is measured in Pascal (Pa). The corresponding sound pressure level (L) is defined as the level in decibels compared to a reference pressure, as:



$$L = 20 \log_{10} \left(\frac{|p|}{|p_0|} \right) \quad [19]$$

Where $p_0=2e-5$ Pa is the accepted standard threshold of human hearing.

The indoor ambient noise level includes noise contributions from:

- **External sources outside** the building (including, but not limited to, noise from road, rail and air traffic, industrial and commercial premises)
- **Building services** (e.g. ventilation system, plant, etc.). If a room is naturally ventilated, the ventilators or windows should be assumed open as required to provide adequate ventilation. If a room is mechanically ventilated, the plant should be assumed to be running at its maximum operating duty.

The indoor sound pressure level can be calculated as function of the outdoor noise level according to ISO 12354-3 [27] through equation [20]

$$L_2 = L_{1,2m} - D_{2m,nT} + 10 \lg \frac{T}{T_0} \quad [dB] \quad [20]$$

where L_2 is the average sound pressure level in the receiving room [in dB], $L_{1,2m}$ is the average sound pressure level at 2 m in front of the room façade [in dB], $D_{2m,nT}$ is the standardized sound level difference of the room façade [in dB], T_0 is the reference reverberation time [in s] (0.5 s) and T is the reverberation time in the receiving room [in s]. Reverberation time can be measured according to the standard EN ISO 3382-2 [30].

The indoor sound pressure level related to the building services is influenced by two parameters: the airborne sound insulation between spaces and the impact sound insulation of floors. The required minimum airborne sound insulation values between rooms are generally defined by the activity noise in the source room and the noise tolerance in the receiving room. The impact sound (e.g. footsteps) transmitted into spaces via the floor is limited by the recommended maximum weighted standardized impact sound pressure level for receiving rooms of different types and uses.

Two more key performance indicators of the acoustic comfort are:

- Reverberation

The reverberation time of a room used to be regarded as the predominant indicator of its acoustic properties. The reverberation time of a room is defined, as the time required the sound pressure level to decrease by 60 dB, at a rate of decay given by the least-squares regression of the measured decay curve from a level of 5 dB below the initial level to 35 dB below the initial level.
- Speech Intelligibility

Within a building, clear communication of speech between the users of the building should be provided. Large spaces, such as open plan spaces, require extra specification, as these may be more complex acoustic spaces. The main issue is that the noise from different groups of people functioning independently in the space may significantly increase the background noise level, and thus decrease speech intelligibility (STI-value).



5. Demonstration in relevant environment (TRL6)

Some of the above methods and means to collect geometric data with laser scans and thermal data with thermal cameras for data collection have already been demonstrated on BIM-Speed demonstration case. These initial demonstrations are summarized in this section.

5.1 Demo Sites / Laser Scanning

The 3Dash tool has been tested with 2 demonstration projects, Poland and Spanish demo. A comparison between the traditional generation of BIM models using point clouds as template or using the 3DASH tool for automatic detection of walls and other basic elements from point clouds has been done and the result is shown below.

5.1.1 Jazdy Konnej-Warsaw II demo (Poland)

This building has the particularity that is an underpass. The first step of the 3DASH tool is launch the plug-in and upload the point clouds available. The point clouds of a part of the building are shown in Figure 55. The following table [Table 8] provides an overview of the required time to transfer the given point clouds of the underpass into a basic BIM model by using the 3DASH tool.



Table 8: Steps and results of the 3DASH tool with the WARSAW II demo

Steps	Time	Results
Analyzed	22"	 <p>DESCRIPTION: ANALYZED POINTS: 14798477 (D) - CLOSE (B) - BACKGROUND 200.0 FPS</p>

Figure 55 – Interior of the point cloud of the WARSAW II shown in the 3DASH tool interface



Pre-processing

16"

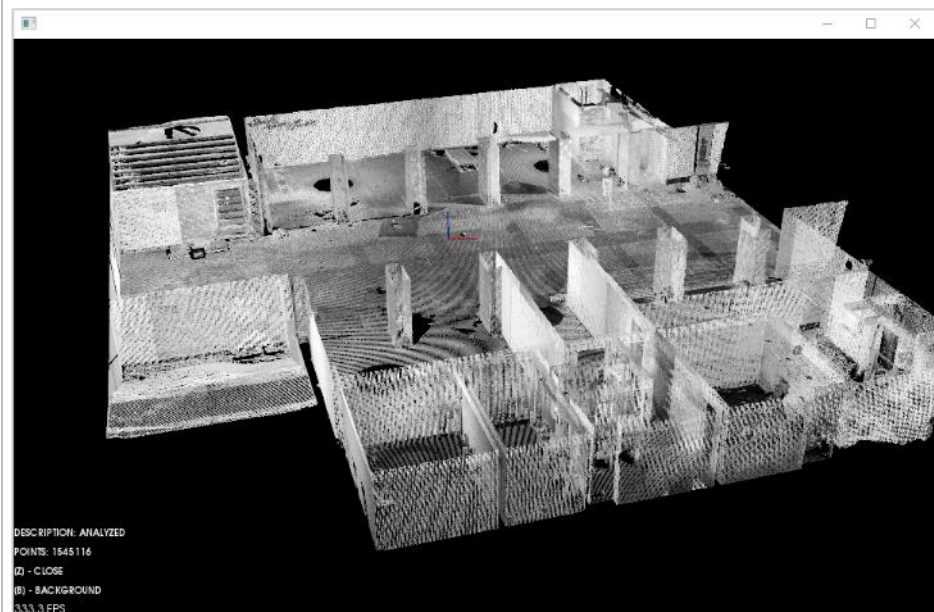
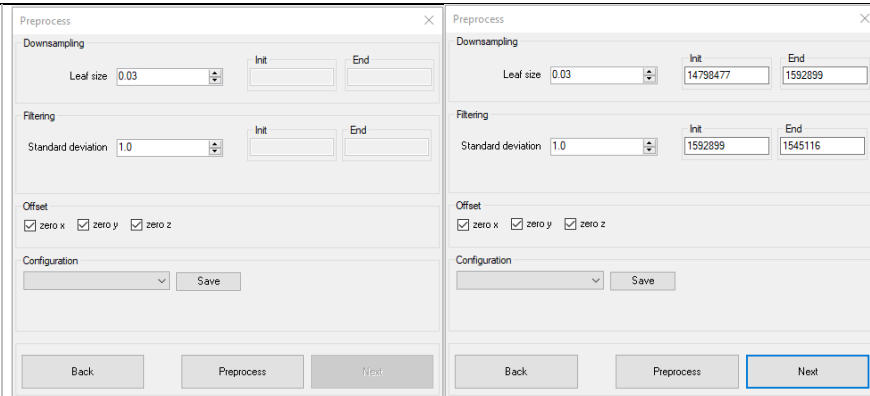


Figure 56 – Pre-processing results shown in the 3DASH tool interface



Segmentation

25"

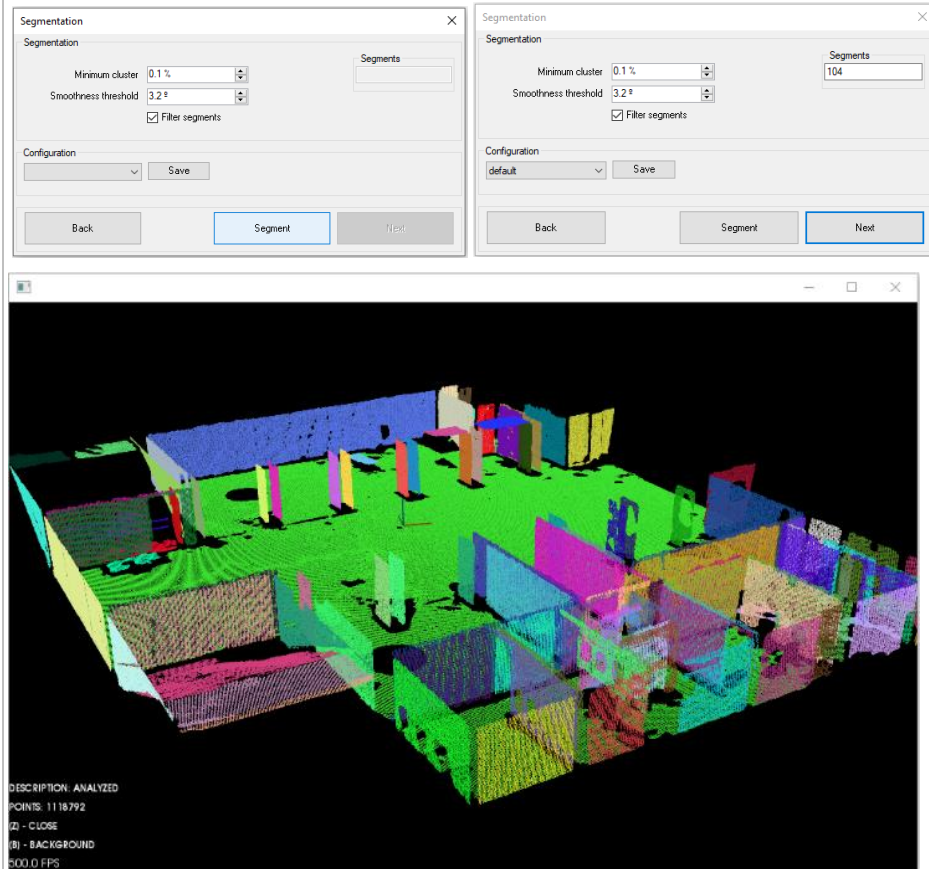
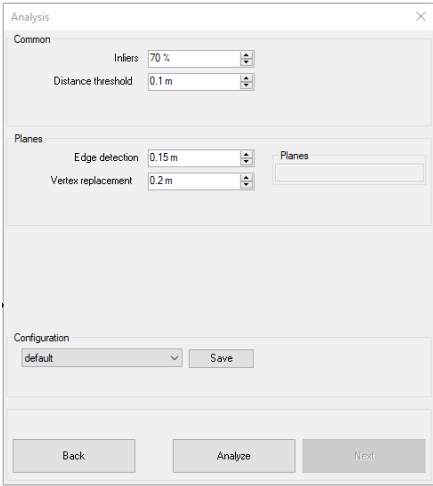


