Synthesis report on demonstration cases of BIM for renovation projects

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BIM-SPEED

Harmonised Building Information Speedway for Energy-Efficient Renovation

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Synthesis report on demonstration cases of BIM for renovation projects

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Main author Agnieszka Łukaszewska,

Co-authors Marek Giluń (FAS), Rafał Łukaszewski (FAS), Magdalena Bogucka-Dzik (FAS), Sharon Verghese (TUB), Maryam Daneshfar (TUB), Sonia Álvarez Díaz (Cartif), Roberto Sanz Jimeno (Cartif), Sofía Mulero Palencia (Cartif), Eva Raggi (RINA), Serena Serroni (UNIVPM), Mikel Cepeda (KREAN), Jessica Steinjan (HOCH), Sama Rezvani (DMO), Chris Kowal (MOW), Marcin Grzelak, (MOW) Josephine Cooke (PB40), Nadya Stamatova (ASP), Julius Jacob (MTB), Jerson Pinzon Amorocho (TUB), Ayberk Aras (TUB), Florencia Perez (TUB), Vladimir Savchuk, Basil Raza (TUB), Paddy Saikia (TUB), Ana Gallegos (TUB), Lara Haidinger [TUB], Bogdan Tofan (ARC), Julian Halm (TUB), STRESS, UNS, CSTB

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Reviewed by Serena Serroni (UNIVPM), Christopher Kowal (MOW)

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Publishable executive summary

The overall aim of this report is to validate, demonstrate and implement all BIM-SPEED innovative solutions developed within the project with the emphasis on testing them in real design and construction conditions. In the BIM-SPEED there are 14 demonstration projects located in 8 European countries (Spain, Germany, Poland, Italy, Bulgaria, Romania, the Netherlands, France). For each of demonstration project As-Built Building Information Model (BIM), Building Information Model for Renovation Design scenarios and BIM Execution Plan (BEP) were developed. In order to ensure the most effective demonstration process, the consortium developed a methodology that is based on the definition of BIM-SPEED use cases for developed tools and methods. BIM-SPEED use cases describe BIM tools and their implementation on demonstration projects. In agreement with Building Smart International, Building Smart International use case database platform is used to transparently document and communicate the use cases (https://ucm.buildingsmart.org/). General context of the demonstration activities and introduction to the use case concept are provided in Chapter 1.

To select the most optimum renovation scenario for demonstration projects two tools developed within BIM-SPEED project were validated Multi-Criteria Decision Support Tool (MCDM tool developed by TUB partner) and Building optimizer (developed by Metabuild partner). Those tools allow the main stakeholders involved in a residential renovation project to decide upon a renovation option that is satisfactory for all and at the same time identify the optimum chosen renovation design options based on the different criteria relevant for them. A summary of the implementation of the Multi-Criteria Decision Support Tool on demonstration projects is provided in Chapter 2.

Chapter 3 presents 27 BIM-SPEED use cases and describes which BIM-SPEED use cases and associated tools were used on various demonstration projects. The chapter ends with explanation of how the selected use cases and tools contribute to the impact of the project.

One of the BIM-SPEED demonstration projects is related to implementation of BIM to production process. This demonstration project is presented in Chapter 4 and it is focused on the analysis and improvement of the production of façade panels performed by Italian company Focchi S.p.A.

Conclusions made from the implementation of BIM-SPEED use cases and associated tools on demonstration projects are presented in Chapter 5. Chapter 6 presents the Literature.

Examples of full version of three BIM-SPEED use cases (Use case #1: 3D Modeling of Existing Asset Based on Point Clouds (Scan2BIM), Use case #10: Decision-making for residential building renovation, Use case #14: Model Checks for compliance testing and design coordination) are in the Appendix in Chapter 7.

The type of this report is PUB (Public), being accessible to public audience with no restrictions. The targeted audience of this report are various actors of renovation process e.g., construction companies (large and SMEs), building owners, architects and engineers, installers, investors, housing associations.

List of acronyms and abbreviations

Example:

DoA: Description of Action

BIM: Building Information Model

BEM: Building Energy Model

Cap/OpEx: Capital / Operational Expenditure

EeB: Energy-efficient Building

EPBD: Energy Performance Buildings Directive

ESCO: Energy Services Company

ETICS: External Wall Insulation System

GIS: Geospatial Information System

HVAC: Heating Ventilation Air Conditioning

IDM: Information Delivery Manual

IEQ: Indoor Environment Quality

IFC: Industry Foundation Classes

IPR: Intellectual Property Right

LCA: Life Cycle Analysis

LCC: Life Cycle Costing

MEP: Mechanical Electrical Plumbing

MCDM: Multi-criteria Decision-Making tool

nZEB: Nearly Zero-Energy Buildings

PnP: Plug and Play

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

Table of Figures

Figure 1 Overview of BIM-SPEED demonstration projects across Europe....12
Figure 2 Decision tree example....15
Figure 3 Aerial view of the urban context and building location....16
Figure 4 Decision tree for #1 Apartment blocks in Vitoria....18
Figure 5 Building Information Model for #1 Apartment blocks in Vitoria with final renovation scenario....19
Figure 6 Decision tree for #2 Apartment blocks in Berlin-Lichtengrade....21
Figure 7: BIM model and final renovation solution for #2 Apartment blocks in Berlin-Lichtengrade (Germany)....22
Figure 8: Decision tree for demonstration project #3 Apartment block in Warsaw (Poland)....24
Figure 9: BIM model and final renovation solution for demonstration project #3 Apartment block in Warsaw....25
Figure 10: Visualisation of final renovation solution with visible elevator shaft for #4 Care point for homeless people in Warsaw (Poland)....28
Figure 11: BIM model with final renovation design for #5 Multi-family dwellings in Barland....31
Figure 12: BIM model with final renovation scenario for demonstration project #7 Historic residential building in Varna....34
Figure 13 Decision tree for demonstration project #8 Historic residential building in Frigento....36
Figure 14: Model with final renovation scenario for demonstration project #7 Historic residential building in Varna BIM model with renovation scenario for demonstration project #8 Historic residential building in Frigento....38
Figure 15: Decision tree for demonstration project #9 Semi-detached building in Gdynia (Poland)....41
Figure 16: Building Information Model with renovation scenario for demonstration project #9 Semi-detached building in Gdynia (Poland)....44
Figure 17 Aerial view of the urban context and building selection....44
Figure 18 Decision tree for demonstration project #10 Multi-family dwellings in Warmond....46
Figure 19: Building Information Model with final renovation solution for demonstration project #10 Multi-family dwellings in Warmond....48
Figure 20 Decision tree for demonstration project #11 Mixed used building in Berlin-Tempelhof....50
Figure 21: Building Information Model with final renovation solution for demonstration project #11 Mixed used building in Berlin-Tempelhof....52
Figure 22 Decision tree for demonstration project #12 Apartment blocks in Antony (France)....54
Figure 23 BIM model with final renovation solution for #12 Apartment blocks in Antony (France)....56
Figure 24 Overview of BIM-SPEED use cases uploaded to Building Smart website....57
Figure 25 Section of the report documenting Use cases....58
Figure 26 Overview of all BIMSPEED use cases segregated across life cycle stages of a renovation project....59
Figure 27 List of implemented BIM-SPEED use cases on demonstration projects....60
Figure 28 Comparison of common practice with BIM-SPEED approach for Use case: 3D modelling of existing asset based Point Clouds....61
Figure 29 Comparison of common practice with BIM-SPEED approach....63

Figure 30 Comparison of Common practice with BIM-SPEED approach for Use case: Site analysis and planning 65
Figure 31 Comparison of Common practice with BIM-SPEED approach for Use case: Retrieving BIM data for acoustic comfort calculation 66
Figure 32 Comparison of Common practice with BIM-SPEED approach for Use case: Crowd Data Collection 67
Figure 33 Comparison of Common practice with BIM-SPEED approach for Use case: Thermal Comfort and Indoor Air Quality Analysis 69
Figure 34 Comparison of Common practice with BIM-SPEED approach for Use case: Decision making for residential building renovation 70
Figure 35 Comparison of Common practice with BIM-SPEED approach for Use case: Model Checks for compliance testing and design coordination 73
Figure 36 Main steps for the Use case: Assessing operational energy costs and energy performance of buildings using measured data 78
Figure 37 Contribution of selected BIM tools to time reduction impact based on implementation on demonstration projects. ...83
Figure 38: Scenario 6: Chronologically shifted workflow; use of implemented interface 86
Figure 39 Project-oriented (top-down) workflow; additional connector concept 87

BIM SPEED

Contents

1. INTRODUCTION 10

1.1 General context 10

2. ANALYSIS OF RENOVATION SOLUTIONS FOR DEMONSTRATION PROJECTS 13

2.1 Introduction to Multi-Criteria Decision-Making Method (MCDM) and tool for housing renovation projects 13

2.2 Demonstration project #1 Apartment blocks in Vitoria (Spain) 16

2.3 Demonstration project #2 Apartment blocks in Berlin-Lichtengrade (Germany) 19

2.4 Demonstration project #3 Apartment block in Warsaw (Poland) 23

2.5 Demonstration project #4 Care point for homeless people in Warsaw (Poland) 26

2.6 Demonstration project #5 Multi-family dwellings in Barland (Romania) 29

2.7 Demonstration project #7 Historic residential building in Varna (Bulgaria) 31

2.8 Demonstration project #8 Historic residential building in Frigent (Italy) 34

2.9 Demonstration project #9 Semi-detached building in Gdynia (Poland) 39

2.10 Demonstration project #10 Multi-family dwelings in Warmond (the Netherlands) 44

2.11 Demonstration project #11 Mixed used building in Berlin-Tempelhof (Germany) 48

2.12 Demonstration project #12 Apartment blocks in Antony (France) 52

3. BIM-SPEED USE CASES 56

3.1 Method and approach 56

3.2 Overview of BIMSPEED use cases 58

3.2.1 Implementation of use cases on demonstration sites 59

3.2.2 Use case #1: 3D modelling of existing asset-based Point Clouds 61

3.2.3 Use case #2: Existing building data collection and download based on IFC model definition 62

3.2.4 Use case #3: Historical Weather Data Collection for Building Energy Modelling 63

3.2.5 Use case #4: Site analysis and planning 64

3.2.6 Use case #5: Retrieving BIM data for acoustic comfort calculation 66

3.2.7 Use case #6: Crowd data collection 67

3.2.8 Use case #7: Geometrical verification of as-built BIM models by deviation analysis 68

3.2.9 Use case #8: Thermal Comfort and Indoor Air Quality Analysis 68

3.2.10 Use case #9: Lighting and Visual Comfort Analysis 69

3.2.11 Use case #10: Decision-making in residential building renovation 70

3.2.12 Use case #11: Semantic Design rules and tool for deep renovation design 71
3.2.13 Use case #12: Estimation of time required for the completion of renovation scenarios using 4D BIM 71
3.2.14 Use case #13: Cost estimation and budget analysis 72
3.2.15 Use case #14: Model Checks for compliance testing and design coordination 72
3.2.16 Use case #15: BIM-BEM approach 73
3.2.17 Use case #16: BIM-SPEED library 74
3.2.18 Use case #17: Creation of thermal 3D Model 75
3.2.19 Use case #18: Holistic Evaluation 75
3.2.20 Use case #19: Remote Simulations of Building Renovation Scenarios by Holographic Twinning 76
3.2.21 Use case #20: BIM based Life Cycle Cost analysis 76
3.2.22 Use case #21: Clash Detection 77
3.2.23 Use case #22: Indoor acoustic comfort calculator 77
3.2.24 Use case #23: Assessing operational energy costs and energy performance of buildings using measured data 78
3.2.25 Use case #24: Determination of Stakeholder's BIM Maturity 79
3.3 Contribution to the impacts 79
4. BIM TO FABRICATION DEMONSTRATION PROJECT 84
4.1 Introduction 84
4.2 Recommendations 85
5. CONCLUSIONS 88
6. LITERATURE 89
7. APPENDIX: EXAMPLE OF THREE BIM-SPEED USE CASES 90

1. Introduction

1.1 General context

The overall aim of this report is to validate, demonstrate and implement all BIM-SPEED innovative solutions developed within the project with the emphasis on testing them in real design and construction conditions. In order to ensure the most effective demonstration process, consortium developed the methodology that is based on definition of BIM-SPEED use cases for developed tools and methods. This approach is based on following steps:

1. **Setting up BIM-SPEED Use Cases** (What will be done? Who will do this? How it will be done? What is the expected benefit?)
2. **Evaluating the requirements** (Which information is needed? Which data format? At what time? In which level of detail?)
3. **Planning for collection of BIM data** (Is the information already available or it should be created? From where it can be extracted – if not available? Which data collection tools/devices/techniques are feasible?)
4. **Comparison of BIM-SPEED approach/solution with common practice for renovation** (How the process would be performed in a "traditional" way – common practice? What are benefits from the use of BIM-SPEED tool/method? What is the difference between BIM-SPEED approach and common practice?)

BIM-SPEED Use Cases have been developed and documented, based on Information Delivery Manual (IDM) standards, to aid standardization practices and open accessibility within the industry. In agreement with Building Smart International, Building Smart International use case database platform will be used to transparently document and communicate the use cases (https://ucm.buildingsmart.org/). BuildingSMART (www.buildingsmart.org) is an international organisation which aims to improve the exchange of information between software applications used in the construction industry. It has developed IFC as a neutral and open specification for BIM. currently, they Focus on the development and active use of open internationally recognized standards, applications, training, and certification procedures. The goal is to achieve wider uptake of BIM by the AEC industry, investors, building owners, and facility managers.

This process of documentation of the demonstration activities is based on ISO 29481-1: 2016 (Building information models — Information delivery manual) and it ensures a common language and a uniform understanding of BIM applications (use cases) within the entire construction and real estate industry. Standardized use cases enable the capture and specification of exchange and actors involved in a unified manner, to ensure the implementation of best practices, which are accessible to all members within the built industry. A list of the developed BIM-SPEED use cases with related tools is provided in Table 1 In total within the BIM-SPEED project, 24 use cases were developed. Till the end of the project, 17 use cases are published and are available in the Building Smart International use case database platform (https://ucm.buildingsmart.org/) and 7 use cases are under finalization process. BIM-SPEED use cases describe how various BIM tools were implemented on real demonstration projects.

Table 1 List of BIM-SPEED use cases and related tools/methods

Name of the BIM-SPEED use case	Related method/tool
Site analysis and planning	GIS Data Provider
Crowd Data Collection	Crowdsourcing app
3D Modeling of Existing Asset Based on Point Clouds	3DASH
Existing building Data collection and download based on IFC model definition	BACN2BIM
BIM to BEM Approach	BIM-BEM
Thermal Comfort and Indoor Air Quality Analysis	Comfort Eye
Lighting and Visual Comfort Analysis	Lighting and visual comfort analysis
Decision-making in residential building renovation	MCDM Tool
Holistic Evaluation	Building Optimizer
Model Checks for compliance testing and design coordination	Model Checker
Semantic design rules and tool for deep renovation design	Semantic Cheker
Creation of thermal 3D model	Thermal survey visualisation
VR Health and Safety Training	VR & Safety
Clash detection	Clash detection
Indoor acoustic comfort calculator	Acoustic Tool
BIM-Based LCC analysis	LCC Tool
BIM-SPEED Library	BIM Library
Determination of Stakeholder's BIM Maturity	BIM Maturity
Assessing operational energy costs and energy performance of buildings using measured data	ECO Tool
Histoical Weather Data Collection for Building Energy Modeling	MEREEN Weather
Estimation of time required for the completion of renovation scenarios using 4D BIM	4D Time Scheduling
Cost estimation and budget analysis	5D Cost Scheduling
Retrieving BIM data for acoustic comfort calculation	IFC4 Acoustic Parser
Remote Simulations of Building Renovation Scenarios via Holographic Twinning	MR simulation tool
Geometrical verification - Deviation analysis	Deviation analysis

The overview of demonstration projects is shown in Figure 1. In total there are 14 demonstration projects located in 8 European countries (Spain, Germany, Poland, Italy, Bulgaria, Romania, the Netherlands, France). Such large number of demonstration projects allows to deal with various technical requirements, culture of working and building conditions. Most of the demonstration projects are related to the renovation of residential buildings. One of the demonstration projects (#14 BIM to fabrication) is focused on implementation of BIM to production process for Italian producer of façade transparent panels Focchi.

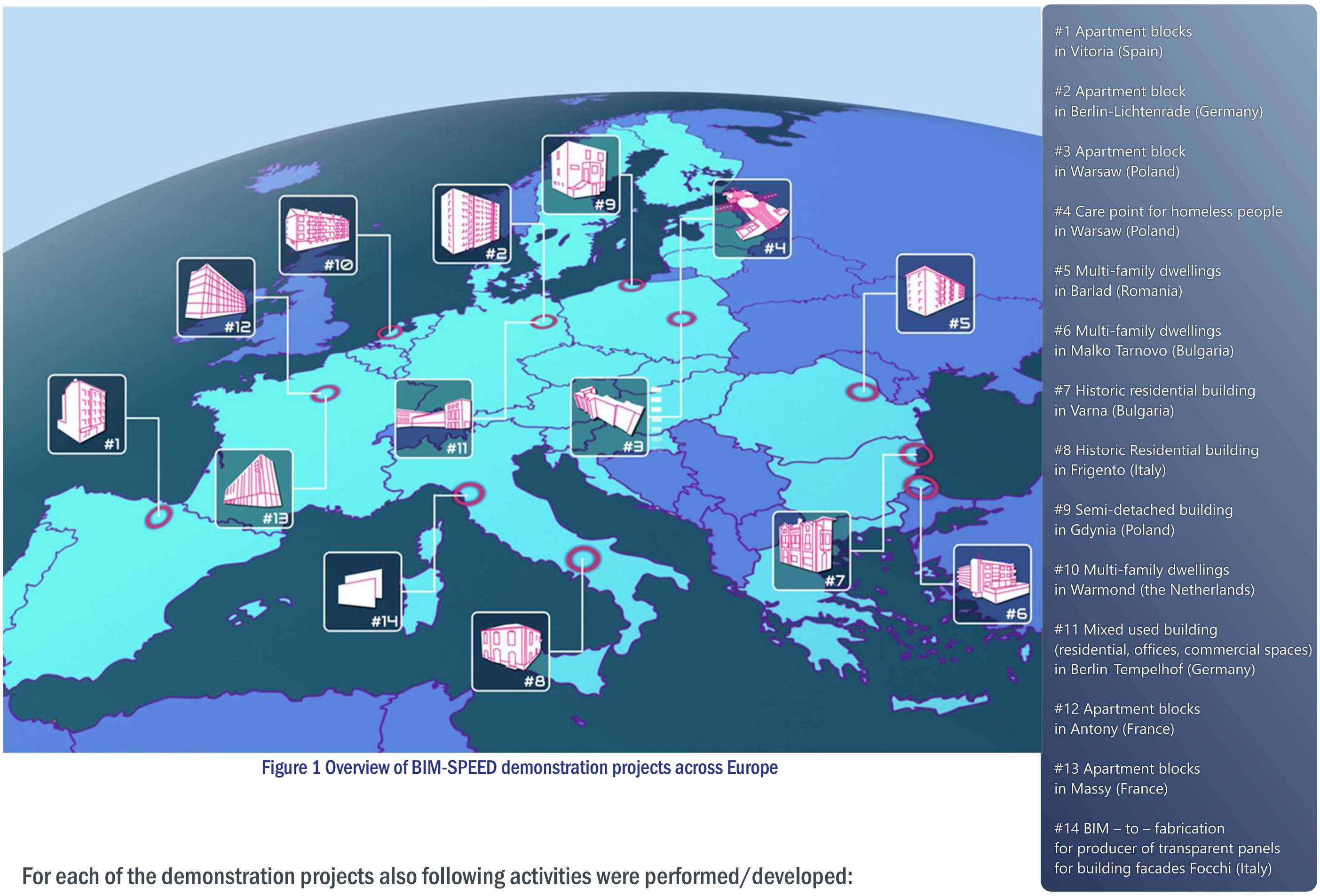


Figure 1 Overview of BIM-SPEED demonstration projects across Europe

For each of the demonstration projects also following activities were performed/developed:

- BIM Execution Plan (BEP): document about optimizing work and model flow across the renovation project, as contrasted with optimizing siloed interests. BEPs are available in report D7.6" BEM Execution Plan for residential deep renovation".
- As-Built Building Information Model (BIM) and Building Information Model with Renovation Design. The models are available on the BIM-SPEED platform.
- Examination of renovation solutions with the use of Multi-Criteria Decision Support Tool (MCDM tool developed by TUB partner) or Building optimizer (developed by Metabuild partner). Those tools allow the main stakeholders involved in a residential renovation project to decide upon a renovation option that is satisfactory for all and at the same time identify the optimum chosen renovation design options based on the different criteria relevant for them. Multi-Criteria Decision Support Tool is described in report D7.1" Multi-criteria decision-making method and tool for housing renovation projects" and Building optimizer tool is described in report D4.5 "BIM-based procedures and tool for holistic performance assessment of renovation design options".

Implementation of Virtual and Augmented Reality tools on demonstration projects is described in report D7.5 "VR/AR demonstrators of deep renovation scenarios".

2. Analysis of renovation solutions for demonstration projects

2.1 Introduction to Multi-Criteria Decision-Making Method (MCDM) and tool for housing renovation projects

When renovating buildings, there are many different solutions that vary from one situation to another. Depending on the priorities set and the aims to be achieved, different factors are considered within the renovation process. This can be a simple change in aesthetics or a major intervention that improves the building's quality (Ferreira et al., 2013). The facility managers are often faced with challenges within the renovation process. Either they lack the expertise, or they do not have the time to carry out an accurate analysis of the renovation building before making a final decision (Mjörnell et al., 2014). In a renovation process a high number of decisions must be made throughout the different phases. Furthermore, many different stakeholders are involved, and multiple objectives must be considered within the renovation process. This often results in conflicts between individuals and groups. According to Jensen & Maslesa (2015) there is a big lack of simple and holistic decision support tools to help in decision making during the early stage of the building renovation process. Therefore, part of the work of BIM-SPEED project was the development of Multi-Criteria Decision-Making Method and tool (MCDM) for housing renovation projects. Due to the increasing complexity of renovations in terms of environmental, economic, and social requirements, it can be beneficial to use Multi-Criteria Decision Making tools that prioritize different renovation alternatives based on different, self-selected criteria. MCDM methods are designed to provide a way for a wide range of stakeholders to make the renovation process as effortless as possible. Because 'Building owners and investors need the right encouragement, information, support, and incentives to choose cost-effective, energy-efficient, and suitable renovation alternative.' (Pinzon Amorocho & Hartmann, 2020). MCDM tool helps the building owners and investors to compare various renovation scenarios and to select the most optimum one that is adjusted to their requirements and needs.

The decision-making framework developed as part of D7.1 Multi-criteria decision-making method and tool for housing renovation projects was implemented in the demonstration sites to illustrate its applicability. The decision-making tool developed in the form of an Excel spreadsheet was used during this process. A detailed description of the proposed framework can be found in the D7.1 report available on the BIM-SPEED website[1], additional training information can be found on the BIM-SPEED YouTube channel[2]. The proposed general process can be summarized as follows:

- To select specific economic, environmental, and social objectives and criteria to assess the performance of the set of alternatives; and design renovation alternatives;
- To assign weights to the selected criteria, and quantify the performance of each renovation alternative according to each criterion;
- To rank the alternatives according to the criteria and weights that represent the interests of the different stakeholders, making easier the final decision to select the renovation alternative that will be implemented in the project.

During the implementation, some of the steps were simplified due to the lack of information or limited access to the inhabitants and other stakeholders of the demonstration projects. Nevertheless, a very detailed and technical illustration of the framework is

[1] https://www.bim-speed.eu/en/results

[2] https://www.youtube.com/watch?v=jzJmGAufdIg&list=PL-lSKZJhMrFJri0goNfl4TNpLVhwiEn-9&index=4

available in a scientific journal paper[3] based on one of the demonstration projects. To facilitate the reading process, only the most relevant steps for each demonstration case are discussed according to the structure presented below and discussed in the following sections.

- Characterization
- Renovation alternatives
- Decision tree
- Alternative's performance
- Criteria weights and preferences
- Renovation solution

Demonstration site characterization

For each of the demonstration cases, a short description is presented, including relevant information for the decision-making process, such as the type of building, current condition of the dwelling units, the motivation to renovate, the scope of the renovation, or/and a number of dwelling units and stakeholders.

Renovation alternatives description

For most of the demonstration cases, three renovation scenarios were designed. In some cases, these renovation scenarios were developed by the responsible partner of the demonstration case in conjunction with the architect or engineer responsible of the renovation project. For other demonstration projects, the renovation scenarios were established using the optimization tool developed by the consortium partner MTB. This tool analyses thousands of possible combinations of different components and identify a set of optimal renovation alternatives based on energy consumption and cost. Once those renovation scenarios were identified, they were evaluated according to the criteria set defined for each demonstration case.

Decision tree

Since each renovation project has specific requirements, a dedicated decision tree was defined for each of the demonstration cases. The decision tree includes general objectives covering the environmental, social, and economic aspects of the project. For each objective, different criteria are included to evaluate the renovation alternatives. Figure 2 presents an example of a decision tree. The image corresponds to a screenshot from the Excel tool developed within deliverable D7.1.

[3] Jerson Alexis Pinzon Amorocho, Timo Hartmann, A multi-criteria decision-making framework for residential building renovation using pairwise comparison and TOPSIS methods, Journal of Building Engineering, Volume 53, 2022, 104596, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2022.104596.

Buiding renovation	Environmental	To reduce Primary energy	Renewable energy
			Operational primary energy
		To reduce Environmental impacts	Global warming potential
			Total water consumption
	Social	To improve Indoor conditions	Visual comfort
			Acoustic comfort
		To increase social acceptance	Accessibility
			Aesthetics
		To increase social technical benefits	Renovation time
	Economic	To reduce Cost	Investment cost
		To reduce O&M Cost	Maintenance cost

Figure 2 Decision tree example

Alternatives' performance

For each of the demonstration cases, the proposed renovation alternatives were analysed according to their performance in terms of the set of criteria included in the decision tree. To do this, multiple energy simulations and additional calculations were conducted. In some of the cases, the energy simulations were carried out following the BIM to BEM workflows using the tools developed by the partner of the consortium, CYPE. In other cases, the simulations were executed as part of the optimization process of the MTB optimization tool. In one of the cases, the simulations were performed directly on EnergyPlus. A more detailed description of the energy modelling and simulations is available in deliverable D4.2 Real demonstration results of BEM performance simulation using BIM-SPEED Toolset. Additional tools and methods such as the comfort tool, manual calculations, 4D (Estimation of time required for the completion of renovation scenarios using 4D BIM) and 5D analysis (Cost estimation and budget analysis), and spreadsheets were used to calculate criteria such as acoustic comfort, investments cost, rent increment, renovation time, among others. For each demo case, the results are summarised in a table describing the performance of each renovation scenario according to the set of criteria.

Criteria weights settings and ranking results analysis

Since in most of the cases it was not possible to collect the preferences of the stakeholders directly, for each demonstration site we created at least three weighting scenarios to analyse diverse alternatives where environmental, social, and economic aspects represent the most important criteria as highlighted in the objectives of the project. A baseline scenario where all the criteria are equally important was also studied for the demonstration cases. The goal of generating these scenarios is to analyse how would the final result (renovation solution) change according to those different perspectives. The weights (level of importance) of the criteria were entered directly on the Excel spreadsheet to obtain the ranking according to the TOPSIS method as described in deliverable D7.1. In all the cases, the results are summarized on a table presenting the most suitable solution (the one occupying the first position in the ranking) according to the level of importance of the criteria.

Final renovation solution

In all cases, one of the renovation scenarios is suggested as the final suitable renovation solution for the building. In some cases, this solution corresponds to the alternative that occupied the first position of the ranking when all the criteria are equally important. In cases such as Gdynia, where input from the stakeholders was collected, the renovation solution corresponds to the renovation scenario that occupied the first position of the ranking according to the preferences of the stakeholders.

2.2 Demonstration project #1 Apartment blocks in Vitoria (Spain)

Demonstration site characterization

The first demonstration project is a multi-story residential building located in Vitoria-Gasteiz (Spain), in Aldabe Kalea, 26 in a densely urbanized context. The building is characterized by a U-shaped plant with a semi-court in the back of the building. Below is the aerial photo of the site with an indicative view of the urban context Figure 3.

Figure 3 Aerial view of the urban context and building location

The building was built in 1958 and consists of 4 floors with 8 dwellings, 2 dwellings on each floor, and a ground floor with a parking lot access and a bar. The constructive characteristics of the building are consistent with the construction period and are characterized by walls with a double layer of brick and an air-camera in between cavity walls, reinforced concrete and brick mixed floors, and a pitched roof with tiles. Regarding the HVAC systems, the building is characterised by separated heating systems. Each apartment is equipped with a traditional gas boiler for heating and domestic hot water production. No cooling systems or mechanical ventilation systems are installed. Table 2 presents general information about the demonstration project.

Table 2: General information

General information	
Location	Vitoria-Gasteiz (Spain)
Use category	Residential
Building type	Multi-story building
Construction year	1958
Renovation year	2021
Number of floors	5
Number of apartments/units	8 dwellings, 1 bar

Renovation alternatives description

Table 3 summarizes the renovation scenarios considered for the building:

Table 3: Overview of the renovation scenarios for #1 Apartment blocks in Vitoria

	External Wall insulation	Roof insulation	Windows replacement	Heating System replacement	Floor insulation	Additional Energy Source
Renovation scenario 1	ETICS	+Styrodur	A 70 Hinged	District Heating	-	-
Renovation scenario 2	ETICS	+Styrodur	-	District Heating	-	-
Renovation scenario 3	-	+Styrodur	A 70 Hindged	-	+Rockwool	Photovoltaic

1. In **renovation scenario 1**, the following interventions have been analysed:
   - An insulation layer made up of Expanded Polystyrene EPS 032 (thickness 0.14m and thermal conductivity 0.032 W/mK) was added on the external side of the external walls.
   - An insulation layer made up of Extruded Polystyrene XPS Styrodur (thickness 0.14m and thermal conductivity 0.029 W/mk) was added on the external side of the roof.
   - All the existing windows were replaced with new pvc windows (A 70 Hinged PVC) with a glazing heat transfer coefficient Uw of 0.9 W/m²K.
   - The heating system of the model is also upgraded from a boiler system to district heating (both for heating and for the DHW production).

2. **Renovation scenario 2** is similar to scenario 1 with the external insulation of the external walls and roof and the replacement of the heating system. The only difference is that the pre-existing windows are kept.

3. In **Renovation scenario 3**, the following interventions have been analysed:
   - An insulation layer made up of XPS Styrodur (thickness 0.14m and thermal conductivity 0.029 W/mk) was added on the external side of the roof (same as scenarios 1 and 2).
   - All the existing windows were replaced with new windows with A70 Hinged PVC) with a glazing heat transfer coefficient of 0.9 W/m²K (same as scenario 1).
   - An insulation layer made up of rockwool (thickness 0.08m and thermal conductivity 0.034 W/mk) was added on the lower side of the external floor of the first floor.
   - Photovoltaic Solar panels were added with a total power installed of 4.5 kWp. They have the potential of producing 5540.1 kWh/year.
   - No insulation of the external walls has been analysed as well as the replacement of the heating and DHW systems.

Decision tree

The high energy consumption of the building is mainly due to the poor thermal insulation properties of the building envelope both for what concern opaque elements, walls, and slabs are not insulated with thermal transmittance varying between 1.23 – 1.73 W/mqK, and windows characterised by thermal transmittance varying between 2.98 – 5.72 W/mqK. Additionally, also the traditional boilers of each flat are not efficient and could be improved. Therefore, the objectives of the renovation focused on the energy performance of the building and the investment cost as presented in Figure 4.

Environmental	To reduce Primary energy	Renewable energy
		Operational primary energy
	To reduce Energy demand	Total energy demand
		Energy savings
Economic	To reduce Cost	Investment cost

Figure 4 Decision tree for #1 Apartment blocks in Vitoria

Alternatives' performance

To perform and assess multiple energy simulations for building renovation scenarios, the CYPETHERM EPlus has been used taking the Calibrated Building Energy Model (BEM) baseline as a reference. The interventions have been modelled changing the relevant parameters within the Calibrated Model. The cost was obtained through a 5D analysis (cost estimation analysis). Table 4 summarizes the results.