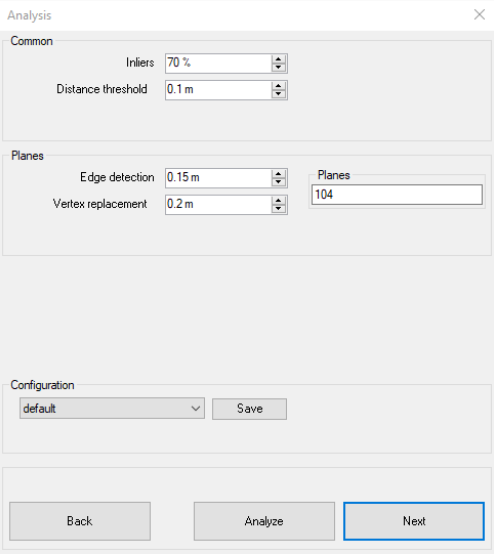
Figure 57 – Segmentation results shown in the 3DASH tool interface

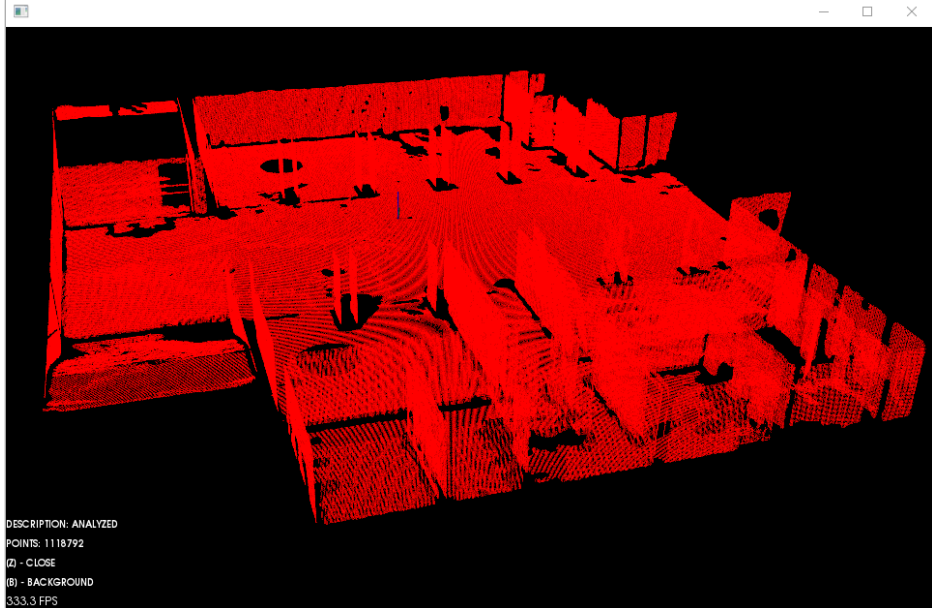


Analysis

2''







DESCRIPTION: ANALYZED
 POINTS: 1118792
 (Z) - CLOSE
 (B) - BACKGROUND
 333.3 FPS

Figure 58 – Analysis results shown in the 3DASH tool interface



Parameterization 6'

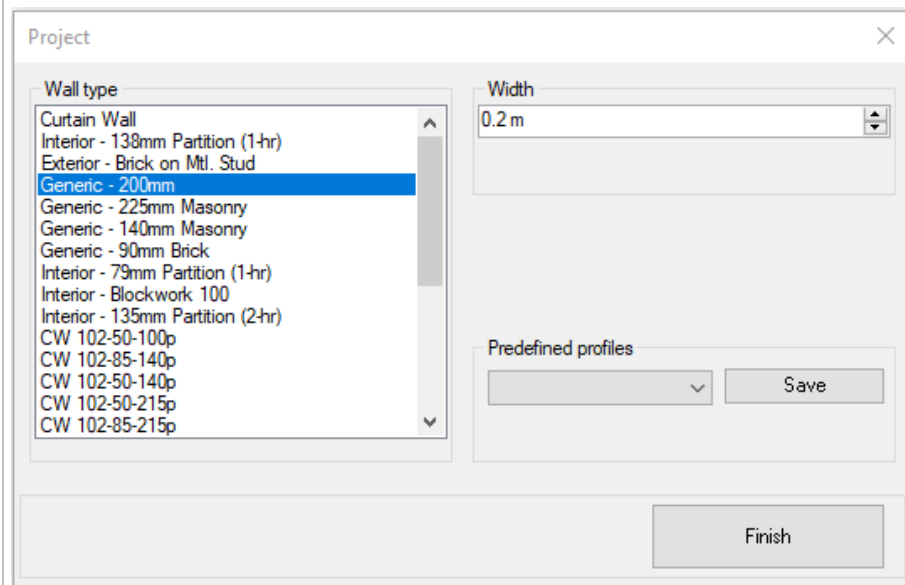


Figure 59 – Type of wall selected

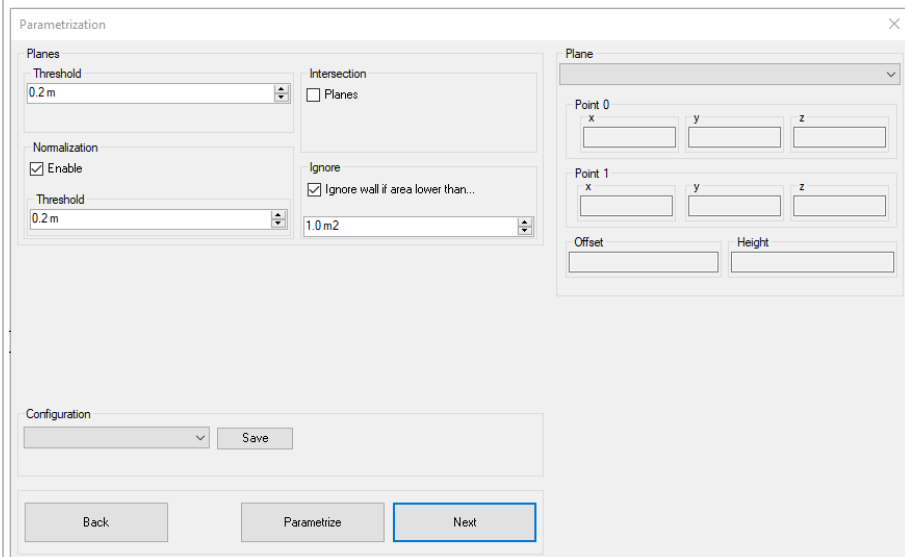


Figure 60 – Parameterization options selected



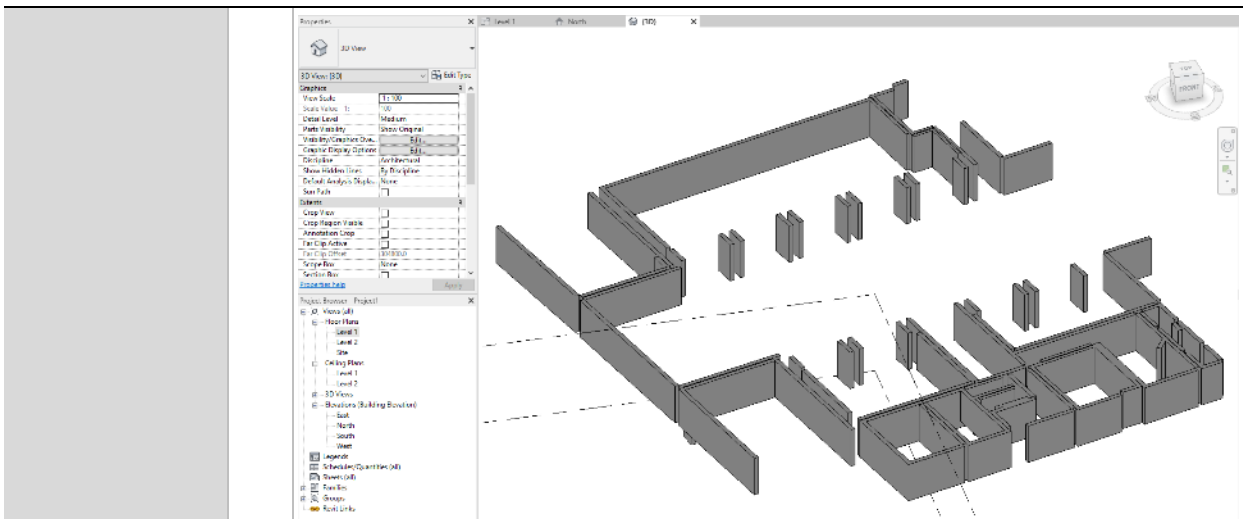


Figure 61 – Results of the parameterization process shown in Revit interface

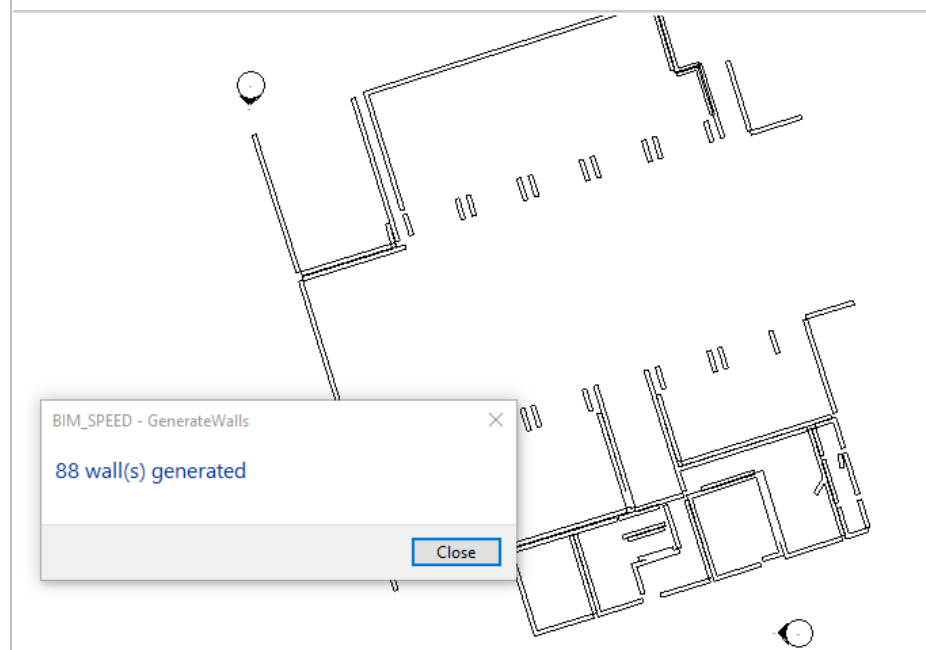


Figure 62 – Result of automatic generation from a point cloud shown in Revit interface