Table 4: Renovation scenarios for #1 Apartment blocks in Vitoria, general results

Alternative	Renewable energy [kWh/m^2/y]	Operational primary energy [kWh/m^2]	Total energy demand [kWh/m^2/y]	Energy savings [kWh/m^2]	Investment cost [€]
Baseline	0	272.66	129.3	0	---
Renovation scenario 1	0	146.24	**90.6**	126.5	44751.23
Renovation scenario 2	0	161.16	104.4	**111.5**	**28569.75**
Renovation scenario 3	**223.2**	**13.9**	104	**258.8**	32069.38

Criteria weights settings and ranking results analysis

Different weighting scenarios were analysed to study the situations where different aspects of the renovation are given more importance during the decision process as presented in Table 5. In the baseline, all the criteria received the same level of importance (20%). In weighting scenario 1, the criteria related to the primary energy (Renewable energy and operational primary energy) received 30% importance summing up to 60%. Meanwhile, the criteria related to energy demand (Total energy demand and energy savings) received 10% each summing up to 20%, and the criterion related to cost (Investment cost) received also 20%. In weighting scenario 2, the criteria related to energy demand sum up to 60%. Finally, in weighting scenario 3, the investment cost corresponded to the most important aspect. Renovation scenario 3 is the most suitable solution in all cases.

Table 5: Weighting scenarios for #1 Apartment blocks in Vitoria

Criteria	Base line	Weighting scenario 1	Weighting scenario 2	Weighting scenario 3
Renewable energy	20%	30%	10%	10%
Operational primary energy	20%	30%	10%	10%
Total energy demand	20%	10%	30%	10%
Energy savings	20%	10%	30%	10%
Investment cost	20%	20%	20%	60%
Best renovation scenario	Renovation scenario 3	Renovation scenario 3	Renovation scenario 3	Renovation scenario 3

Final renovation solution

Considering that all the criteria are equally important, the most suitable solution corresponds to renovation scenario 3. This renovation alternative performs the best in three of the five criteria studied, the implementation of a PV (Photovoltaics) system brings benefits in different aspects of the building performance, reducing the operational primary energy considerably. Figure 7 presents a screenshot of the model including the final renovation solution for the building.

Figure 5 Building Information Model for #1 Apartment blocks in Vitoria with final renovation scenario.

2.3 Demonstration project #2 Apartment blocks in Berlin-Lichtengrade (Germany)

Demonstration site characterization

The building complex consists of two separate structures that have a basement, a ground floor, and six floors. There are four living units on each upper floor. Each floor consists of two one-bedroom and two two-bedroom apartments. According to the structural inventory, one of the buildings has a total of 1,389.47 m2 /living area. The other building has a living area of 1,410.87 m2. The building complex is conditioned by district heating. General information about the demonstration project is shown in Table 6.

Table 6: General information

General information	
Location	Lichtenrade, Berlin (Germany)
Use category	Residential
Building type	Multi-story building
Construction year	1960
Renovation year	----
Number of floors	7
Number of apartments/units	55 dwellings

Renovation alternatives description

Table 7 summarizes the renovation scenarios considered for the building:

Table 7: Overview of renovation scenarios for #2 Apartment blocks in Berlin-Lichtengrade

	Roof insulation	Windows replacement
Scenario 1	---	Pvc triple-glazed windows
Scenario 2	Mineral wool insulation	---
Scenario 3	Mineral wool insulation	Pvc triple-glazed windows

1. In **Renovation scenario 1**, the following interventions have been analysed:
    - All windows were replaced with triple-glazed windows. The frames are made of polyvinyl chloride (PVC). The German Energy Saving Ordinance (EnEV) was used to define the recommended heat transfer coefficient of the windows. The U-value of 1.30 W/(m2 K) of the windows was used.
2. In **Renovation scenario 2**, includes:
    - Mineral wool insulation was added for the rooftop. According to Annex 3 of the EnEV, the maximum recommended U-value is Umax = 0.24 W/(m2 K).
3. In **Renovation scenario 3**,
    - A combination of renovation scenarios 1 and 2 is presented. Renovation alternative 3 consists of triple-glazed windows and insulation under the rooftop.

Decision tree

Different aspects of the renovation were considered while defining the objectives and criteria. Common objectives such as reducing the energy demand and reducing the cost were included. Since the building complex is managed by a housing company and the dwelling units are rented, considering the social aspects of the inhabitants was important, and the rent increment was included to consider the impact on economic aspects. Figure 6 depicts the final decision tree for this demonstration project.

Environmental	To reduce Energy demand	Energy savings
Social	To increase social technical benefits	Rent increment
Economic	To reduce Cost	Investment cost
		Payback period

Figure 6 Decision tree for #2 Apartment blocks in Berlin-Lichtengrade

Alternatives' performance

To study the different renovation scenarios, energy simulations were performed directly on EPlus, modifying the BEM model in the idf. file according to the components included in each of the scenarios. The rent increment and investment cost were calculated using data from the German market. The results are presented in Table 8. The best performances are indicated in bold font.

Table 8: Renovation scenarios for Lichtenrade, general results

Alternative	Energy savings [kWh/m²]	Rent increment [€]	Investment cost [€]	Payback period [years]
Baseline	---	---	---	---
Renovation scenario 1	36650.31	48.14	1685159.57	5.83
Renovation scenario 2	6737.59	**43.97**	**1538965.96**	**5.32**
Renovation scenario 3	**44356.93**	53.47	1871706.34	6.41

Criteria weights settings and ranking results analysis

Different weighting scenarios were analysed to study the situations where different aspects of the renovation are given more importance during the decision process as presented in Table 9. In the baseline all the criteria received the same level of importance (25%). In weighting scenario 1, the environmental aspect (Energy savings) received 60% importance meanwhile the social aspect (Rent increment) received 20%, and the two economic criteria received 10% each summing up to 20% for that category. In weighting scenario 2, the social aspect is the most important (60%). Finally, in weighting scenario 3, Investment cost and payback period received 30% each summing up to 60% for the economic aspects. Renovation scenario 3 is the most suitable solution when all the aspects are equally important as well as when the environmental criteria are prioritized. On the other hand, since Renovation scenario 1 requires the lowest investment costs and rent increment, it is the most suitable solution when the rent increments for the inhabitants and the economic aspects are the most important aspects of the decision.

Table 9: Weighting scenarios for Lichtenrade

Criteria	Base line	Weighting scenario 1	Weighting scenario 2	Weighting scenario 3
Energy savings	25%	60%	20%	20%
Rent increment	25%	20%	60%	20%
Investment cost	25%	10%	10%	30%
Payback period	25%	10%	10%	30%
Best renovation scenario	Renovation scenario 3	Renovation scenario 3	Renovation scenario 1	Renovation scenario 1

Final renovation solution

Considering that all the criteria of the renovation are equally important, the most suitable solution for this case is Renovation scenario 3, it is the most complete renovation strategy that will bring benefits in terms of energy savings but will require a higher effort from the housing company and the inhabitants to cover the investment cost. Figure 7 presents a screenshot of the Building Information Model including the final renovation solution for the building.

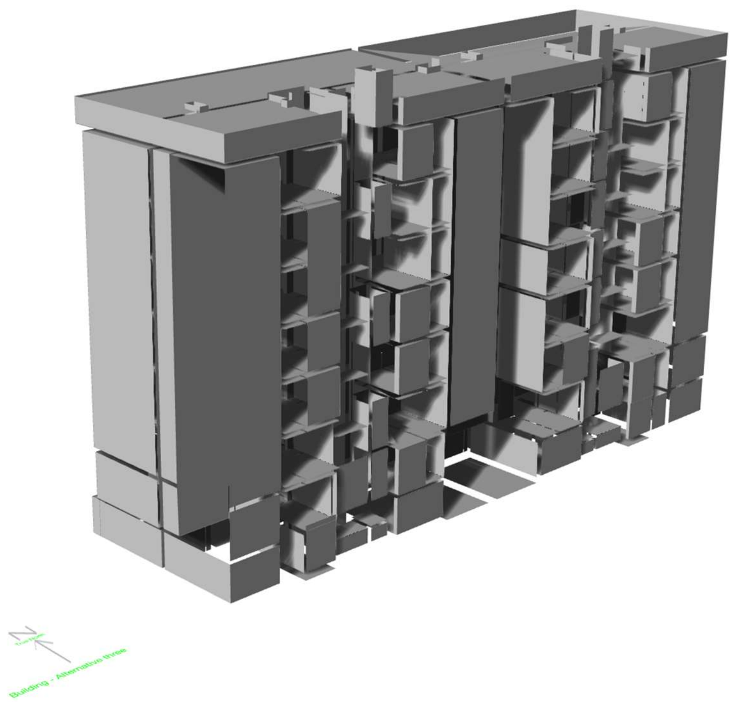


Figure 7: BIM model and final renovation solution for #2 Apartment blocks in Berlin-Lichtengrade (Germany).

2.4 Demonstration project #3 Apartment block in Warsaw (Poland)

Demonstration site characterization

This demonstration project consists of three large buildings connected into one bigger, with 294 apartments in total, located in a high-density area of Warsaw. Buildings are connected to the district heating system, which is covering space heating needs and delivers heat for domestic hot water production. Table 10 shows general information about this demonstration project.

Table 10: General information

General information	
Location	Warsaw, Poland
Use category	Residential
Building type	Multi-family block
Construction year	1976
Renovation year	-
Number of floors	13
Number of apartments/units	294

Renovation alternatives description

Table 11 summarizes the renovation scenarios considered for the building:

Table 11: Overview of renovation scenarios for demonstration project #3 Apartment block in Warsaw

	ETICS	Ventilated	Rooftop module	Windows	Second window	Indoor insulation	PV	Thermal solar
Renovation Scenario 1	X		X	X		X	X	
Renovation Scenario 2	X		X		X			
Renovation Scenario 3		X	X			X		X

1. In **Renovation scenario 1**, the following interventions have been analysed:
   - ETICS has been added to the external walls with a thermal transmittance of 0.14 W/m2K. Insulation has been added to the roof of the building with thermal transmittance of 0.232W/m2K. Type 1 windows have been exchanged with windows with better thermal properties of 0,9W/m2K, triple glazing, and a PVC frame.

Indoor floor insulation has been added to all of the slabs with 0.23W/m2K and a PV system has been installed on the roof with a yield of 43000kWh (47kWp).

2. **Renovation scenario 2**, includes:
    - The same External Thermal Insulation Composite System (ETICS) is added to the exterior walls and insulation is added to the roof.
3. **Renovation scenario 3**,
    - A ventilated facade with insulation and thermal transmittance of 0,136W/m2K has been added to the exterior walls as well as roof insulation. Indoor floor insulation has been added to the ground slabs. Windows type 2 with triple glazing and PVC frame have been exchanged. On top of the building thermal solar has been added with a yield of 80000kWh per year (47kWp).

Decision tree

Different aspects of the renovation were considered while defining the objectives and criteria. Common objectives such as reducing the energy demand and reducing the cost were included. Figure 8 depicts the final decision tree for this demonstration project.

Environmental	To reduce Energy demand	Energy savings
Social	To increase social technical benefits	Renovation time
Economic	To reduce Cost	Payback period

Figure 8: Decision tree for demonstration project #3 Apartment block in Warsaw (Poland)

Alternatives' performance

To study the different renovation scenarios, energy simulations were performed directly in CYPETHERM EPlus. The payback period was calculated using data from the German market. The results are presented in Table 8. The best performances are indicated in bold font.

Table 12: Renovation scenarios for demonstration project #3 Apartment block in Warsaw, general results

Alternative	Energy savings [kWh/m²]	Renovation duration [working days]	Payback period [years]
Baseline	---	---	---
Renovation scenario 1	1726642	2548	8,4
Renovation scenario 2	1553270	**834**	**1,7**
Renovation scenario 3	**1831019**	1912	3,5

Criteria weights settings and ranking results analysis

Different weighting scenarios were analyzed to study the situations where different aspects of the renovation are given more importance during the decision process as presented in Table 13. In the baseline, all the criteria received the same level of importance (33%). In weighting scenario 1, the environmental aspect (Energy savings) received 75% importance meanwhile the social aspect (renovation duration) received 12,5%, and the two economic criteria received 12,5% each summing up to 25%. In weighting scenario 2, the social aspect is the most important (60%). Finally, in weighting scenario 3, energy savings and payback period received 20% and payback time has been prioritized. Renovation scenario 3 is the most suitable solution if the ecological criteria are prioritized. On the other hand, since Renovation scenario 2 requires the lowest investment costs and renovation duration, it is the most suitable solution when all criteria weights are equally important.

Table 13: Weighting scenarios for demonstration project #3 Apartment block in Warsaw

Criteria	Base line	Weighting scenario 1	Weighting scenario 2	Weighting scenario 3
Energy savings	33%	75%	20%	20%
Renovation duration	33%	12,5%	60%	20%
Payback period	33%	12,5%	20%	60%
Best renovation scenario	Renovation scenario 2	Renovation scenario 3	Renovation scenario 2	Renovation scenario 2

Final renovation solution

Considering that all the criteria of the renovation are equally important, the most suitable solution for this case is Renovation scenario 2, it is the most complete renovation strategy that will bring benefits in terms of energy savings while being quite economical as well as tenant friendly. Figure 9: BIM model and final renovation solution for demonstration project #3 Apartment block in Warsaw Figure 9 presents a screenshot of the Building Information Model including the final renovation solution for the building.

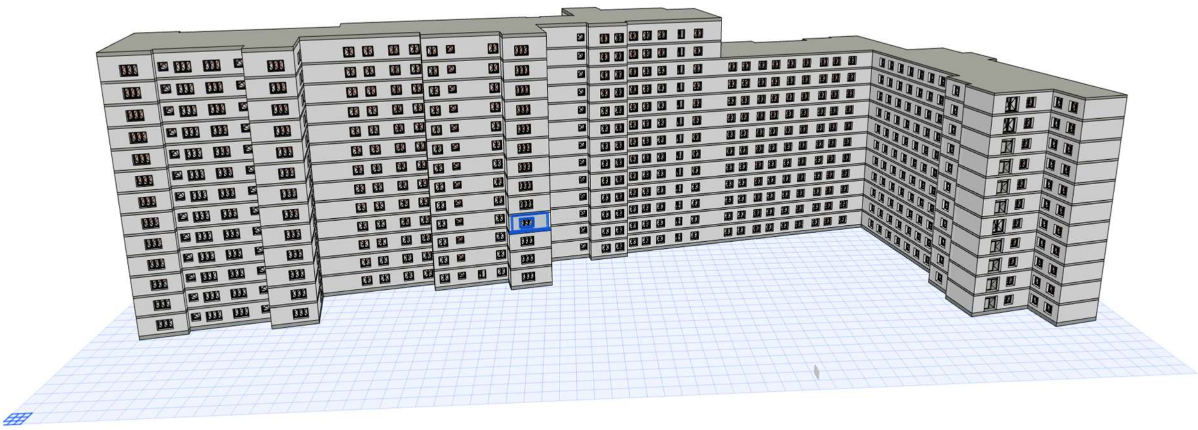


Figure 9: BIM model and final renovation solution for demonstration project #3 Apartment block in Warsaw

2.5 Demonstration project #4 Care point for homeless people in Warsaw (Poland)

Demonstration site characterization

This demonstration project is located beneath a busy Warsaw road and is a former pedestrian underpass built in 1974. The city-owned structure will be renovated into a point of first contact for homeless people in the city including conference rooms, and offices, as well as social and sanitary facilities which will provide people with meals and a place to bathe and rest. The main part of the existing structure is composed of reinforced concrete with pre-cast ceiling beams and will require new insulation and waterproofing to be installed as part of the renovation. As-built 2D drawings of the design were available. During the BIM-SPEED project, new tools supporting design and energy simulation will be tested. Additionally, 3D Scan-to-BIM (Revit Plug-in) has been tested in terms of creating a structural model based on a point cloud. General information about this demonstration project is shown in Table 14.