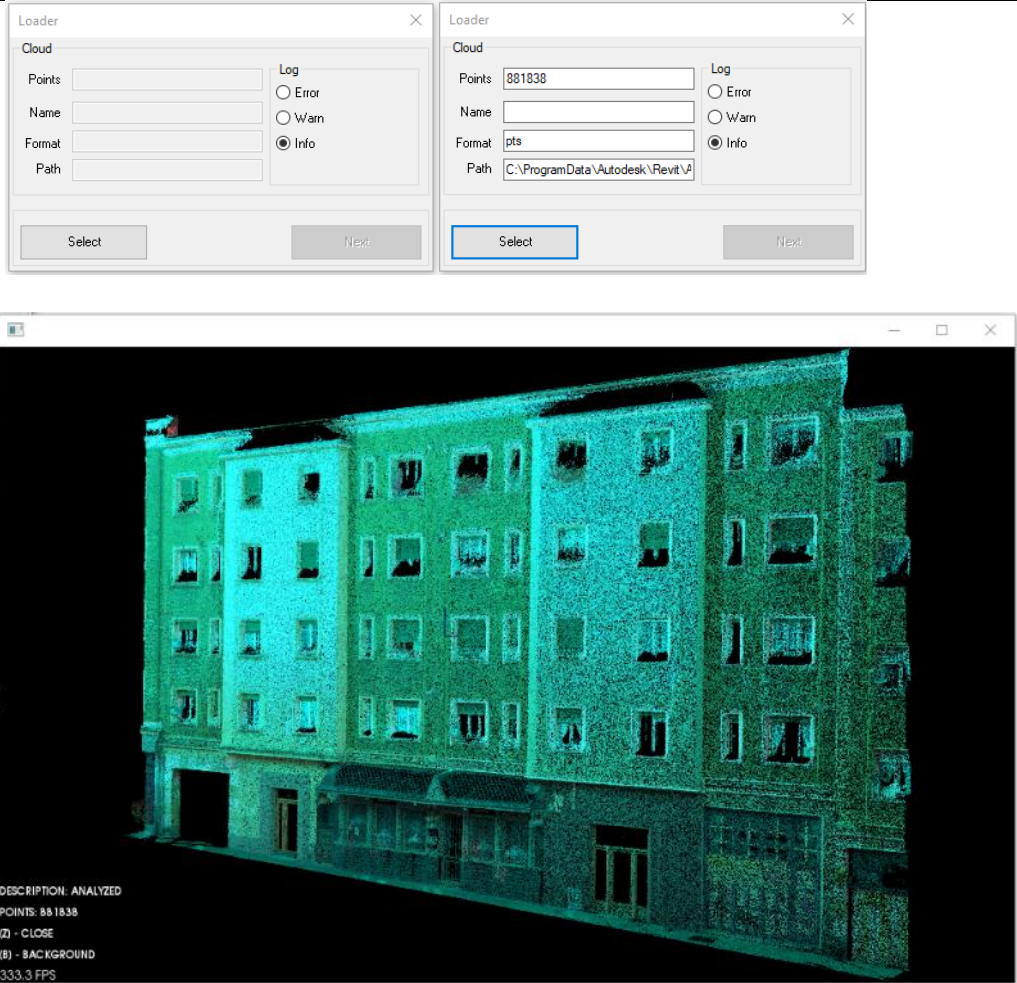


5.1.2 ARCAYA5-Vitoria demo (Spanish)

The point clouds of the main façade of the building Manuel Diaz Arcaya 5 (located in the city of Vitoria-Gasteiz in Spain) are shown in Figure 63.

The following table [Table 9] provides an overview of the required time to transfer the given point clouds of the underpass into a basic BIM model by using the 3DASH tool.

Table 9: Steps and results of the 3DASH tool with the Vitoria-Gasteiz demo in Spain

Steps	Time	Results
Analyzed	2"	 <p>Figure 63 – Point clouds of the main façade of ARCAYA building shown in the 3DASH tool interface</p>



Pre-processing

3"

Preprocess

Downsampling

Leaf size: 0.05

Filtering

Standard deviation: 1.0

Offset

zero x zero y zero z

Configuration

arcaya Save

Back Preprocess Next

Preprocess

Downsampling

Leaf size: 0.05

Init: 881838 End: 392253

Filtering

Standard deviation: 1.0

Init: 392253 End: 366288

Offset

zero x zero y zero z

Configuration

arcaya Save

Back Preprocess Next

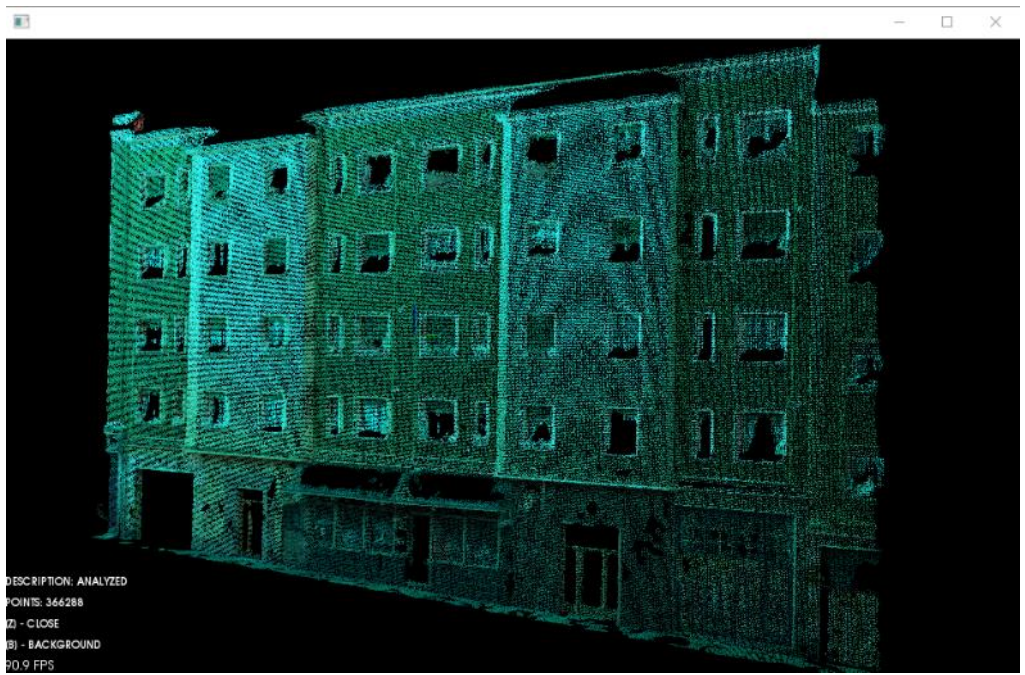


Figure 64 – Pre-processing results shown in the 3DASH tool interface



Segmentation 6'

Segmentation

Segmentation

Minimum cluster: 0.2%

Smoothness threshold: 4.3°

Filter segments

Configuration: arcaya

Save

Back Segment Next

Segmentation

Segmentation

Minimum cluster: 0.2%

Smoothness threshold: 4.3°

Filter segments

Configuration: arcaya

Save

Back Segment Next

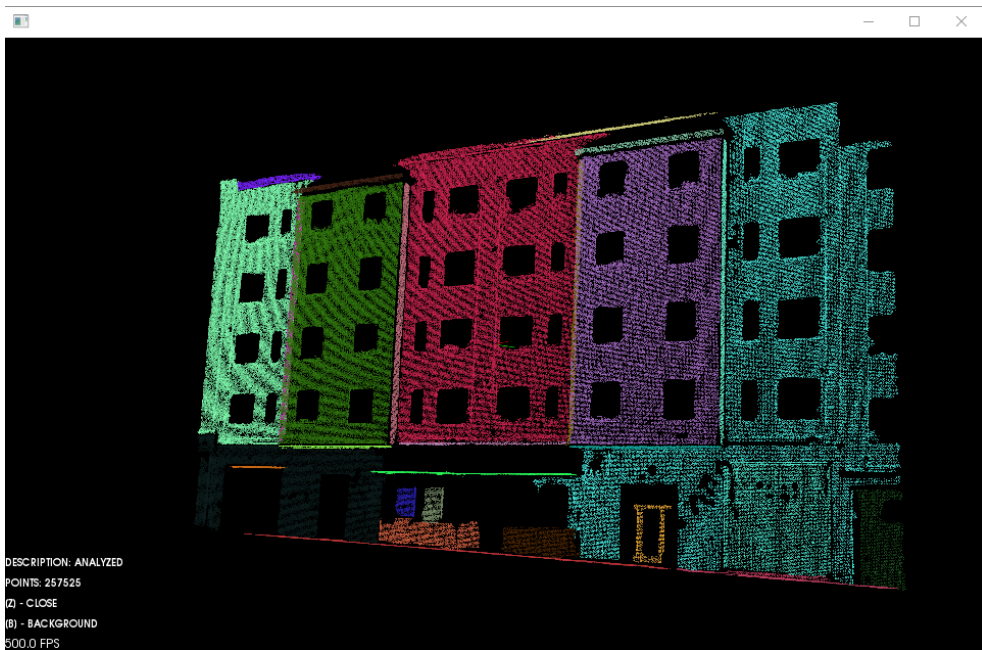


Figure 65 – Segmentation results shown in the 3DASH tool interface



Analysis

4'