Table 14: General information

General information	
Location	Warsaw, Poland
Use category	healthcare
Building type	pedestrian underpass
Construction year	1974
Renovation year	To be renovated
Number of floors	1

Renovation alternatives description

Table 15 summarizes the renovation scenarios considered for the building:

Table 15: Overview of renovation scenarios for demonstration project #4 Care point for homeless people in Warsaw

	Elevator	Solar Panels	Stairlift
Scenario 1	---	---	Present
Scenario 2	Present	---	---
Scenario 3	Present	5 kW Installation	---
Scenario 4	---	5 kW Installation	Present

4. In **Renovation scenario 1**, the following interventions have been analysed:
    - A platform stairlift will be installed on one staircase for people with limited mobility.
5. **Renovation scenario 2**, includes:
    - An elevator shaft will be built at one of the building entrances.

6. In **Renovation scenario 3**, includes:
   - An elevator shaft will be built at one of the building entrances.
   - A 5 kW solar panel installation will be built.
7. In **Renovation scenario 4**, includes:
   - A platform stairlift will be installed on one staircase for people with limited mobility.
   - A 5 kW solar panel installation will be built.

Decision tree

The city of Warsaw has a responsibility to serve its residents, including those less fortunate. Therefore, the city is prioritizing the accessibility of the building to those in need and with limited mobility. Still important, but not the top priority for a project of this type are the environmental and economic interests at play. The city does not expect a financial return on its investment, but it is still required to spend public funds responsibly as it is acting on behalf of its residents and taxpayers. By the same token, reducing energy will also reduce the long-term cost both financially and environmentally.

Table 16: Decision tree for demonstration project #4 Care point for homeless people in Warsaw

Category	Objectives	Criteria
Environmental	To reduce Energy demand	Energy savings
Social	To increase social acceptance	Accessibility
Economic	To reduce Cost	Investment cost

Alternatives' performance

To study the different renovation scenarios, data was collected for the Polish market. The cost estimate for the demo project was also analysed to determine help determine the costs of the different solutions. The results are presented in Table 17. The best performances are indicated in bold font.

Table 17: Renovation scenarios for demonstration project #4 Care point for homeless people in Warsaw, general results

Alternative	Accessibility Rating [-]	Investment Cost [PLN]	Energy savings (Elevator as baseline) [kWh/year]
Renovation scenario 1	0.5	10 447 816.11	1651.48
Renovation scenario 2	**1**	10 837 605.42	0
Renovation scenario 3	**1**	10 862 205.42	**6406.48**
Renovation scenario 4	0.5	**10 472 413.11**	6401.48

Criteria weights settings and ranking results analysis

Different weighting scenarios were analysed to study the situations where different aspects of the renovation are given more importance during the decision process as presented in Table 18. The most important criterion was accessibility (54.17%). After analysing the data, the tool generated a ranking of the most optimal solutions based on the scores allocated to each scenario. Renovation scenario 3 is the most suitable solution.

Table 18: Weighting criteria for demonstration project #4 Care point for homeless people in Warsaw

Criteria	Base line
Energy savings	29.93%
Accessibility	54.17%
Investment cost	15.90%

Final renovation solution

Considering the weighting of all criteria, the most suitable solution for this case is Renovation scenario 3, bringing the most benefits in terms of accessibility and energy savings. Despite having the highest cost of all scenarios, the cost difference was insignificant enough to not outweigh the benefits the solution provides. The city will be able to get the accessible building it needed with the added benefit of reduced energy consumption. The budget will not increase significantly with this solution, meaning it will most likely be acceptable to taxpayers.

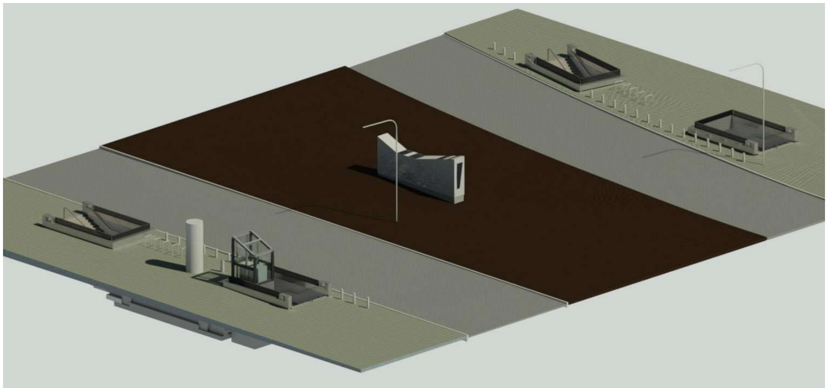


Figure 10: Visualisation of final renovation solution with visible elevator shaft for #4 Care point for homeless people in Warsaw (Poland)

2.6 Demonstration project #5 Multi-family dwellings in Barland (Romania)

Demonstration site characterization

This demonstration project is a residential building located in Barlad, a city with around 55 000 people in Romania. The city is situated in the county of Vaslui, Romania. The building is situated on the street Epureanu, number 40, and has a typical architecture for when it was built (between 1967-1968). From an architectural point of view, the building has a rectangular shape, with dimensions of 59 m long and 11.85 m wide. It is comprised of a ground floor and 4 additional floors. The building is split into 2 areas, part A and part B, both with 20 apartments on all floors (4 for each floor). The structure of the building is comprised of confined brick walls with reinforced concrete slabs with an uncirculated terrace above the last level. The building did not have any major renovation process of any kind (structural, thermal) and according to the latest structural report, it needs structural renovation work. Regarding thermal insulation, there was no major renovation done in this sense, each apartment owner taking own measures to improve in any way the thermal efficiency of his flat. Considering this, some apartments have exterior insulation and newer windows, while some do not have any thermal insulation and are with an old window system comprised of wood. Regarding building services, the heating is mostly done with gas-fired boilers, one per apartment, and radiators for heating. An insignificant number of apartments have a split unit cooling system. Domestic hot water is produced locally, using gas-fired boilers. The lighting system is mixed, from fluorescent lamps and LED lamps. There is no mechanical ventilation system inside the building. Table 19 shows general information about the demonstration project.

Table 19: General information

General information	
Location	Barlad, Romania
Use category	Residential
Building type	Multi-apartment building
Construction year	1966-1967
Renovation year	None
Number of floors	5
Number of apartments/units	4/floor

Renovation alternatives description

Table 20 summarizes the renovation scenario considered for the building.

Table 20: Overview of renovation scenarios for demonstration project #5 Multi-family dwellings in Barland

	Walls insulation	Roof insulation	Windows & Main entrance doors
Scenario 1	☑	☑	☒
Scenario 2	☑	☒	☑
Scenario 3	☑	☑	☑

Decision tree

For this case, the criteria set focused on the environmental and social aspects of the renovation. Table 21 depicts the final decision tree for this case.

Table 21: Decision tree for demonstration project #5 Multi-family dwellings in Barland

Environmental	To reduce Primary energy	Operational primary energy
	To reduce Energy demand	Total energy demand
		Energy savings
Social	To improve Indoor conditions	Thermal comfort
	To increase social acceptance	Aesthetics

Alternatives' performance

To study different renovation scenarios, energy simulations were performed using CYPETHERM tool and BIM-BEM approach. The results are presented in Table 22. The best performances are indicated in bold font.

Table 22 Renovation scenarios for demonstration project #5 Multi-family dwellings in Barland

Alternative	Operational Primary Energy demand [kWh/m²]	Total Energy Demand [kWh/m²year]	Energy savings [%]	Thermal comfort [-]	Aesthetics [-]
Current building	---	209,5	---		
Renovation scenario 1	762,8	141,1	32,8	4,1	3
Renovation scenario 2	762,8	159,6	30.9	4,3	4
Renovation scenario 3	762,8	124,6	39.2	4,8	5

Criteria weights settings and ranking results analysis

In this case, renovation scenario 3 performs the best according to the five criteria analysed. Therefore, changing the weights or preferences on the criteria will not affect the final ranking.

Final solution

The most suitable solution for this case is Renovation scenario 3, it is the most complete alternative, providing the best energy building performance after renovation, the best thermal comfort, and aesthetics. Figure 11 shows the BIM model for the final renovation solution selected for the building

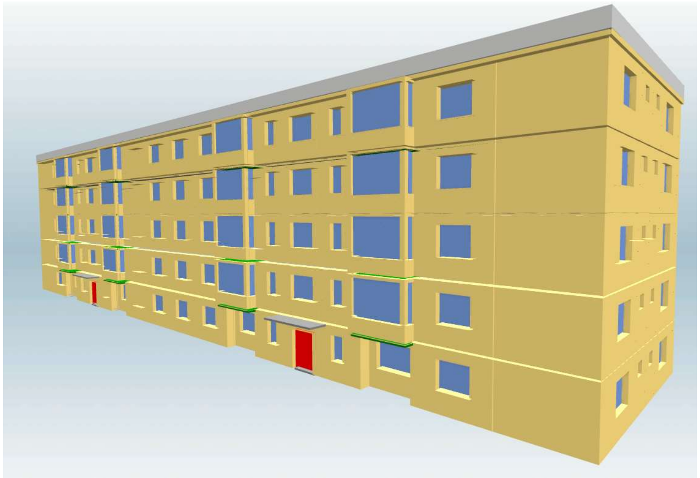


Figure 11: BIM model with final renovation design for #5 Multi-family dwellings in Barland

2.7 Demonstration project #7 Historic residential building in Varna (Bulgaria)

Demonstration site characterization

This two-story emblematic historical residential building was constructed in 1915 in the city of Varna, Bulgaria. On its ground floor, there are shops, an art studio, and a bookstore. The external walls are made from bricks and are not insulated. There is no heating and cooling system in the building, except local electrical heaters on the residential floor and local air-conditioning units on the ground floor. The building is under cultural heritage protection. Partial old paper documentation from 1912 is available. During the BIM-SPEED project, new tools supporting the as-built data acquisition and Virtual Reality/Augmented reality will be demonstrated. General information about this demonstration project is shown in Table 23.

Table 23 General information

General information	
Location	Varna (Bulgaria)
Use category	Historical residential building
Building type	Multi-storey building
Construction year	1915
Renovation year	---
Number of floors	2
Number of apartments/units	5 dwelling

Renovation alternatives description

Table 24 summarizes the renovation scenarios considered for the building:

Table 24 Overview of renovation scenarios for demonstration project #7 Historic residential building in Varna

	ETICS	Roof insulation	Windows replacement	Floors insulation
Renovation Scenario 1	Polistyrene Insulation	Polistyrene Insulation	PVC triple-glazed windows	Polistyrene Insulation
Renovation Scenario 2	---	---	PVC triple-glazed windows	---
Renovation Scenario 3	Polistyrene Insulation	Polistyrene Insulation	---	---

1. **Renovation scenario 1**, the following interventions have been analysed:
    - All facades above the ground were insulated with 0,12m thick polystyrene with λ=0,032W/mK (External wall insulation system – ETICS),
    - Roof insulation – roof insulated with 0,12m thick polystyrene with λ=0,032W/mK
    - Windows were replaced with triple-glazed windows. The frames are made of polyvinyl chloride (PVC). The U-value of 0,90 W/(m2 K) of the windows was used.
    - Floor insulation – basement floor was insulated with 0,10m thick polystyrene with λ=0,036W/mK

2. **Renovation scenario 2**, includes:
    - Windows were replaced with triple-glazed windows. The frames are made of polyvinyl chloride (PVC). The U-value of 0,90 W/(m2 K) of the windows was used.
3. **Renovation scenario 3**,
    - All facades above the ground were insulated with 0,12m thick polystyrene with λ=0,032W/mK (External wall insulation system – ETICS),
    - Roof insulation – roof insulated with 0,12m thick polystyrene with λ=0,032W/mK

Decision tree

For a historic building located in an important part of the city, social criteria are very significant. Therefore, the stakeholders indicated multiple aspects that they wanted to consider during the evaluation of the renovation alternatives. Table 25 depicts the final decision tree for this case.

Table 25 Decision tree for demonstration project #7 Historic residential building in Varna

Social	To improve Indoor conditions	Visual comfort
		Indoor air quality
		Thermal comfort
	To increase social acceptance	Aesthetics
	To increase social technical benefits	Renovation time
		Durability

Alternatives' performance

To study the different renovation scenarios, each scenario was given a score for each criterion. The results are presented in Table 26. The best performances are indicated in bold font.

Table 26 Renovation scenarios for demonstration project #7 Historic residential building in Varna, general results

Alternative	Visual comfort [-]	Indoor air quality [-]	Thermal comfort [-]	Aesthetics [-]	Renovation Time [-]	Durability [years]
Baseline	---	---	---	---	---	---
Renovation scenario 1	**5**	**4,7**	**4,8**	***5***	**2**	**14**
Renovation scenario 2	3,5	4	3	2	4	10
Renovation scenario 3	2	3,7	4,3	4	2,5	12

Criteria weights settings and ranking results analysis

Different weighting scenarios were analysed to study the situations where different aspects of the renovation are given more importance during the decision process as presented in Table 26. The most important criteria are thermal comfort (24,09%), aesthetics (20,41%), and durability (18,92%). After analysing the data, the tool generated a ranking of the most optimal solutions based on the scores allocated to each scenario. Renovation scenario 1 is the most suitable solution.

Table 27 Weighting criteria for demonstration project #7 Historic residential building in Varna

Criteria	Weights
Visual comfort	14,33%
Indoor air quality	12,78%
Thermal comfort	24,09%
Aesthetic	20,41%
Renovation time	9,46%
Durability	18,92%

Final renovation solution

Considering the weighting of all criteria, the most suitable solution for this case is Renovation scenario 1, it is the most complete renovation strategy that will bring benefits in terms of thermal comfort, aesthetics, and durability. This renovation alternative performs the best according to every important criterion. Figure 12 presents a screenshot of the model including the final renovation solution for the building.

Figure 12: BIM model with final renovation scenario for demonstration project #7 Historic residential building in Varna

2.8 Demonstration project #8 Historic residential building in Frigent (Italy)

Demonstration site characterization

This demonstration project is a residential building called “Palazzo Testa Cipriano” located in the historical center of Frigento (Italy) in a densely urbanized context, between via Duomo, via San Giovanni, and vico dietro Campanile. The building is characterized by a rectangular plant and by a compact volume with a central court. The original building construction year dates back to 1700 with subsequent restoration actions, one of the latest in 1783, date impress on the main entrance. Due to the cultural value of the whole historical centre, the building is protected by the Cultural Heritage Office. In 1980 the building was subjected to a consistent consolidation intervention, mostly addressed to the first floor, due to damages caused by an earthquake. The demonstration building consists of 2 apartments (Flat “Testa” and Flat “Cipriano”) and 2 floors (ground floor and first floor) and it is characterized by stone-brick masonry walls and reinforced concrete and brick mixed floor and roof. In addition to the 2 apartments, on the ground floor, there are also a few unheated rooms. Regarding the HVAC systems, the building is characterised by 2 separate heating systems. Each apartment is equipped by a traditional gas boiler for heating and domestic hot water production.

No cooling systems or mechanical ventilation systems are installed. General information for this demonstration project is shown in Table 28.

Table 28 General information

General information	
Location	Frigento, Italy
Use category	Historical residential building
Building type	Multi-storey building
Construction year	1700
Renovation year	1980
Number of floors	2
Number of apartments/units	2

Renovation alternatives description

The best renovation alternatives were generated automatically by an artificial intelligence tool Building optimizer (developed by Metabuild)

- Alternative A: Energy optimal. AI-generated solutions ID 1286
- Alternative B: Energy optimal. AI-generated solutions ID 1726

The following building renovation elements have been assessed in the simulations:

- External walls (indoor) insulation
- Windows replacement (incl. shading system)
- Indoor floors insulation
- Boilers replacement

Table 29 Description renovation alternative A

Type of intervention	Optimisation settings and ranges of variation	
External walls insulation	Insulation material: Mineral wool Total thickness of external wall U-Value	0,24 m 0,46 m 0,14 W/m²K
Roof insulation	Insulation material: Mineral wool Total thickness U-Value	0,23 m 0,60 m 0,14 W/m²K
Ground floor insulation	Insulation material: XPS Total thickness U-Value	0,10 m 0,21 m 3,75 W/m²K
Windows replacement	Glazing type: Triple glazing, Low-E PVC frame no change in windows dimensions	Ug = 0,7
Shading system	Exterior blind high reflectivity slats 60°	
HVAC	Heat distribution: Hot water radiator Heat supply: Air-source heatpump & Gas boiler support Cooling: None	

Table 30 Description renovation alternative B

Type of intervention	Optimisation settings and ranges of variation	
External walls insulation	Insulation material: Mineral wool Total thickness of external wall U-Value	0,21 m 0,43 m 0,16 W/m²K
Roof insulation	Insulation material: Stone wool Total thickness U-Value	0,23 m 0,60 m 0,14 W/m²K
Ground floor insulation	Insulation material: EPS Total thickness U-Value	0,18 m 0,49 m 3,75 W/m²K
Windows replacement	Glazing type: Triple glazing, Low-E PVC frame no change in windows dimensions	Ug = 0,7
Shading system	Exterior blind high reflectivity slats 60°	
HVAC	Heat distribution: Hot water radiator Heat supply: Air-source heatpump & Gas boiler support Cooling: None	

Decision tree

Different aspects of the renovation were considered while defining the objectives and criteria. The Building optimizer tool developed by the consortium partner Metabuild identified two renovation scenarios based on energy and cost, then additional criteria were defined to evaluate those two renovation alternatives, and the one that fulfilled the requirements was selected. For this demo site, the evaluation included ten criteria covering different elements of the renovation initiative. Figure 13 depicts the final decision tree for this case.

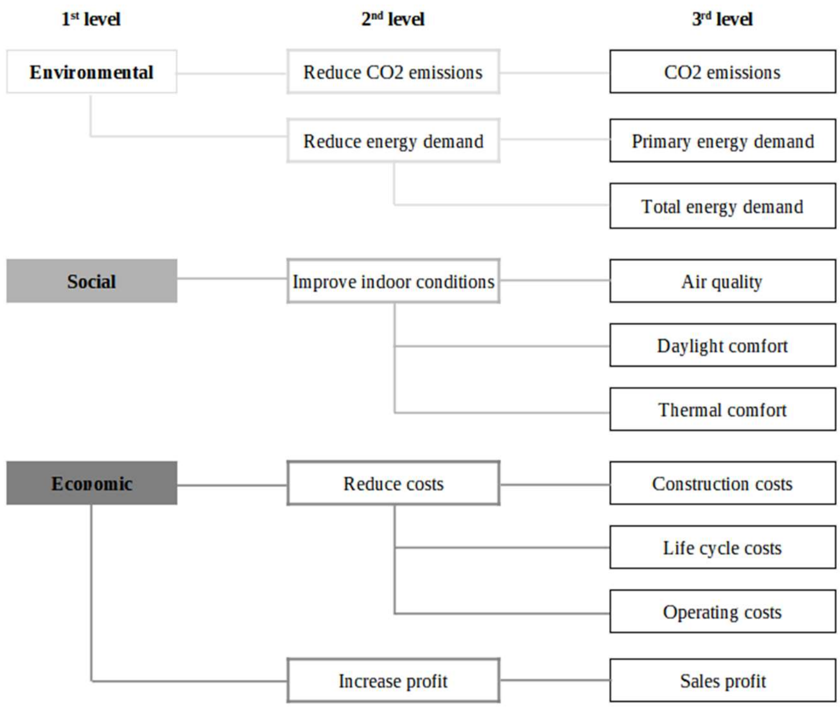


Figure 13 Decision tree for demonstration project #8 Historic residential building in Frigento

Alternatives' performance

To assess different renovation alternatives the Building optimizer tool was implemented. For each type of renovation element within the building, different solutions were examined, making the characteristic parameters vary between a certain range of values. The tool is a dynamic optimization process with 4080 automated year-round simulations, after which technically and economically optimal building variants are determined on a data-analytical basis.

Table 31: Renovation scenarios for demonstration project #8 Historic residential building in Frigento general results

Alternative	Investment costs [Mio. €]	Operating cost [€/m²/month]	Life cycle costs [€]	Gain sale [Mio. €]	Air quality (Score out of 10)	Daylight comfort (Score out of 10)	Thermal comfort (Score out of 10)	CO2 balance Kg CO2/(m² GFA .a)	Primary energy kWh/(m² GFA .a)	Total energy demand kWh/m². a
A	0.28	**1.99**	**0.90**	3.02	8	1	6	**22.73**	**89.48**	**51.30**
B	0.28	2.01	0.91	**3.07**	8	1	6	23.17	90.35	51.76

Criteria weights settings and ranking results analysis

In this section, different scenarios for criteria weigh are considered. The first scenario, the baseline, considers all the criteria equally important. In scenario N°1 a higher level of importance is assigned to environmental aspects. Scenarios N°2 and N°3 prioritize either the owner's benefits or the tenant's benefits, respectively. The goal of these scenarios is to analyze how would the final result (renovation solution) change according to those different perspectives. It can be noted that overall Alternative A performs better than Alternative B. Only in scenario 2 (priority to owner benefits) the Alternative B has a better score, however, the gap between both alternatives is not so big if compared to the results of scenarios 1 and 3.

Table 32: Weighting scenarios for demonstration project #8 Historic residential building in Frigento

Criteria	Base line	Scenario 1 – *Priority to environment*	Scenario 2 – *Priority to owner benefits*	Scenario 3 - *Priority to tenants benefit*
Investment costs [Mio. €]	10%	5%	20%	5%
Operating cost [€/m²/month]	10%	5%	5%	20%
Life cycle costs [€]	10%	5%	20%	5%
Gain sale [Mio. €]	10%	5%	25%	5%

Air quality (Score out of 10)	10%	5%	5%	10%
Daylight comfort (Score out of 10)	10%	5%	5%	10%
Thermal comfort (Score out of 10)	10%	5%	5%	10%
CO2 balance Kg CO2/(m² GFA .a)	10%	25%	5%	5%
Primary energy kWh/(m² GFA .a)	10%	20%	5%	10%
Total energy demand kWh/m².a	10%	20%	5%	20%
Best renovation scenario	Renovation scenario A	Renovation scenario A	Renovation scenario B	Renovation scenario A

Final renovation solution

If we consider that all the criteria are equally important, the renovation scenario A is the most suitable one. It performs the best in five of the criteria and it has a good performance in the additional aspects. The better ground insulation provided by renovation scenario seems to not be as beneficial as the insualtion of the internal walls. The better insulation of the internal walls provided in renovation scenario A improves different aspects of the renovation such as the operating cost, the primary energy, etc. presents the Building Information model of the demonstration project.

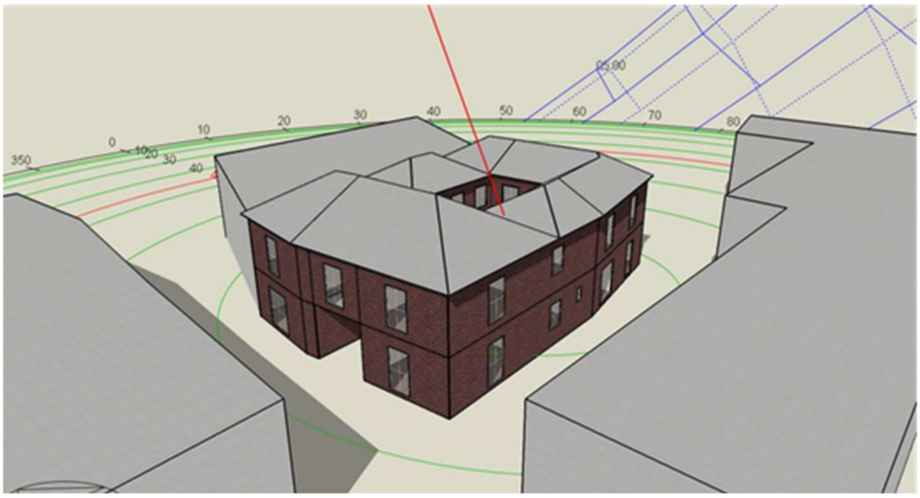


Figure 14: Model with final renovation scenario for demonstration project #7 Historic residential building in Varna BIM model with renovation scenario for demonstration project #8 Historic residential building in Frigento

2.9 Demonstration project #9 Semi-detached building in Gdynia (Poland)

Demonstration site characterization

It is a duplex (two-family) dwellings constructed in 1961 and located in Gdynia, in the North of Poland. The building has three stories. External walls are made from full brick and have a thickness of 56cm, the building is partially insulated with expanded polystyrene. It is connected to the natural gas and the heating system is based on the gas boiler. The reasons for the renovation are: very low building condition, the age of the building, low energy performance and the need to rearrange and enlarge the usable area. As-built 2D drawings and BIM model were available for the building.

Table 33: General information

General information	
Location	Gdynia (Poland)
Use category	Single family household (half of duplex)
Building type	Multi-storey building
Construction year	1961
Renovation year	---
Number of floors	3
Number of apartments/units	1 dwelling

Renovation alternatives description

Table 34 summarizes the renovation scenarios considered for the building:

Table 34: Overview of renovation scenarios for demonstration project #9 Semi-detached building in Gdynia

	External wall insulation	Ventilated	Roof insulation	Windows replacement	Second window	Floors insulation
Renovation Scenario 1	EPS 032 Insulation XPS 200-036 (basement)	----	EPS 032 insulation	PVC triple-glazed windows	---	EPS 100 Insulation EPS 036 (basement floor)
Renovation Scenario 2	---	EPS 032 insulation	---	---	PVC triple-glazed windows	EPS 100 Insulation (basement floor)
Renovation Scenario 3	EPS 032 Insulation XPS 200-036 (basement)	---	EPS 032 insulation	PVC triple-glazed windows	---	EPS 100 Insulation (basement floor)

	Lighting	Radiators	Piping	Boilers	Ventilation	Thermal solar
Renovation Scenario 1	LED 7-60W	---	PVC triple-glazed windows	Gas condensing boiler	---	Evacuate-tube collectors
Renovation Scenario 2	LED 7-60W	Panel 917-1072W	---	---	Decentralised mechanical ventilation	---
Renovation Scenario 3	LED 7-60W	---	---	---	---	---

1. In **Renovation scenario 1**, the following interventions has been analysed:
   - ETICS (External Wall Insulation System) – All facades above the ground were insulated with 0,12m Expanded polystyrene - EPS 032 with λ=0,032W/mK, basement external walls were insulated with 0,12m extruded polystyrene XPS 200-036 with λ=0,036W/mK
   - Roof insulation – roof insulated with 0,12m thick expanded polystyrene EPS 032 with λ=0,032W/mK
   - Windows were replaced with triple-glazed windows. The frames are made of polyvinylchloride (PVC). The U-value of 0,90 W/(m2 K) of the windows was used.
   - Floor insulation – floors between storeys were insulated with 0,04m thick expanded polystyrene EPS 036 with λ=0,036W/mK, basement floor was insulated with 0,10m thick expanded polystyrene EPS 100 with λ=0,036W/mK
   - Lighting – all light sources were replaced by LED technology
   - Piping – all pipes in system were replaced with new ones
   - Boilers- boiler was replaced with gas condensing boiler Thermal solar was installed
2. In **Renovation scenario 2**, includes:
   - Ventilated facade – all walls insulated with 0,12m thick expanded polystyrene EPS 032 with λ=0,032W/mK and with 0,03m air gap
   - Second window - triple-glazed windows. The frames are made of polyvinylchloride (PVC). The U-value of 0,90 W/(m2 K) of the windows was used
   - Floor insulation – floors between storeys were insulated with 0,04m thick expanded polystyrene EPS 036 with λ=0,036W/mK, basement floor was insulated with 0,10m thick expanded polystyrene EPS 100 with λ=0,036W/mK
   - Radiators- radiators were replaced with 917-1072W panel radiators
   - Decentralised mechanical ventilation was installed
3. In **Renovation scenario 3**,
   - ETICS (External Wall Insulation System) – All facades above the ground were insulated with 0,12m thic EPS 032 with λ=0,032W/mK, basement external walls were insulated with 0,12m thick XPS 200-036 with λ=0,036W/mK
   - Roof insulation – roof insulated with 0,12m thick EPS 032 with λ=0,032W/mK
   - Windows were replaced with triple-glazed windows. The frames are made of polyvinylchloride (PVC). The U-value of 0,90 W/(m2 K) of the windows was used.

- Floor insulation – floors between storeys were insulated with 0,04m thic EPS 036 with λ=0,036W/mK, bacement floor were insulated with 0,10m thic EPS 100 with λ=0,036W/mK
- Lighting – all light sources were replaced by LED technology
- Piping – all pipes in system were replaced with new ones
- Boilers- boiler was replaced with gas condensing boiler
- Thermal solar was installed

Decision tree

For a private investor renovating their house and being aware of the risks caused by global warming and pollution, diverse economic, social and environmental aspects are relevant while selecting the renovation alternative. Therefore, the stakeholders indicated multiple aspects that they wanted to consider during the evaluation of the renovation alternatives. Figure 15 depicts the final decision tree for this case.

Environmental	To reduce Primary energy	Operational primary energy
	To reduce Energy demand	Total energy demand
		Energy savings
	To reduce Environmental impacts	Global warming potential
Social	To improve Indoor conditions	Visual comfort
		Indoor air quality
		Thermal comfort
	To increase social acceptance	Aesthetics
	To increase social technical benefits	Renovation time
		Durability
Economic	To reduce Cost	Investment cost
		LCC Cost
	To reduce O&M Cost	Maintenance cost
		Operational energy cost

Figure 15: Decision tree for demonstration project #9 Semi-detached building in Gdynia (Poland)

Alternatives' performance

To study the different renovation scenarios, energy simulations were performed directly on Energy Plus, modifying the BEM model in the idf. file according to the components included in each of the scenarios. The performance of the renovation scenarios according to other criteria was calculated using different methods. The results are presented in Table 35. The best performances are indicated with the bold font.

Table 35: Renovation scenarios for #9 Semi-detached building in Gdynia (Poland), general results

Alternative	Operational primary energy [kWh/m²·year]	Total energy demand [kWh/m²·year]	Energy savings [kWh/m²·year]	Global warming potential [years]
Baseline	---	180,3	---	---
Renovation scenario 1	**88**	**124,1**	**56,2**	20
Renovation scenario 2	117,42	156,6	23,7	**28**
Renovation scenario 3	101,51	**124,1**	**56,2**	18

Alternative	Visual comfort [-]	Indoor air quality [-]	Thermal comfort [-]	Aesthetics [-]	Renovation Time [-]	Durability [years]
Baseline	---	---	---	---		
Renovation scenario 1	3.5	**4,7**	4,4	3	2	**12**
Renovation scenario 2	5	4,4	4,7	**5**	1,5	**12**
Renovation scenario 3	**4,8**	4,2	**4,8**	3,3	**1**	9

Alternative	Investment cost [€]	LCC cost [€]	Maintenance cost [€]	Operational energy cost [€]
Baseline	---	---	---	---
Renovation scenario 1	33500	369000	**3240**	**1390**
Renovation scenario 2	30500	381000	3590	1510
Renovation scenario 3	**25500**	**365000**	3770	1620

Criteria weights settings and ranking results analysis

In this case, the real stakeholders of the project, the owners of the apartment, indicated their preferences on the different criteria included in the decision tree as summarized in Table 9. The most important criteria are the investment cost (23,15%), thermal comfort (15,68%) and global warming potential (15,15%). After analysing the data, the DM-tool generated a ranking of the most suitable solutions based on the scores allocated to each criterion. According to the results, renovation scenario 3 is the most suitable solution.

Table 36: Weighting criteria for #9 Semi-detached building in Gdynia (Poland)

Criteria	Weights
Operational primary energy	3,03%
Total energy demand	2,53%
Energy savings	12,63%
Global warming potential	15,15%
Visual comfort	3,14%
Indoor air quality	3,14%
Thermal comfort	15,68%
Aesthetic	2,96%
Renovation time	1,40%
Durability	7,02%
Investment cost	23,15%
LCC cost	4,63%
Maintenance cost	4,63%
Operational energy cost	0,93%
Best renovation scenario	Renovation scenario 3

Final renovation solution

Considering the weighting of all criteria, the most suitable solution for this case is Renovation scenario 3, it is the most complete renovation strategy that will bring benefits in terms of investment cost, thermal comfort and global warming potential. This renovation alternative performs the best according to thermal comfort and investment cost, which are two of the three most important criteria. This scenario performs similar to scenario 1 in terms of criteria such as energy savings, durability, and total energy demand. However, scenario 3 performs the best in other aspects such as LCC cost, visual comfort, and renovation time. Figure 16 presents a screenshot of the model including the final renovation solution for the building.