Analysis
✕

Common

Inliers

Distance threshold

Planes

Edge detection

Vertex replacement

Planes

Configuration

Analysis
✕

Common

Inliers

Distance threshold

Planes

Edge detection

Vertex replacement

Planes

Configuration



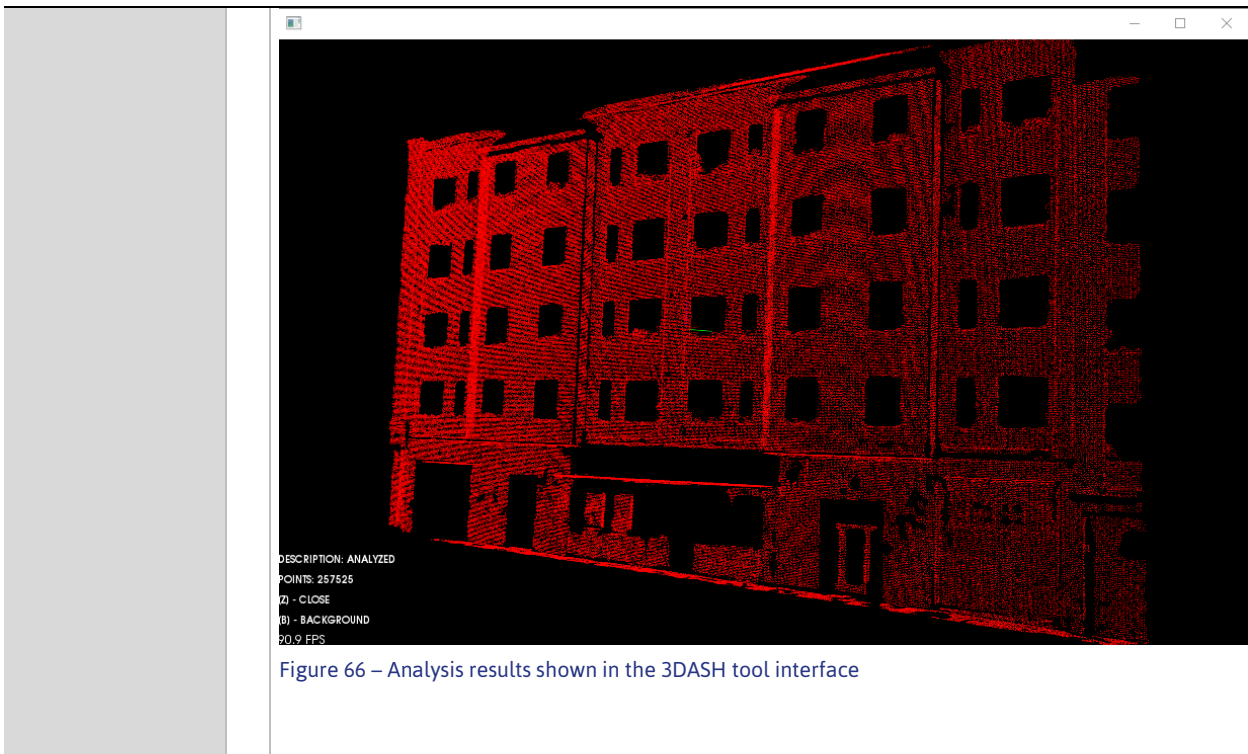


Figure 66 – Analysis results shown in the 3DASH tool interface



Parameterization

3'

n

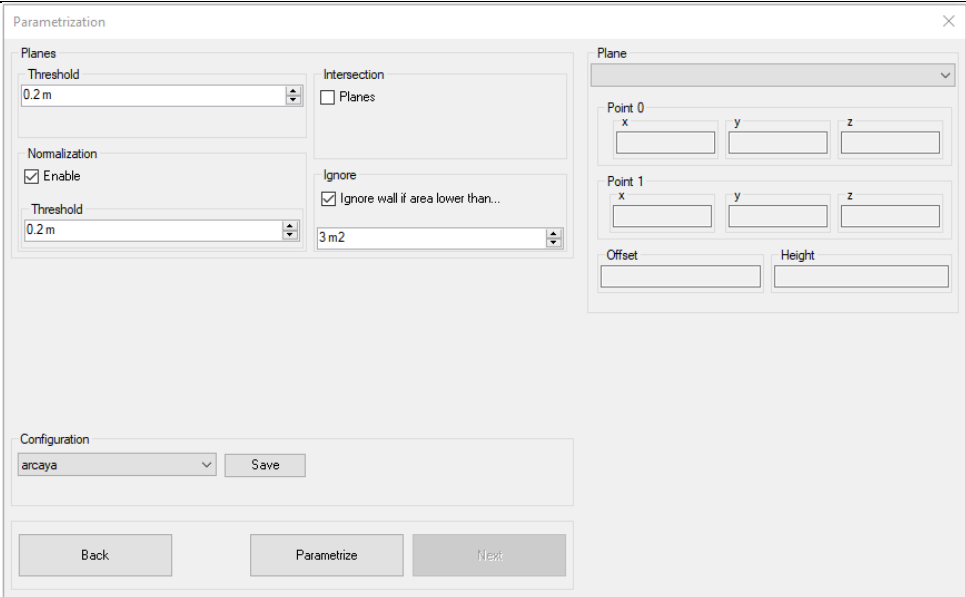


Figure 67 – Parameterization options selected

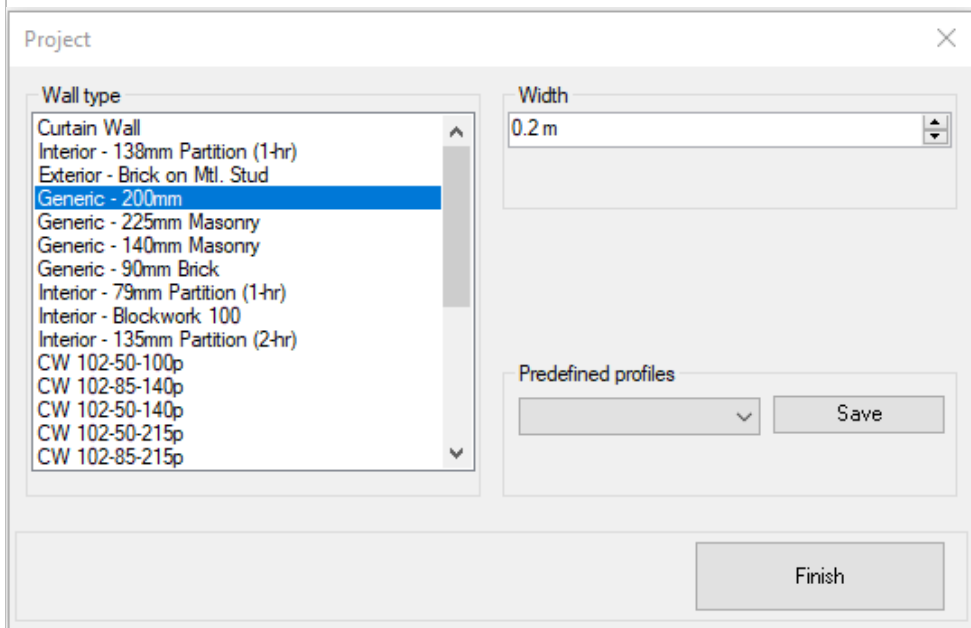


Figure 68 – Type of wall selected



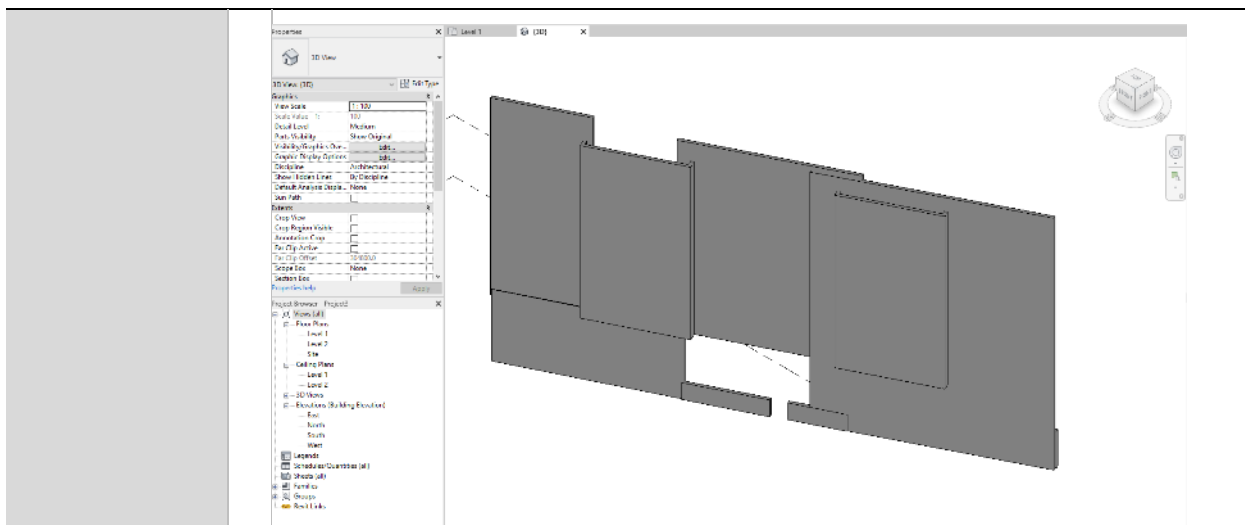


Figure 69 – Result of automatic generation from a point cloud shown in Revit interface

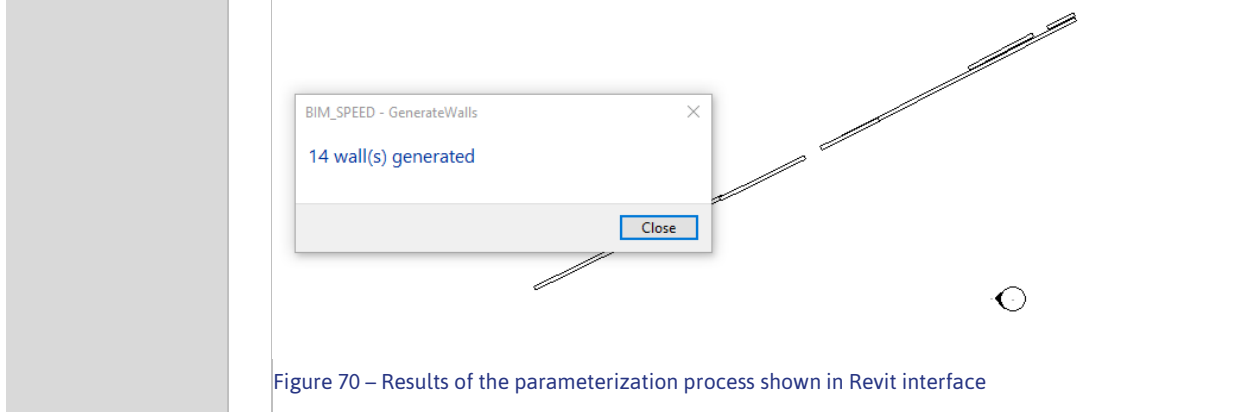


Figure 70 – Results of the parameterization process shown in Revit interface

5.1.3 Comparison of results

Using the 3DASH tool to automatically detect an architectonic features/elements from a given point cloud and generate the mesh of these elements allows anticipate time savings to the users. The accuracy and quality of the generated mesh is improved compared to traditional methods to obtain these surfaces using the point cloud as a base/guide for the as-built modelling of the building due to the low precision of manual point selection to define the position of the walls.