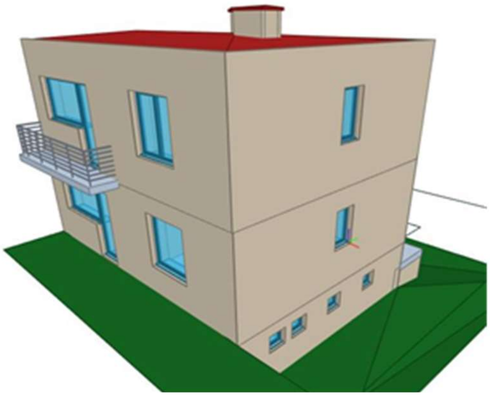


Figure 16: Building Information Model with renovation scenario for demonstration project #9 Semi-detached building in Gdynia (Poland)

2.10 Demonstration project #10 Multi-family dwelings in Warmond (the Netherlands)

Demonstration site characterization

This demonstration project is a complex of 4 buildings located in Warmond (the Netherlands), at van den Woudestraat. For the generation of the BEM model, one of the buildings was selected (block A), as seen in Figure 17.

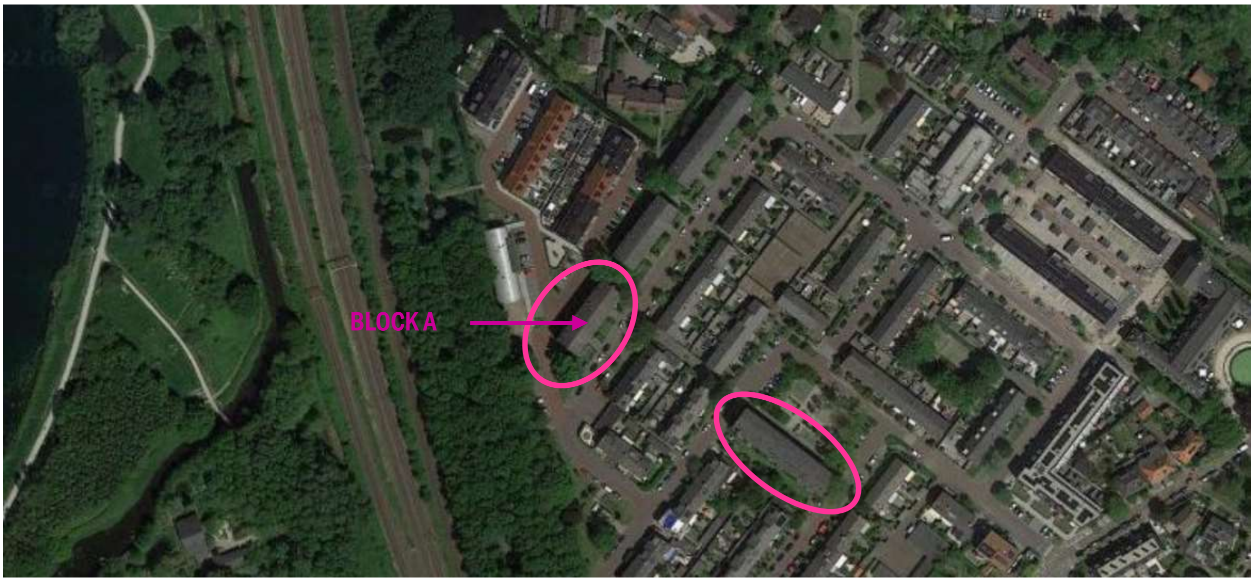


Figure 17 Aerial view of the urban context and building selection

The building Block A was built in 1969 and consists of 12 dwellings, 2 staircases, a non-heated basement, and a non-heated attic. The constructive characteristics of the building are consistent with the construction period and are characterized by not-insulated walls and brick mixed floors. Insulation in the cavity wall was added as part of the last renovation. Table 37 shows general information about the building.

Table 37: General information

General information	
Location	Warmond (The Netherlands)
Use category	Residential
Building type	Three-story building
Construction year	1969
Renovation year	n.d.
Number of floors	4 (including the basement)
Number of apartments/units	12 dwellings

Renovation alternatives description

To perform and assess multiple energy simulations for building renovation scenarios, the MTB Optimization tool has been applied. Following the specific optimization set-up of the project, the theoretical number of possible renovation scenarios to be assessed is nearly 218 million. Out of these, 4.000 scenarios have been automatically simulated and assessed, controlled by an evolutionary optimization algorithm. After the assessment, 2 renovation scenarios were identified as among optimal solutions in terms of energy efficiency, cost, and comfort performance.

For the Warmond demo case, the following building renovation elements have been assessed:

- External walls insulation
- Windows replacement (incl. shading system)
- Roof insulation
- HVAC replacement
- PV system installation

Table 38 summarizes the renovation scenarios considered for the building:

Table 38: Overview of renovation scenarios for demonstration project #10 Multi-family dwellings in Warmond

Type of intervention	Optimization settings and ranges of variation	Scenario 1	Scenario 2
External walls insulation	Insulation material: Mineral wool Total thickness of external wall U-Value	0,18 m 0,40 m 0,17 W/m²K	0,21 m 0,43 m 0,16 W/m²K
Roof insulation	Insulation material: PUR foam Total thickness U-Value	0,26 m 0,63 m 0,09 W/m²K	0,29 m 0,66 m 0,10 W/m²K
Windows replacement	Glazing type: Triple glazing, Low-E PVC frame no change in windows dimensions	Ug = 0,7	Ug = 0,7
Shading system	Exterior blind low reflectivity slats 90°		

HVAC	Heat distribution: Hot water ceiling Heat supply: Ground Source Heat Pump Cooling: None		
Electricity Generation	Solar Thermal size Solar Collector type Roof area covered by PV Battery type PV orientation option (respect to south) PV tilt options (respect to horizontal)	21.11 m² Flat solar collector 158.33 m² Lithium, 32 kWh -45° 30°	42.22 m² Flat solar collector 158.33 m² Lithium, 32 kWh -45° 30°

Decision tree

Different aspects of the renovation were considered while defining the objectives and criteria. Common objectives such as reducing the energy demand and reducing construction cost were included. The optimization tool developed by Metabuild identified two renovation scenarios based on energy and cost. Additional criteria were defined to evaluate those two final renovation alternatives, in order to select the most optimum solution fulfilling the requirements of the demo site project.

For this demo site, the evaluation included ten criteria covering different elements of the renovation initiative. Figure 18 depicts the final decision tree for this case.

Buiding renovation	Environmental	To reduce Primary energy	Operational primary energy
		To reduce Energy demand	Total energy demand
		To reduce Environmental impacts	Global warming potential
	Social	To improve Indoor conditions	Visual comfort
			Indoor air quality
			Thermal comfort
	Economic	To reduce Cost	Investment cost
			LCC Cost
		To reduce O&M Cost	Operational energy cost
		To increase Financial benefits	Dwelling value increment

Figure 18 Decision tree for demonstration project #10 Multi-family dwellings in Warmond

Alternatives' performance

To study the different renovation scenarios, for each type of intervention, different solutions were examined, making the characteristic parameters vary between a certain range of values. 4.000 scenarios were automatically simulated and assessed. The results are presented in Table 39Table 8. The best performances are indicated with the bold font.

Table 39: Renovation scenarios for for demonstration project #10 Multi-family dwellings in Warmond, general results

Alternative	Investment costs [Mio. €]	Operating costs [€/m²/month]	Life cycle costs [€]	Gain sale [Mio. €]	Air quality (Score out of 10)	Daylight comfort (Score out of 10)	Thermal comfort (Score out of 10)	CO2 balance Kg CO2/(m² GFA .a)	Primary energy kWh/(m² GFA .a)	Total energy demand kWh/m².a
1	0.73	**1.36**	1.76	3.81	10	2	**7**	**-9.51**	40.51	19.75
2	**0.70**	1.38	**1.75**	**3.84**	10	2	6	-9.17	**38.15**	**18.18**

Criteria weights settings and ranking results analysis

In this section different scenarios for criteria weights are considered. The first scenario, the baseline, considers all the criteria equally important. In scenario N°1 a higher level of importance is assigned to environmental aspects. Scenarios N°2 and N°3 prioritize either the owner's benefits or the tenant's benefits, respectively. The goal of these scenarios is to analyze how the result (renovation scenario) would change according to the different defined priorities. It can be noted that overall Alternative 2 performs better than Alternative 1. Only in the baseline scenario, the renovation scenario 1 has a better score.

Table 40: Weighting scenarios for demonstration project #10 Multi-family dwellings in Warmond

Criteria	Base line	Scenario 1 – *Priority to environment*	Scenario 2 – *Priority to owner benefits*	Scenario 3 - *Priority to tenants benefit*
Investment costs [Mio. €]	10%	5%	20%	5%
Operating cost [€/m²/month]	10%	5%	5%	20%
Life cycle costs [€]	10%	5%	20%	5%
Gain sale [Mio. €]	10%	5%	25%	5%
Air quality (Score out of 10)	10%	5%	5%	10%
Daylight comfort (Score out of 10)	10%	5%	5%	10%
Thermal comfort (Score out of 10)	10%	5%	5%	10%
CO2 balance Kg CO2/(m² GFA .a)	10%	25%	5%	5%
Primary energy	10%	20%	5%	10%

kWh/(m² GFA .a)				
Total energy demand kWh/m².a	10%	20%	5%	20%
Best renovation scenario	Renovation scenario 1	Renovation scenario 2	Renovation scenario 2	Renovation scenario 2

Final renovation solution

The most suitable solution for this case is Renovation scenario 2. It performs the best in five of the criteria and is the most complete renovation strategy that will bring benefits in terms of energy savings, as well as on investment cost. Figure 19 presents a screenshot of the model including the final renovation solution for the building.

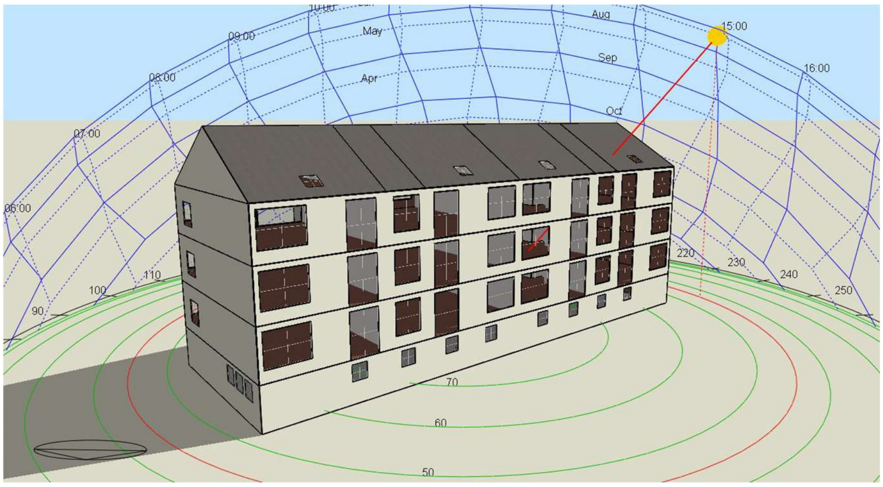


Figure 19: Building Information Model with final renovation solution for demonstration project #10 Multi-family dwellings in Warmond

2.11 Demonstration project #11 Mixed used building in Berlin-Tempelhof (Germany)

Demonstration site characterization

Tempelhof demonstration project is a multi-story residential building, which was formerly the officers' hotel of the US Americans, located in Berlin (Germany), in the south-central Berlin borough of Tempelhof-Schöneberg, it ceased operating in 2008. The building consists of 6 floors (4 floors with 2 underground floors), and 2 stairwells on each side of the floor. The constructive characteristics of the building are consistent with the construction period and are characterized by brick walls with limestone shells, reinforced concrete and brick mixed floors, and a sloping roof. Regarding the HVAC systems, the building is characterized by central heating systems. The whole building is equipped with district heating for the heating and domestic hot water production. No cooling systems or mechanical ventilation systems are installed.

Table 41: General information

General information	
Location	Tempelhof, Berlin (Germany)
Use category	Residential/offices
Building type	Multi-story building
Construction year	1926
Renovation year	----
Number of floors	6
Number of units	90

Renovation alternatives description

Table 42 summarizes the renovation scenarios considered for the building:

Table 42: Overview of renovation scenarios for #11 Mixed used building in Berlin-Tempelhof

	External Wall insulation	Roof insulation	Windows replacement	Heating System replacement	Floor insulation	Additional Energy Source
Renovation Scenario 01	ETICS	+ Grafipol	Energy 82 mm - PVC	-	+ Grafipol	-
Renovation Scenario 02	ETICS	+ Grafipol	-	-	-	-
Renovation Scenario 03	Ventilated	+ Grafipol	Energy 82 mm - PVC	-	+ Grafipol	Photovoltaic

1. In **Renovation scenario 1**, the following interventions have been analyzed:
    - An insulation layer made up of expanded polystyrene EPS Grafipol TR 31 (thickness 0.08 m and thermal conductivity 0.031 W/mK) was added to the external side of the external walls.
    - An insulation layer made up of expanded polystyrene EPS Grafipol TR 32 (thickness 0.08 m and thermal conductivity 0.032 W/mk) was added to the internal side of the roof.
    - All the existing windows were replaced with new PVC windows (Energy 82 mm - PVC) with a glazing heat transfer coefficient Uw of 0.79 W/m2K.
    - An insulation layer made up of expanded polystyrene EPS Grafipol TR 32 (thickness 0.08 m and thermal conductivity 0.032 W/mk) was added to the internal side of each floor slab.
2. In **Renovation scenario 2** , includes:
    - Scenario 2 is like scenario 1 with the internal insulation of the external walls and roof. There are two differences: the windows and the internal floor slabs are kept as the pre-existing ones.
3. In **Renovation scenario 3** ,

- An insulation layer made up of expanded polystyrene EPS Grafipol TR 32 (thickness 0.08 m and thermal conductivity 0.032 W/mk) was added to the internal side of the roof (Same as scenarios 1 and 2).
- All the existing windows were replaced with new PVC windows (Energy 82 mm - PVC) with a glazing heat transfer coefficient Uw of 0.79 W/m2K. (Same as scenario 1).
- An insulation layer made up of expanded polystyrene EPS Grafipol TR 32 (thickness 0.08 m and thermal conductivity 0.032 W/mK) was added to the internal side of each floor slab. (Same as scenario 1)
- An insulation layer made up of Rockwool (thickness 0.08 m and thermal conductivity 0.034 W/mK) and an air gap were added on the external side of the external walls and making it a ventilated wall.
- Photovoltaic Solar panels (450wp SUNERGY, 2108×1048×35) were added with a total power installed of 18kW. They have the potential of producing 19045.0 kWh/year.

Decision tree

The objectives and criteria were developed while taking into account various renovation-related factors. Common goals including lowering primary energy use, energy demand, and cost were also addressed. The final decision tree for this case is shown in Figure 20.

Environmental	To reduce Primary energy	Renewable energy
		Operational primary energy
	To reduce Energy demand	Total energy demand
		Energy savings
Economic	To reduce Cost	Investment cost

Figure 20 Decision tree for demonstration project #11 Mixed used building in Berlin-Tempelhof

Alternatives' performance

To study the different renovation scenarios, energy simulations were performed on CYPETHERM EPlus with the help of the BIM to BEM procedure and modifying the BEM baseline as a reference. Within the baseline Model, the interventions have been modelled by modifying the pertinent parameters. The cost was discovered via a 5D analysis. The figures were calculated using data from the German market. The results are summarized in Table 43.

Table 43: Renovation scenarios for demonstration project #11 Mixed used building in Berlin-Tempelhof, general results

Alternative	Renewable energy [kWh/m^2/y]	Operational primary energy [kWh/m^2]	Total energy demand [kWh/m^2/y]	Energy savings [kWh/m^2]	Investment cost [€/m2]
Baseline	0	162.98	100	0	---

Renovation scenario 1	0	95.11	43.2	67.8	375
Renovation scenario 2	0	107.53	53.6	55.4	**321**
Renovation scenario 3	**9.1**	**87.32**	**41**	**79.5**	402

Criteria weights settings and ranking results analysis

As shown in Table 44, different weighting scenarios were examined to determine the effect of giving certain factors more weight during the decision-making process. At the start of the study, each criterion was given the same percentage weight (20%). The primary energy criteria (renewable energies and operational primary energy) receive 30% of the total weight in the weighting of scenario 1. Criteria related to costs (investment costs) received 20%, while criteria related to energy requirements (total energy requirements and energy savings) received 10%, which corresponds to 20%. The energy requirement criteria in the weighted scenario 2 add up to 60%. Finally, the investment costs ranked highest when considering scenario 3. In all situations, renovation scenario 3 is the best option.