As can be seen in Table 8, for the Warsaw II demonstration project, the time spent for the automatic generation of the 88 walls (Image 60, Image 61) was only 71 seconds, and for the ARCAYA5 building (Table 9) the time spent for the automatic generation of the 14 walls (Image 68, Image 69) was 18 seconds, thus considerably reducing the time compared to the traditional method. The final as-built building of WARSAW II or ARCAYA5 will be modelled using these 88 walls or 14 walls respectively, since it is necessary to edit the join and properties of some of them.



5.2 Thermal Data Acquisition on Demo Sites

5.2.1 Data Acquisition of existing thermal condition based on 2D scans

ASP performed Data acquisition by taking exterior and interior thermal scans twice per year (cold season and hot season). The thermal scans are the main prerequisite for thermal analysis. Without it a repair or instalment of insolation is often meaningless. It is needed for the removal of Thermal bridges, detecting leaks, and overall proper understanding of the thermal situation of the building. The following images (Figure 71 and Figure 72) provide an overview of the amount of thermal scans, which have been taken by using following hardware: FLIR E8:



Figure 71 – Demonstration site: Varna, Bulgaria – Demonstration site: Varna, Bulgaria

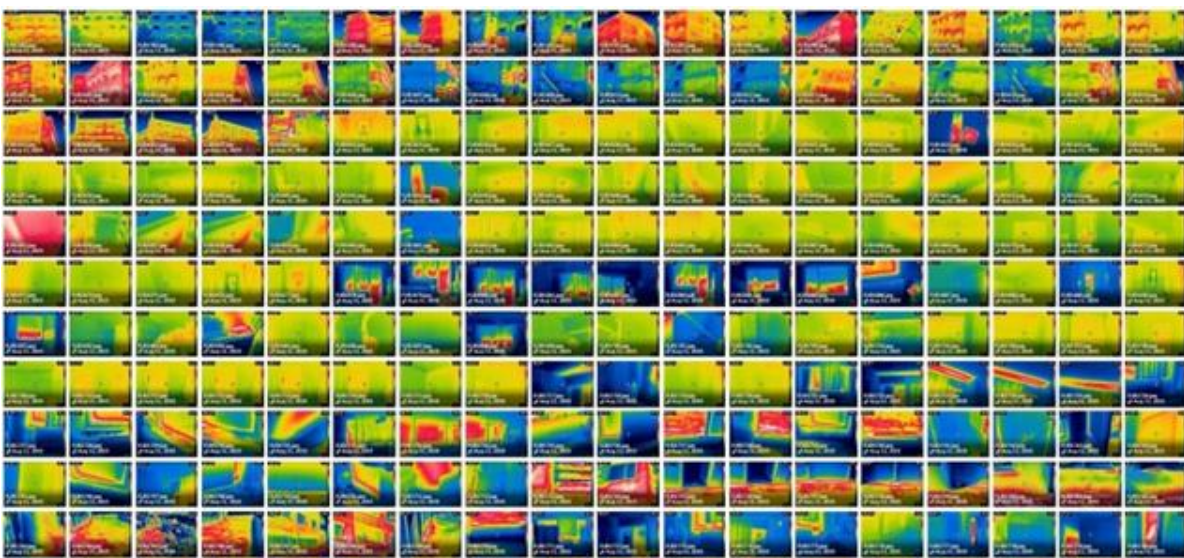


Figure 72 – Demonstration site: Malko Tarnovo, Bulgaria



To receive better results the color scale has been tuned and reports have been generated by using the Software FLIR TOOL (Figure 74 - [FLIR Tools Thermal Analysis and Reporting \(Desktop\) | Teledyne FLIR](#)).

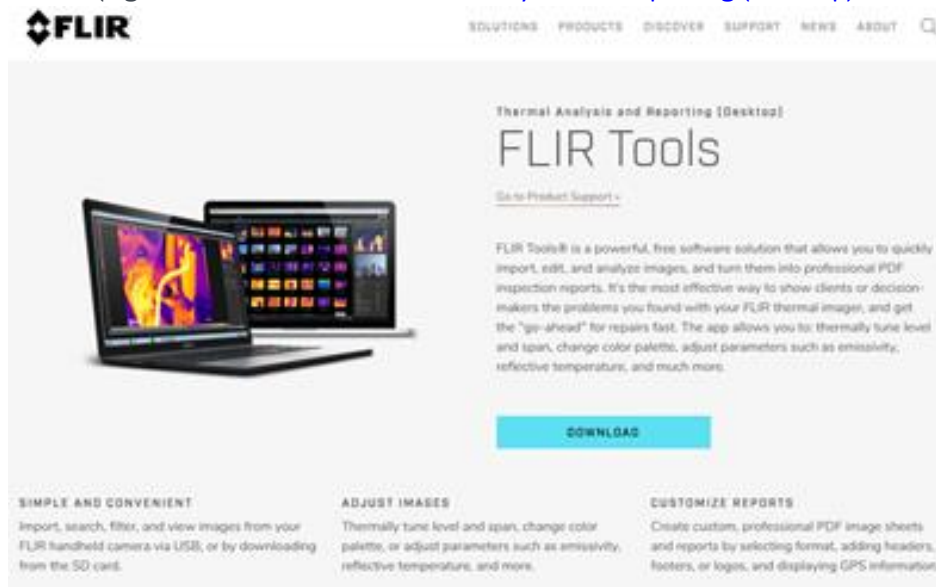


Figure 73 – FLIR Tools software



Figure 74 – Pages of FLIR report of M. Tarnovo (exterior and interior)

Producing 3D models for the 2 demo sites, based on the 2D FLIR scans and the geometry of the BIM model (could use the 3D photogrammetric model instead BIM) by using software BLENDER (Figure 75).

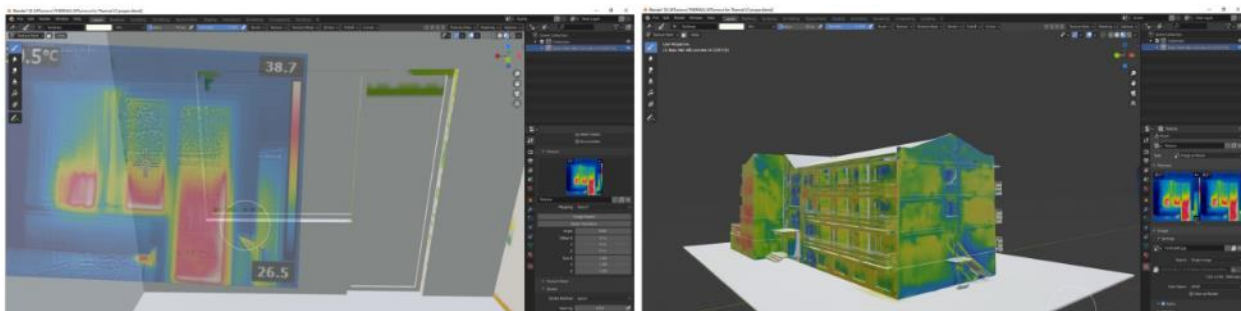


Figure 75 – Creating the 3D FLIR model of the demo Malko Tarnovo (interior and exterior) by BIM



5.2.2 3D thermal model of the existing condition based on 2D thermal scans

Final result is a 3D model with an integrated overlay of the thermal scans (Figure 76). This information is intended to be forwarded to an AR and/or VR model to provide those information directly on site.

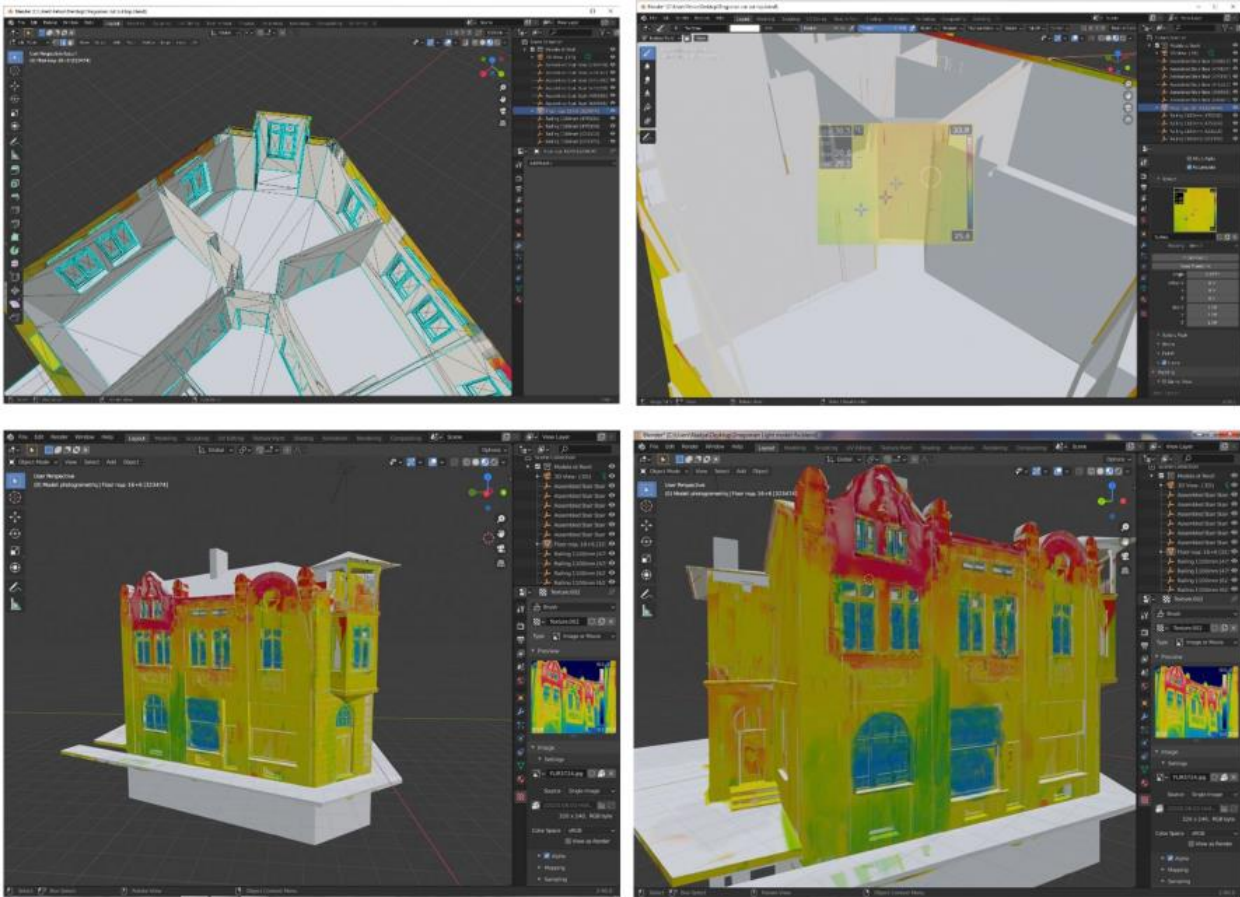


Figure 76 – Creating the 3D FLIR model of the demo Varna, Bulgaria (interior and exterior) by BIM