Table 44: Weighting scenarios for #11 Mixed used building in Berlin-Tempelhof

Criteria	Baseline	Weighting scenario 1	Weighting scenario 2	Weighting scenario 3
Renewable energy	20%	30%	10%	10%
Operational primary energy	20%	30%	10%	10%
Total energy demand	20%	10%	30%	10%
Energy savings	20%	10%	30%	10%
Investment cost	20%	20%	20%	60%
Best renovation scenario	Renovation scenario 3	Renovation scenario 3	Renovation scenario 3	Renovation scenario 3

Final renovation solution

The most suitable solution for this case is renovation scenario 3, it is the most complete renovation strategy that will bring benefits in terms of energy savings but will require a higher effort from the housing company and the inhabitants to cover the investment cost. Figure 21 shows a model of a building with the final renovation solution.

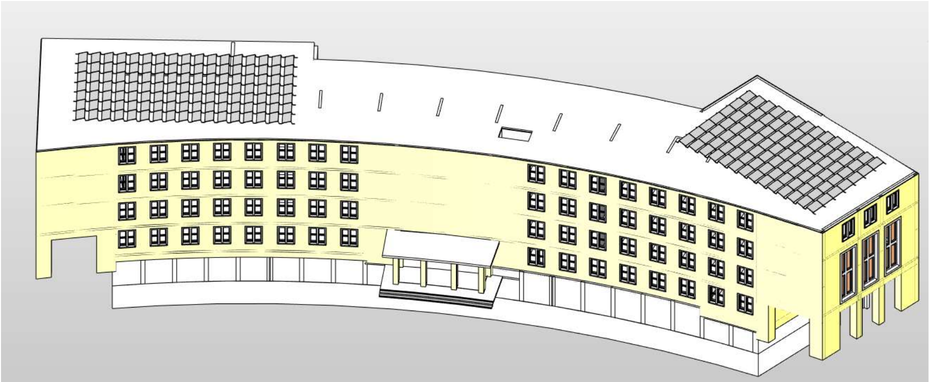


Figure 21: Building Information Model with final renovation solution for demonstration project #11 Mixed used building in Berlin-Tempelhof

2.12 Demonstration project #12 Apartment blocks in Antony (France)

Demonstration site characterization

This demonstration project is a residential building located in the centre of Antony (France) in a densely urbanized context. The building is one of the four buildings of allée de Villemilan et rue des Nations Unies and can be characterized by its rectangular floor plan. The building is a series of 4 adjacent individual building units with unique entrances/staircase and share 3 pairwise common walls. Table 45 shows general information about this demonstration project.

Table 45: General information

General information	
Location	Paris, France
Use category	Residential
Building type	Multi-story building
Construction year	1963
Renovation year	----
Number of floors	4
Number of apartments/units	32 dwellings

Renovation alternatives description

Table 46 summarizes the renovation scenarios considered for the building:

Table 46: Overview of renovation scenarios for #12 Apartment blocks in Antony

Type of intervention		Scenario 1	Scenario 2	Scenario 3	Scenario 4
External walls insulation	Insulation material	Stone wool : 0,18 m	Mineral wool : 0,16 m	Stone wool : 0,18 m	Mineral wool : 0,27 m
	Total thickness of external wall	0,40 m	0,38 m	0,40 m	0,49 m
	U-Value	0,18 W/m²K	0,18 W/m²K	0,17 W/m²K	0,12 W/m²K
Roof insulation	Insulation material	Mineral wool : 0,20 m	Mineral wool : 0,26 m	Mineral wool : 0,17 m	Mineral wool : 0,26 m
	Total thickness	0,57 m	0,63 m	0,54 m	0,63 m
	U-Value	0,12 W/m²K	0,12 W/m²K	0,14 W/m²K	0,09 W/m²K
Shading system	Exterior blind high reflectivity slats	135°	30°	90°	135°
HVAC	Heat distribution	Hot water underfloor heating	Hot water underfloor heating	Hot water underfloor heating	Hot water underfloor heating
	Heat supply	Condensation boiler (gas)	Condensation boiler (gas)	Condensation boiler (gas)	Condensation boiler (gas)
Electricity generation	Solar Thermal size	143.01 m²	143.01 m²	143.01 m²	143.01 m²
	PV monocrystalline, eff.	0.15	-	0.19	0.21
	Roof area covered by PV	143.01 m² (18 kWp)	-	357.53 m² (51 kWp)	357.53 m² (60 kWp)

In all the Renovation scenarios all windows were replaced with Triple glazing, Low-E PVC frame windows. The frames are made of polyvinylchloride (PVC). The German Energy Saving Ordinance (EnEV) was used to define the recommended heat transfer coefficient of the windows. In all the scenarios 143.01 m² of Solar Thermals were included.

8. **Renovation scenario 1:**
   - This renovation scenario being a cost optimal need an investment cost of only 1.36 M €. Even though it is a cost optimal design it still has 143.01 m² of low efficiency (18 kWp) PV cells. However, the inclusion of the PV cells does not show up in the 18.89 kWh/m² total energy demand.
9. **Renovation scenario 2:**
   - This renovation scenario is the most cost-efficient scenario and needs an investment cost of merely 1.27 M €. This scenario requires the least quantity of wall insulation and require no PV to be fitted. However, the total energy demand sits at an enormous 25.65 kWh/m².
10. **Renovation scenario 3:**

- This renovation scenario is the most energy efficient scenario with the total energy demand of 2.64 kWh/m^2 for an investment of 1.58 M €. In fact the enormous 357.53 m^2 of 60 kWp PV is able to accommodate the total energy demand and would still produce surplus energy.

11. **Renovation scenario 4**:
    - This renovation scenario being a energy optimal need a slightly larger investment cost of 1.47 M €. But the total energy demand 6.74 kWh/m^2, is also slightly higher.

Decision tree

Different aspects of the renovation were considered while defining the objectives and criteria. Common objectives such as reducing the energy demand and reducing the cost were included. Since the building complex is managed by a housing company and the dwelling units are rented, considering social aspects of the inhabitants was important, the rent increment was included to consider the impact on their economic aspects. Figure 22 depicts the final decision tree for this case.

Environmental	To reduce Primary energy	Operational primary energy
	To reduce Energy demand	Total energy demand
		Energy savings
	To reduce Environmental impacts	Global warming potential
		Total water consumption
Social	To improve Indoor conditions	Visual comfort
		Indoor air quality
		Thermal comfort
Economic	To reduce Cost	Investment cost
		LCC Cost

Figure 22 Decision tree for demonstration project #12 Apartment blocks in Antony (France)

Alternatives' performance

To study the different renovation scenarios, BEM models were used to perform energy simulations using Metabuild Tool. Each idf. file presented each of the scenarios. The rent increment and investment cost were calculated using data from the German market. The results are presented in Table 47.

Table 47: Renovation scenarios for Antony, general results

Alternative	Primary energy [kWh/(m² GFA .a)]	Total energy demand [kWh/m².a]	Energy Savings [kWh/m².a]	Global warming potential [m² GFA · a]	Total water consumption [m² GFA · a]	Visual comfort (Score out of 10)	Air quality (Score out of 10)	Thermal comfort (Score out of 10)	Investment costs [Mio. €]	Life cycle costs [€]
1	19.48	18.89	39.77	4.62	1131.24	0.4	0.4	0.6	1.36	4.27
2	31.56	25.65	33.01	7.38	1131.24	0.2	0.4	0.4	1.27	5.1

3	-10.28	2.64	56.02	-2.58	1131.24	0.4	0.4	0.6	1.58	4.11
4	-4.13	6.74	51.92	-1.48	1131.24	0.3	0.4	0.7	1.47	4.16

Criteria weights settings and ranking results analysis

Different weighting scenarios were analysed to study the situations where different aspects of the renovation are given more importance during the decision process In the base line all the criteria received the same level of importance (25%). In weighting scenario 1, the environmental aspect (Energy savings) received 60% of level of importance meanwhile the social aspect (Rent increment) received 20%, and the two economic criteria received 10% each to sum up 20% for that category. In weighting scenario 2, the social aspect is the most important (60%). Finally, in weighting scenario 3, Investment cost and payback period received 30% each to sum up 60% for the economic aspects. The renovation scenario 3 is the most suitable solution when all the aspects are equally important and when the environmental criteria is prioritized. On the other hand, since Renovation scenario 1 requires the lowest investment cots and rent increment, it is the most suitable solution when the rent increments for the inhabitants and the economic aspects are the most important aspects in the decision.

Table 48: Weighting scenarios for Antony

Criteria	Base line	Weighting scenario 1	Weighting scenario 2	Weighting scenario 3
Total energy demand	25%	60%	20%	20%
Global warming potential	25%	20%	60%	20%
Investment cost	25%	10%	10%	30%
LCC	25%	10%	10%	30%
Best renovation scenario	Renovation scenario 3	Renovation scenario 4	Renovation scenario 1	Renovation scenario 2

Final renovation solution

Considering that all the criteria of the renovation are equally important, the most suitable solution for this case is renovation that is proposed in scenario 3, that is the most complete renovation strategy that will bring benefits in terms of energy savings but will require a higher effort from the housing company and the inhabitants to cover the investment cost. This is intuitive given the increment of energy efficiency is the reason of the renovation. Figure 23 presents a screenshot of the model including the final renovation solution for the building.

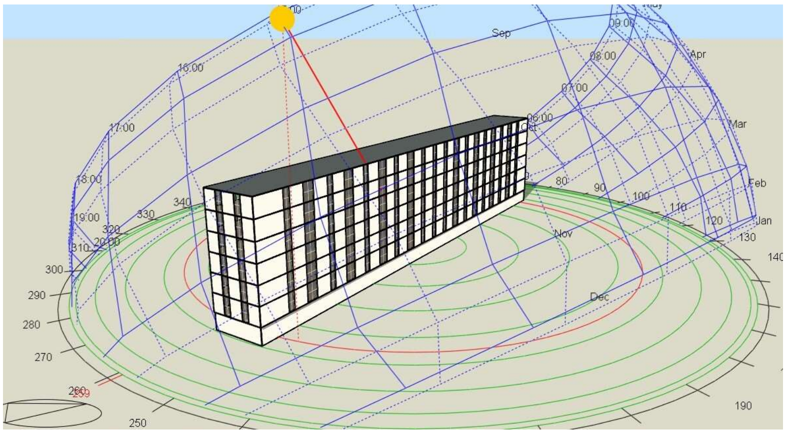
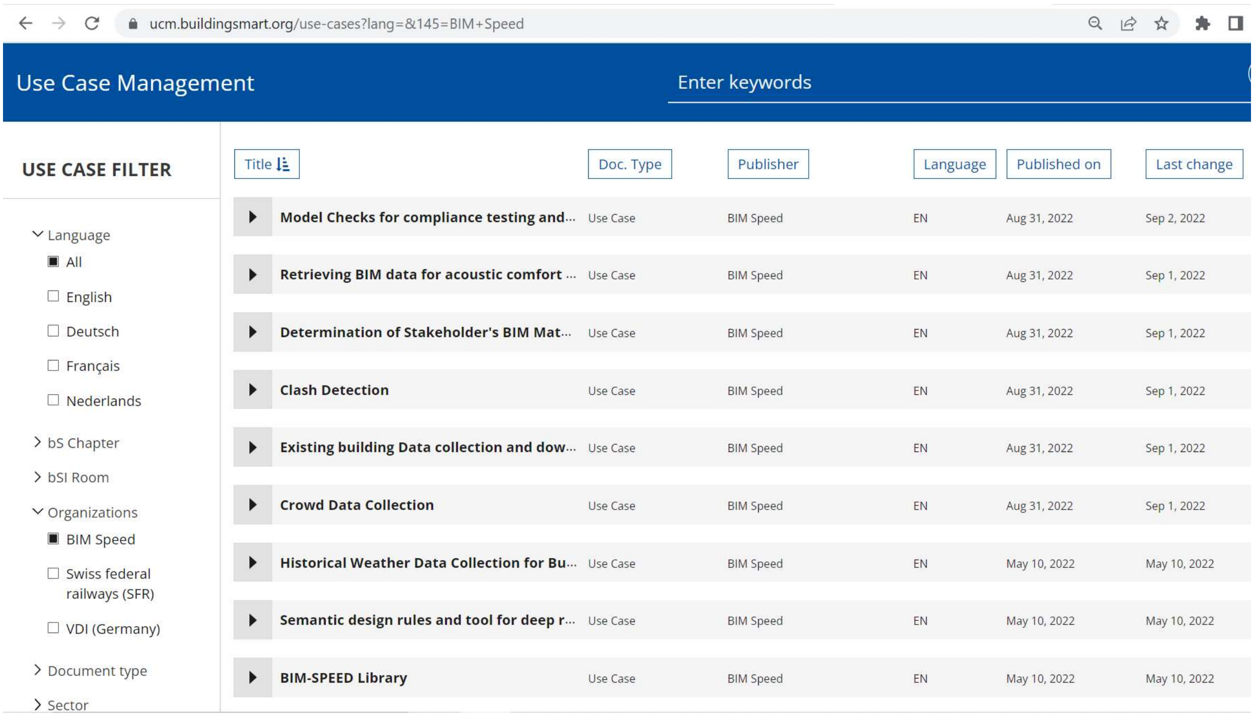


Figure 23 BIM model with final renovation solution for #12 Apartment blocks in Antony (France)

3. BIM-SPEED Use Cases

3.1 Method and approach

The BIMSPEED Project has developed several methodologies and tools, with BIM at it's center, to aid energy efficient renovation. As a standardization effort, use cases have been identified to aid users with the implementation of these developed best practices. These use cases are defined based on IDM standards which aim at the definition of processes, specifications of exchanges, and actors involved during implementation, and are openly accessible on the BuildingSMART Use Case Management (UCM) system (https://ucm.buildingsmart.org/use-cases?lang=&145=BIM+Speed), see Figure 24. Upon accessing the UCM website and filtering existing use cases, by selecting BIM-SPEED as Organization, the list of published BIMSPEED use cases is made available to the users. Each use case can be openly accessed for the general sections of the use case, followed by logging in to access the entire use-case.


ucm.buildingsmart.org/use-cases?lang=&145=BIM+Speed

Use Case Management

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- Language
  - All
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- bS Chapter
- bSI Room
- Organizations
  - BIM Speed
  - Swiss federal railways (SFR)
  - VDI (Germany)
- Document type
- Sector

Title	Doc. Type	Publisher	Language	Published on	Last change
Model Checks for compliance testing and...	Use Case	BIM Speed	EN	Aug 31, 2022	Sep 2, 2022
Retrieving BIM data for acoustic comfort ...	Use Case	BIM Speed	EN	Aug 31, 2022	Sep 1, 2022
Determination of Stakeholder's BIM Mat...	Use Case	BIM Speed	EN	Aug 31, 2022	Sep 1, 2022
Clash Detection	Use Case	BIM Speed	EN	Aug 31, 2022	Sep 1, 2022
Existing building Data collection and dow...	Use Case	BIM Speed	EN	Aug 31, 2022	Sep 1, 2022
Crowd Data Collection	Use Case	BIM Speed	EN	Aug 31, 2022	Sep 1, 2022
Historical Weather Data Collection for Bu...	Use Case	BIM Speed	EN	May 10, 2022	May 10, 2022
Semantic design rules and tool for deep r...	Use Case	BIM Speed	EN	May 10, 2022	May 10, 2022
BIM-SPEED Library	Use Case	BIM Speed	EN	May 10, 2022	May 10, 2022

Figure 24 Overview of BIM-SPEED use cases uploaded to Building Smart website

The BIM-SPEED use cases are formulated based on the framework developed by BuildingSMART International with ISO 29481-1 as the foundation for a standardized method for mapping of use-cases, processes, and exchange requirements. Although Information Delivery Manual (IDM) standards are followed for use case definition, the BIMSPEED use cases are tailored to include objectives of the use case as well as BIMSPEED Project objectives being validated upon demonstrating the use case on a project site. Accordingly, a BIMSPEED Use case contains the following sections:

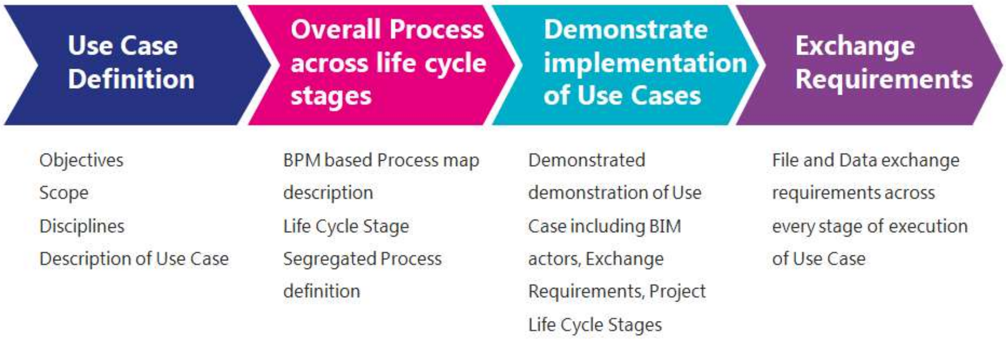


Figure 25 Section of the report documenting Use cases

Section 1: Use case definition

The first section gives an overview of the use-case description followed by the scope of the use case, benefits, limitations, comparison to conventional methods of the implementation of the use-case, and objective-based BIM-SPEED solution for the same.