6. CONCLUSION

Deliverable D1.1 provides structured guidelines about processes to collect and understand the relevant information for refurbishment projects to be integrated into BIM models. It also provides an extensive overview about possible hard- and software to be used. Since technology and software is evolving rapidly (and therefore, suggestions cannot be given in an enduring way), the focus to optimize data collection for refurbishment projects was set to enhance processes.

The most important fact is to know exactly, which information is required to perform specific BIM use cases on the sites. Based on these defined use cases the required information can be derived to collect exactly those information to support the project without spending too much time, collection unnecessary information. These dependencies and process have been elaborated in this deliverable.

The developed methodology toolkit is a great tool for identifying those information. Since the toolkit is based on the input data about use cases, it must be further detailed and elaborated (which will be done in a practical way in Work Package 8 – Demonstration projects). Since it is impossible to cover all possible use cases, the tool provides more the methodology and the guidance on how to pass on from defining aimed use cases to the data to be collected to enable them. At the current state, the methodology toolkit shows possibilities on how to improve data collection processes in a very structured way and therefore to reduce time and cost spent. This methodology toolkit is a living approach and has to be further elaborated within the demonstrator projects. It defines a structured way to collect and manage as-is data within the BIM-Speed platform.

Data collection based on findings from this deliverable have already been tested on the mentioned demonstration sites to verify the enhancements in data collection methods. Especially the 3DASH tools indicates in a great way the possibilities to speed up processes for transferring point clouds to BIM models. Additionally, the combination of BIM models and thermal scans as shown at the Bulgarian demo sites, provide an insight on how to provide detailed information to the project teams.



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APPENDIX 1 - Guidelines of 3DASH tool

This guideline describes the installation of the plug-in and the option menus of the 3DASH tool (Figure 77).

Installation

The folder of the tool has the files shown in Figure 77:

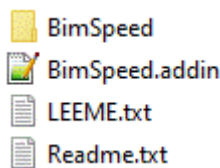


Figure 77 - Files contained in the 3DASH tool folder

For the installation of the 3DASH tool in Revit follows the instructions explained in the *Readme* file included in the folder of the tool:

“Paste the BimSpeed folder and the file BimSpeed.addin in the following location (for all users of the machine): C:\ProgramData\Autodesk\Revit\Addins\2019 (If the Revit version is not 2019, rename the path directory).

The tool has been tested only for Revit2019, but could be work on the closest versions”

Option menus

Before using the 3DASH tool, a new project needs to be created within REVIT in order to load a set of parametric elements to be used by the plug-in later on. Once loaded, a specific icon is created to allow the final user modifying some of the processing steps for the automatic shape recognition (Figure 78).

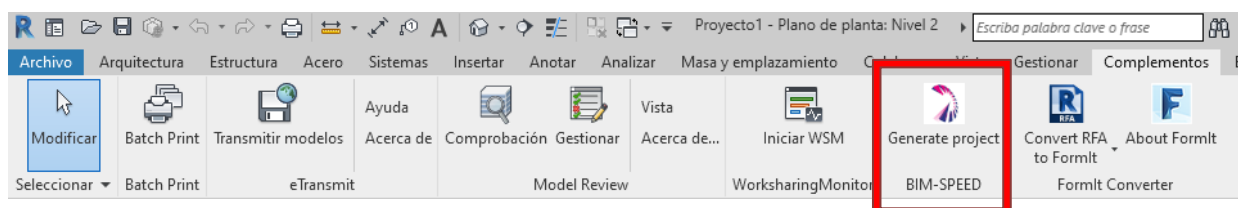


Figure 78 - 3DASH button into REVIT



Clicking on the “Generate project” button, the “Loader” menu is deployed. In this form, a browser is displayed once the “Select” button is pressed, where the point cloud can be selected by the user according to the format of the file (Figure 79).

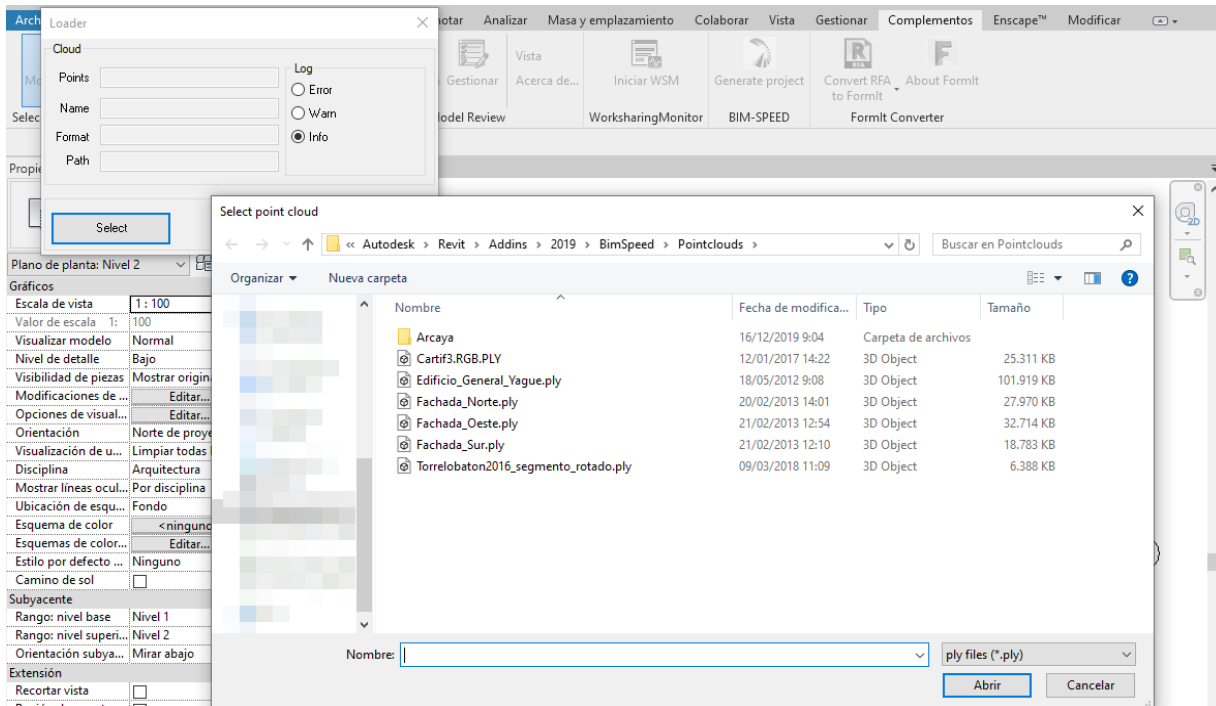


Figure 79 - 3DASH tool. Point cloud selection.

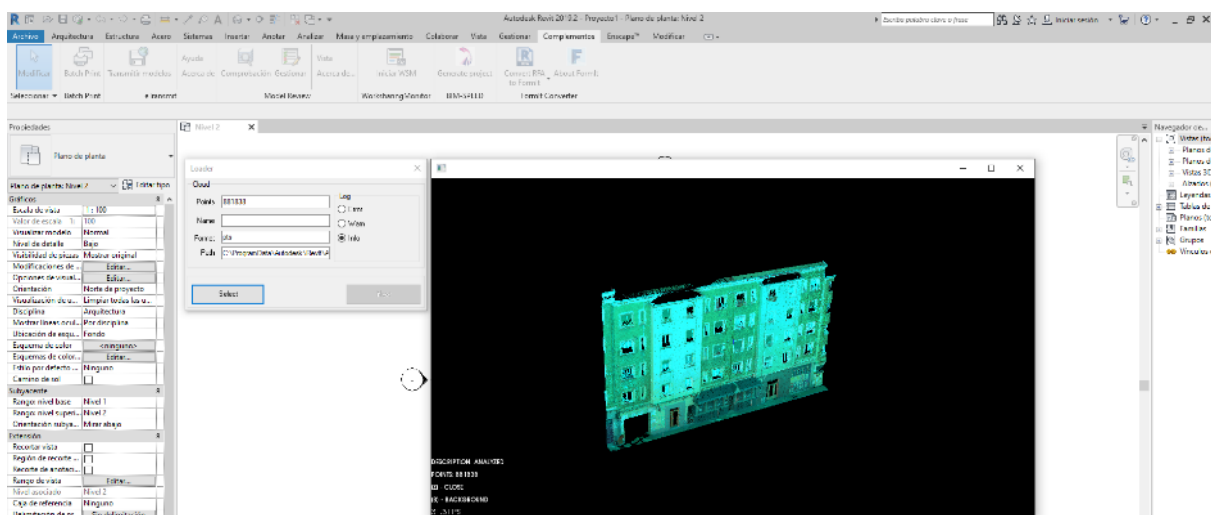


Figure 80 - 3DASH tool. Loaded point cloud.



Once the point cloud has been loaded, the “Next” button can be clicked after closing the viewer, displaying a new form where the pre-processing options can be chosen (Figure 81).

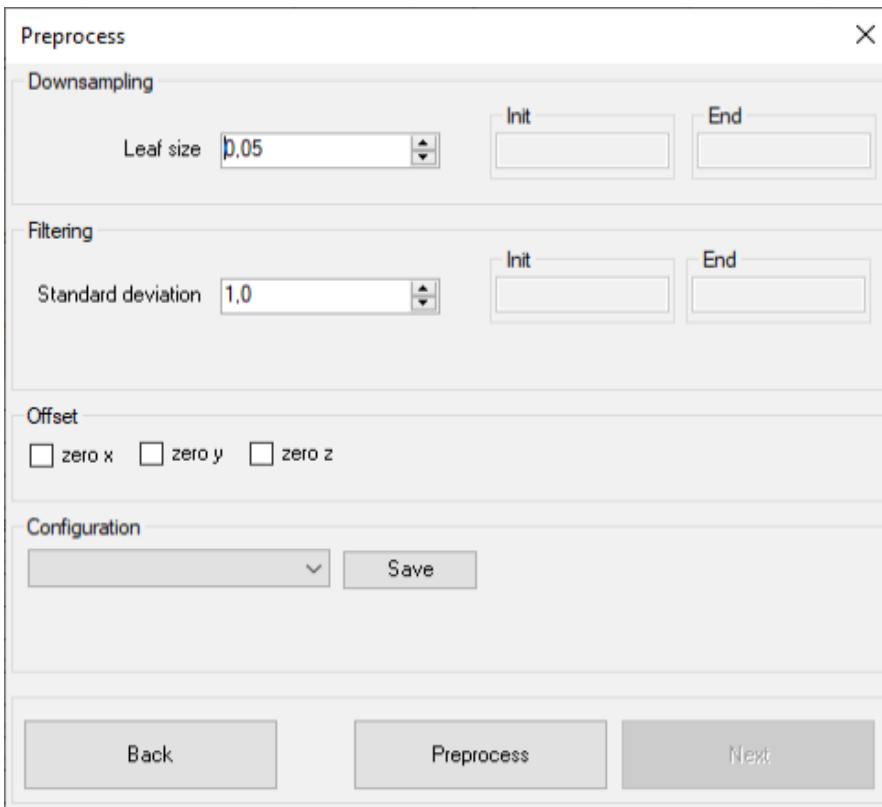


Figure 81 - 3DASH tool. Pre-processing options.

The “pre-processing” form allows the user to modify the options shown in Table 10.

Pre-processing	Description
Downsampling	Allows the plug-in to operate internally with a smaller point cloud in order to speed up some steps of the process.
Filtering	Filters spurious NaN ² and outliers from the cloud.
Offset	Forces the minimum coordinate (x, y, z) of the point cloud to zero.
Configuration	Allows to load/save configuration profiles.

Table 10 - Pre-processing options

² Not a Number



The “Pre-process” button processes the cloud taking into account the selected values. The final output is shown in a separated viewer. Once the result is validated, the “Next” button can be pressed, displaying a new form where the segmentation options can be selected (Figure 82).

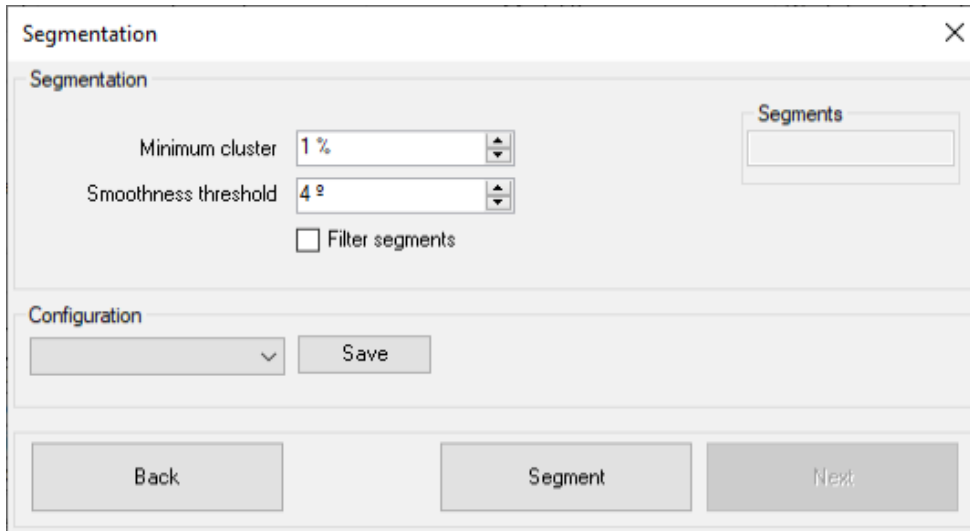


Figure 82 - 3DASH tool. Segmentation options.

The “segmentation” form allows the user to modify the options shown in Table 11.

Segmentation	Description
Minimum cluster	Sets the minimum percentage of points, with regard to the points of the main point cloud, which a cluster should have to be saved.
Smoothness threshold	Maximum deviation between the normal of neighboring points.
Filter segments	Enables the filtering of the detected segments.
Configuration	Load/save configuration profiles.

Table 11 - Segmentation options



The “Segment” button processes the cloud taking into account these values (Figure 83)
 Once the result is validated, the “Next” button can be pressed after closing the viewer, displaying a new form where the analysis options can be selected (Figure 84).

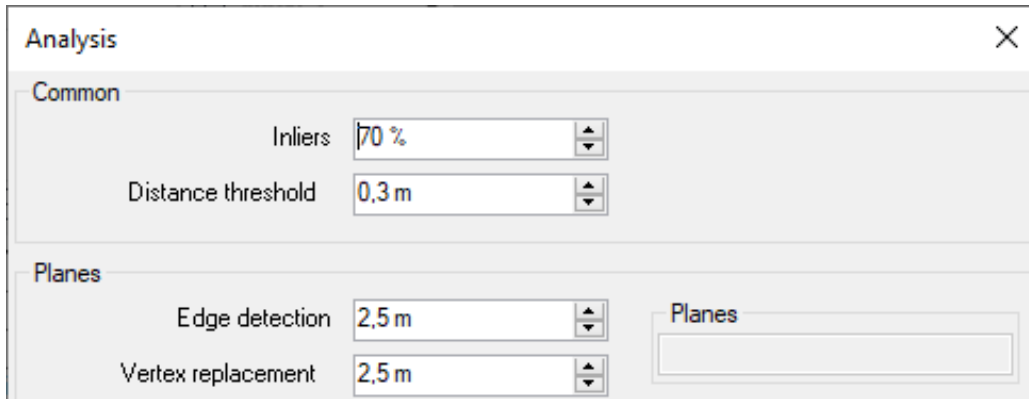


Figure 83 - 3DASH tool. Segmentation form

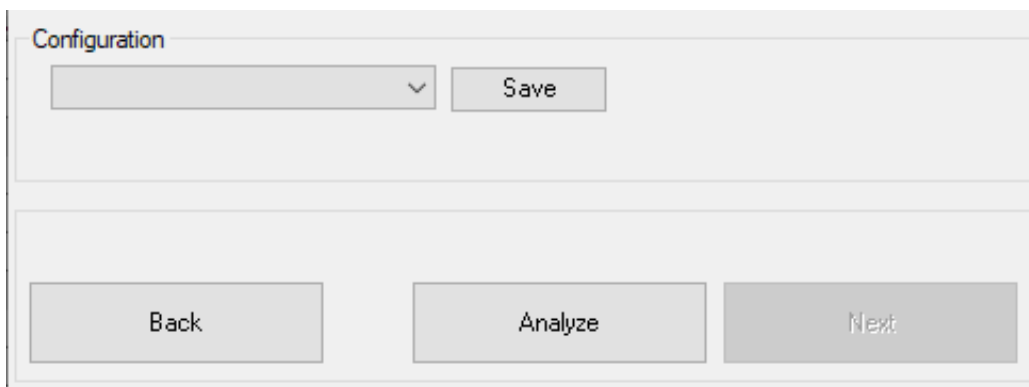
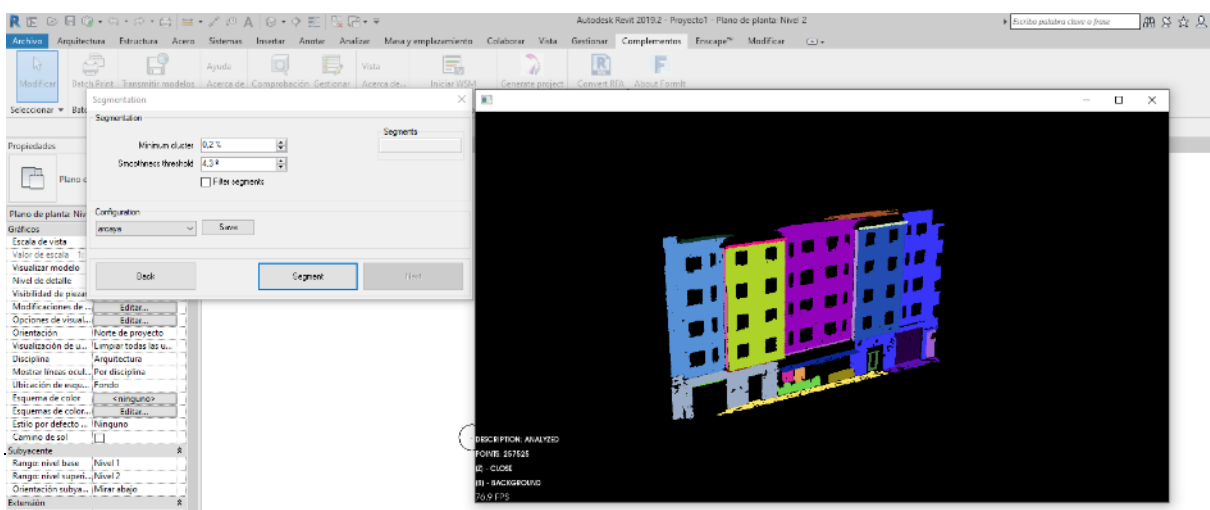


Figure 84 - 3DASH tool. Analysis options.

The “analysis” form allows the user to modify the options shown in Table 12.



The “Analyze” button processes the cloud taking into account the selected values. Once the result is validated, the “Next” button can be pressed after closing the viewer, displaying a new form where the parameterization options can be selected (Figure 85).

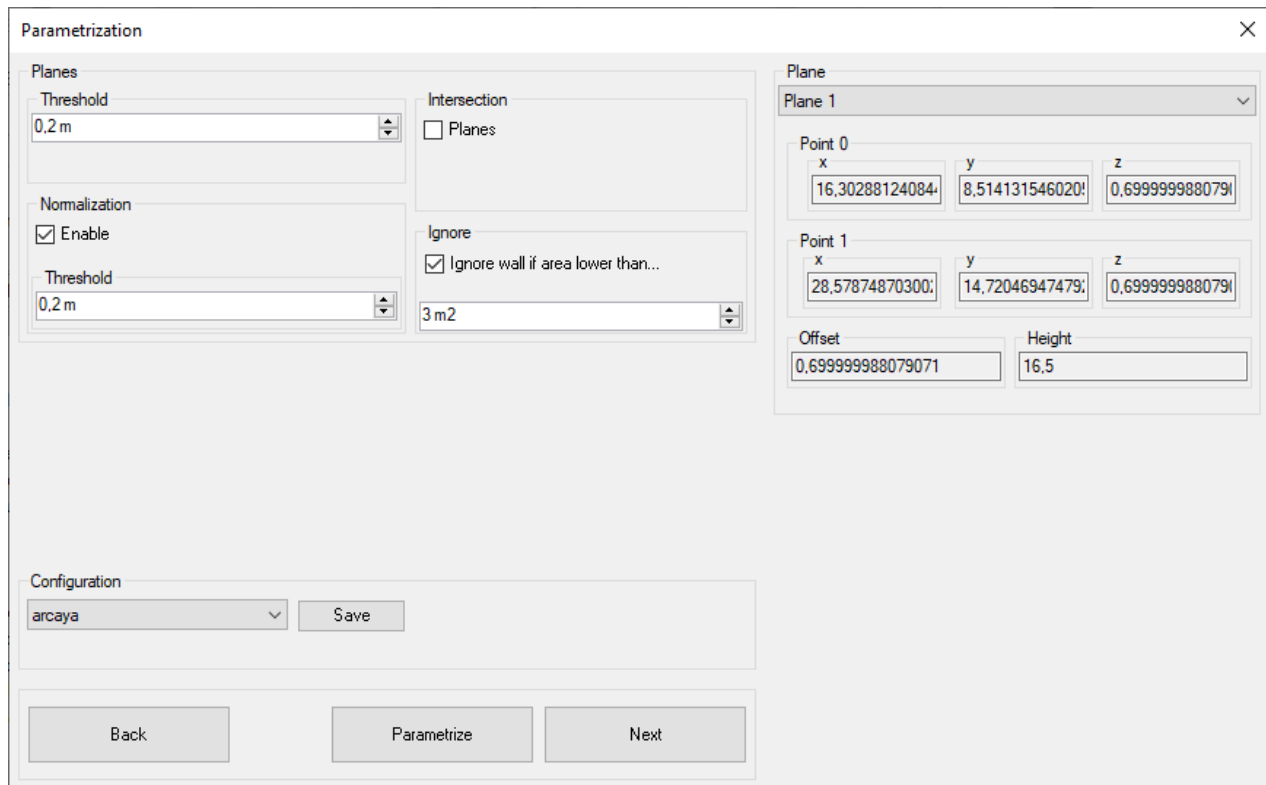


Figure 85 - 3DASH tool. Parameterization form.

The “parameterization” form allows the user to modify the options shown in Table 13 - Parameterization options.

Parameterization	Description
Planes threshold	Maximum distance between planes to be considered as neighbours.
Intersection	Enables the auto-detection of neighbouring planes.
Normalization	Enables the normalization of heights and offsets of the detected walls.
Ignore	Discards walls with an area lower than the selected threshold.
Configuration	Load/save configuration profiles.

Table 13 - Parameterization options.



The “Parameterize” button processes the cloud taking into account the selected values. Once the result is validated, the “Next” button can be pressed displaying a new form where the project options can be selected (Figure 86).

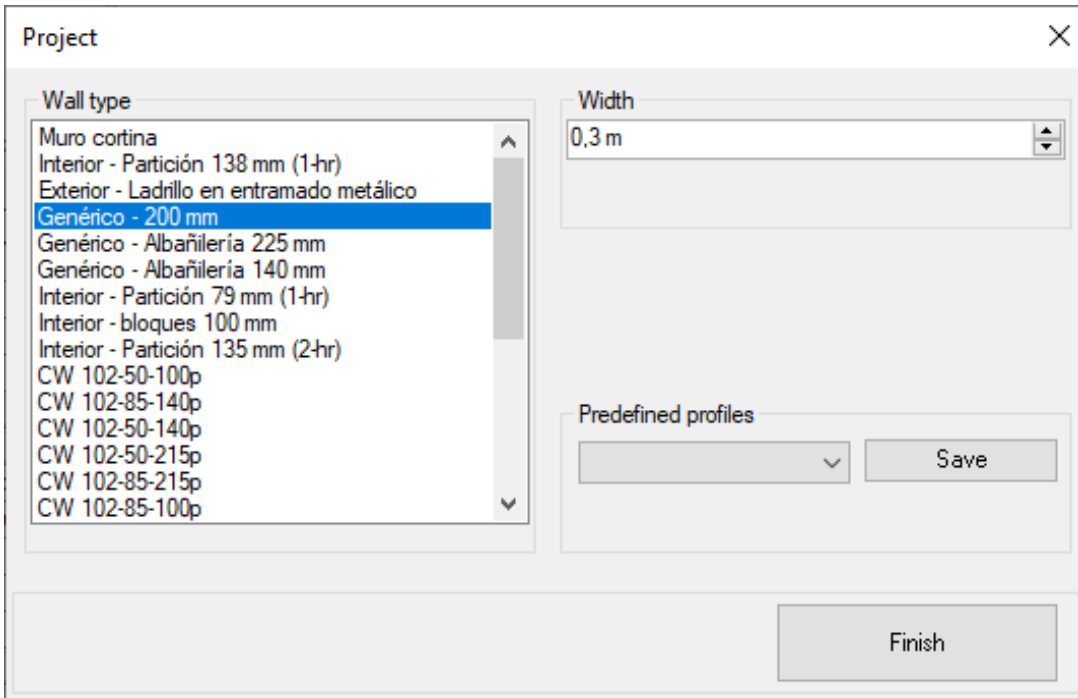


Figure 86 - 3DASH tool. Project form.

Finally, the “project” form allows the user to modify the options shown in Table 14.

Project	Description
Wall type	Sets the wall base type for the generated elements.
Width	Allows changing the width of the generated elements.
Predefined profiles	Load/save configuration profiles.

Table 14 - Project parameters.



The parametric elements generated by the *plug-in* are part of the REVIT library loaded when the new project was created (Figure 87). Thus, the extraction can be readily exported to IFC from REVIT as well.

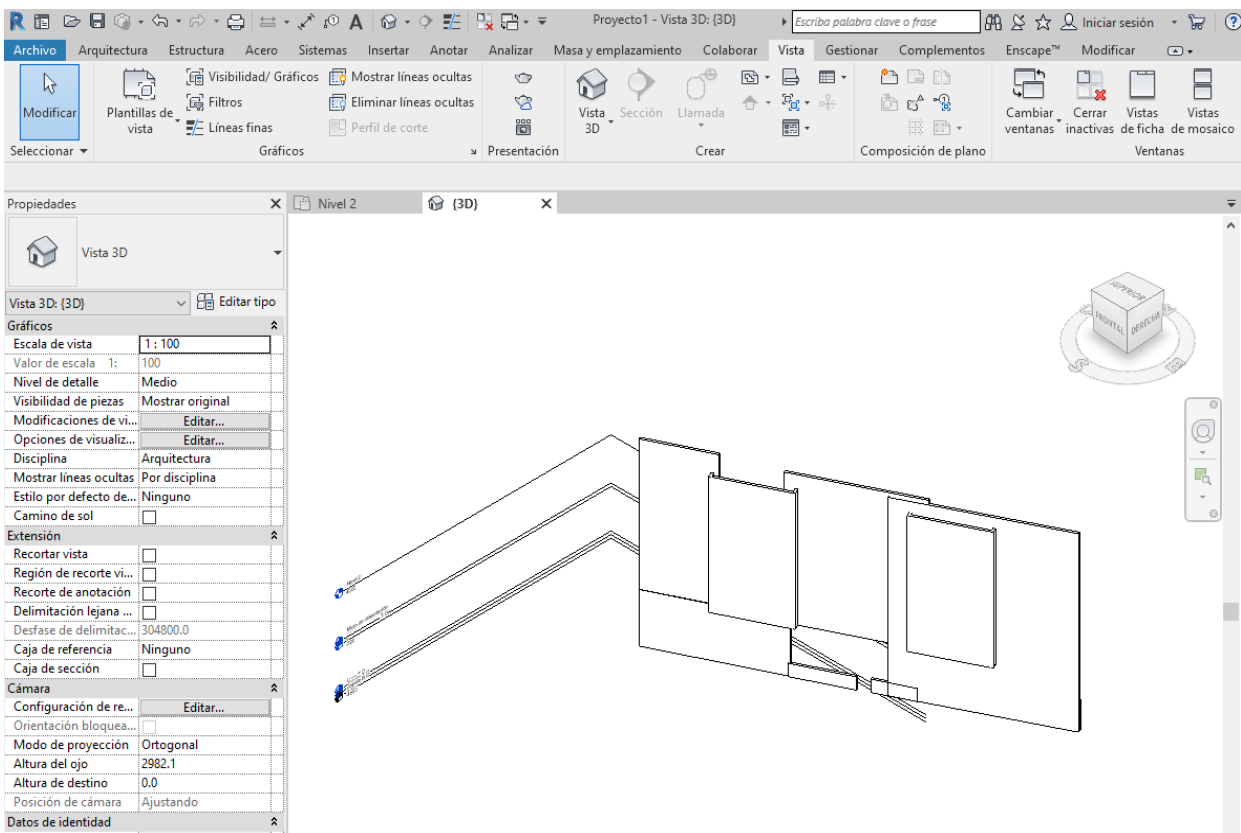


Figure 87 - 3DASH tool. Final result.