Section 2: Overall Process across life cycle stages

The process of implementation of the use case is described using a process map based on Business Process Modelling Notation highlighting life cycle stage segregated processes, actors involved in the process, and exchange requirements for the entire process. The process is also described for life cycle stages based on ISO22263.

Section 3: Demonstration of implementation of Use cases

The process described in the previous section is demonstrated through a project site to provide an example of the implementation of the use case as well as validate the objectives of the use case based on results analysis from the implementation of the use case on the demonstration site.

Section 4: Exchange requirements

File format exchange requirements across life cycle stages and processes are highlighted and described in the last section.

3.2 Overview of BIMSPEED use cases

Figure 26 gives an overview of all BIMSPEED use cases segregated across life cycle stages of a renovation project. Life cycle segregated use cases allows the definition of use cases and processes for a particular stage of the renovation project. Certain use cases are implemented on several life cycle stages of a project which is highlighted in the image below by repeated use cases.

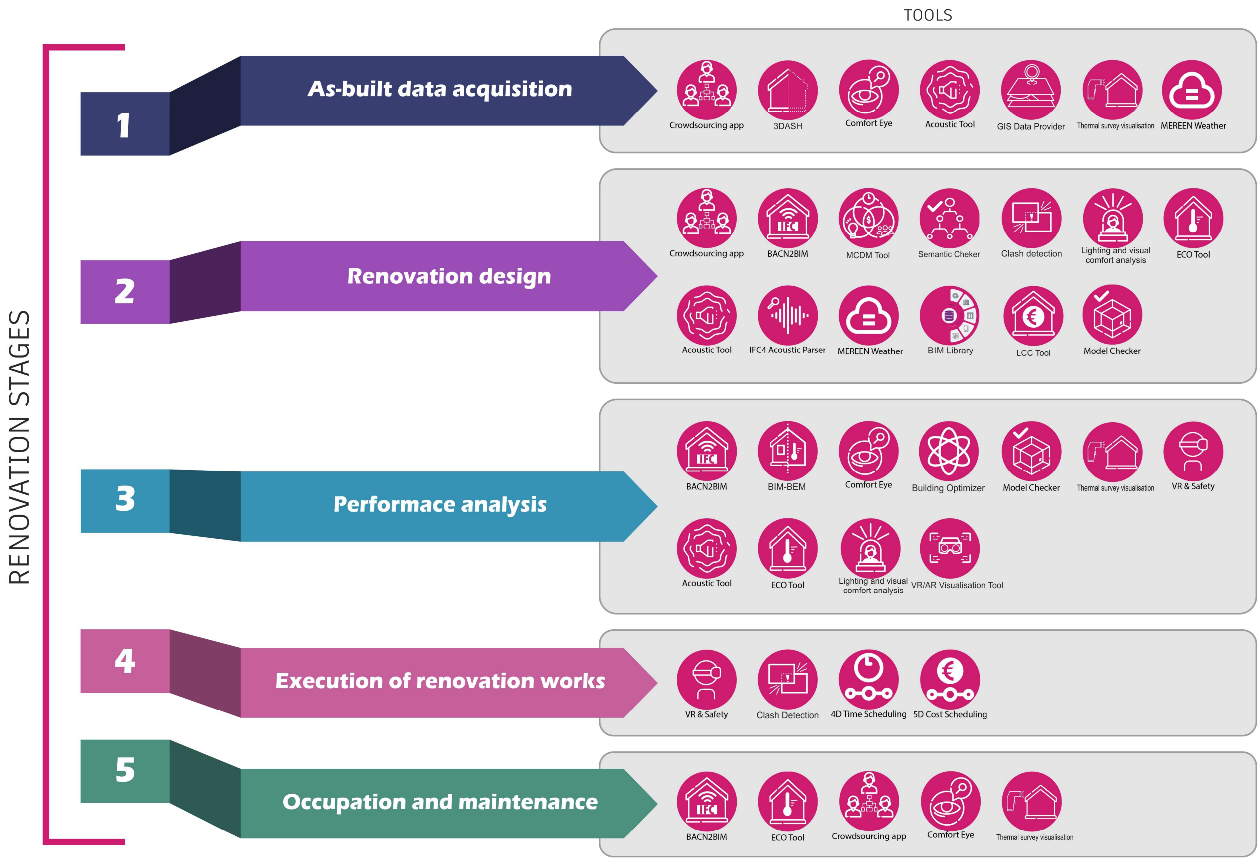


Figure 26 Overview of all BIMSPEED use cases segregated across life cycle stages of a renovation project

3.2.1 Implementation of use cases on demonstration sites

Figure 27 presents the list of developed BIM-SPEED Use Cases and their implementation in various demonstration projects. Each of the Use cases was applied on at least one demonstration project. Chapters 3.2.2 – 3.2.25 provide a short description of each of the BIM-SPEED use case, their status (if it is published or not yet) and on which demonstration projects the use case was implemented.

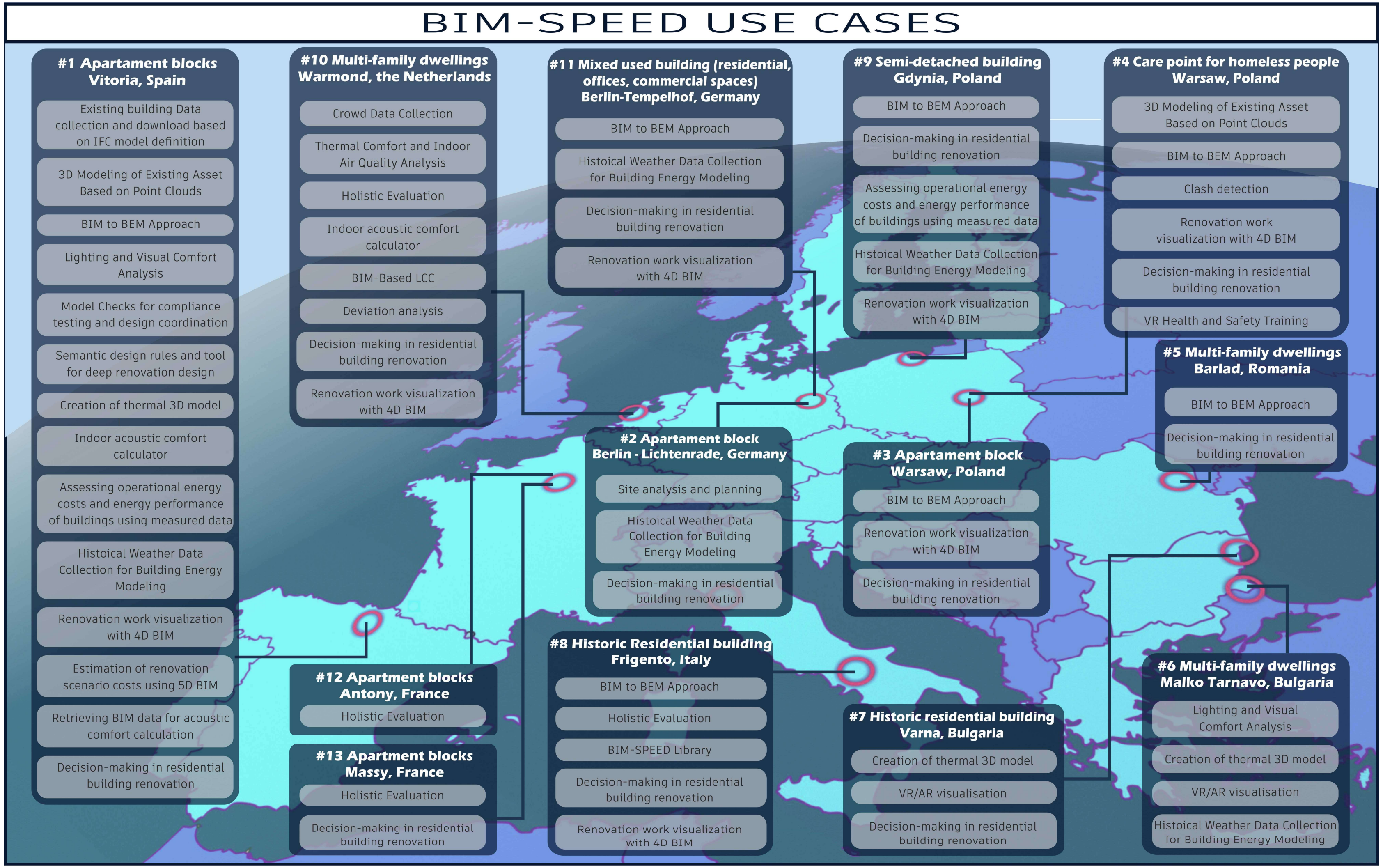


Figure 27 List of implemented BIM-SPEED use cases on demonstration projects.

3.2.2 Use case #1: 3D modelling of existing asset-based Point Clouds

One of the main problems faced by designers and architects when carrying out renovation projects is the lack of information available on the current state of the buildings. Development of actual building documentation is time and cost-consuming for the building owner. While new methods of geometry data collection, such as the use of laser scanning to obtain the 3D point cloud of the building are being applied, the conversion of the point cloud into BIM models is time-consuming and needs to be made manually. The BIM-SPEED solution for the improvement of Scan-to-BIM process is based on the application of 3DASH tool (developed by project partner Cartif). This tool is a specified tailored plug-in Revit software in that allows the automatic generation of walls in BIM using point clouds as input. This facilitates the creation of the As-Built BIM models of the buildings.

The 3DASH tool has been integrated as a service on the BIM-SPEED platform, to allow the user to download the plug-in through a Graphical User Interface. To launch the service, the user has to select in the BIM-SPEED platform a point cloud available in one of the formats required by the tool (.pts, .ply or .ptx). The next step is the automatic generation of the walls in Revit software. After this, a manual process needs to be applied by the user, to check that the unions of the walls are well defined, and the properties of the walls are correct. Comparison of common practice with BIM-SPEED approach for Use case: 3D modelling of existing asset-based Point Clouds is shown in Figure 28.

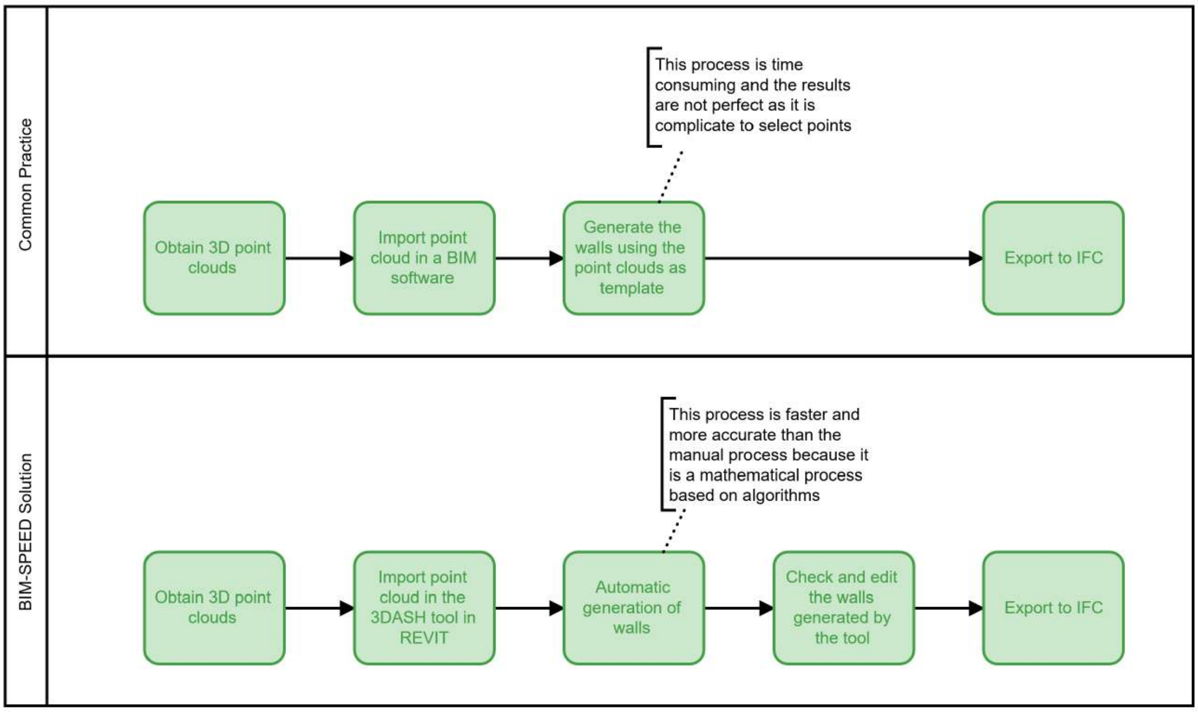


Figure 28 Comparison of common practice with BIM-SPEED approach for Use case: 3D modelling of existing asset based Point Clouds

The benefits of using 3DASH tool are:

- Time reduction: Both for the generation of the As-Built models and for comparison with previous existing models of the building, or for generating these models if no previous documentation is available. Use of the 3DASH tool for a Scan-to-BIM process can significantly speed up the process of creating a structural model. This can be very useful when it is needed quick information is needed on for quantity take offs and there is no time for detailed modelling.

- Accuracy: the tool gives a high accuracy as it is a mathematical process based on algorithms for the detection and generation of walls from point clouds as input, compared to the traditional process where the user would have to generate the walls manually using the point clouds as a template, thus no obtaining the same accuracy in the manual selection of the points.

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2388/en .

The use case was implemented in following demonstration projects: #1 Apartment blocks in Vitoria, Spain and #4 Care point for homeless people in Warsaw, Poland.

3.2.3 Use case #2: Existing building data collection and download based on IFC model definition

Data collection from sensors installed in buildings during the operation and maintenance phase (O&M) is most often encountered to be a difficult process due to the reduced possibility to connect to different monitoring systems and to download data in various formats. In addition to this, linking the data within the IFC file is also rendered difficult in several cases. The BACN2BIM tool developed by CARTIF aids to address these problems encountered by providing users the possibility to set up monitoring systems within the BIM-SPEED platform followed by allowing the download of data from these devices followed by the automatic update of the IFC file with information regarding the monitoring systems, which enables visualization in BIM based tools. The process of using the tool is detailed within the use case available at https://ucm.buildingsmart.org/use-case-details/2416/en which details using a process map, the functionalities of creating a new monitoring project as well as downloading data of monitoring devices from existing projects. Essentially, the BACN2BIM tool reads the IFC and CSV files of the existing projects and configures the ThingsBoard database to support the data from the monitoring devices within the project, and a specific driver is set up and run which automatically updates the data from devices, upon reformatting, these are added to the ThingsBoard database. In the case of downloading existing data, users need to select the desired demo site along with starting and ending dates of the collection of data and the format of downloaded data. The tool then collects the data, reformats it, and returns it to the user in the preferred format. Meanwhile, the BIM-SPEED platform is automatically updated. This entire process is also demonstrated on the Vitoria, Spain demo site and the process and results are available within the use-case.

A qualitative analysis of conventional processes to yield data from monitoring devices was compared to the process identified within the use case of collection of data using the BACN2BIM tool as shown below

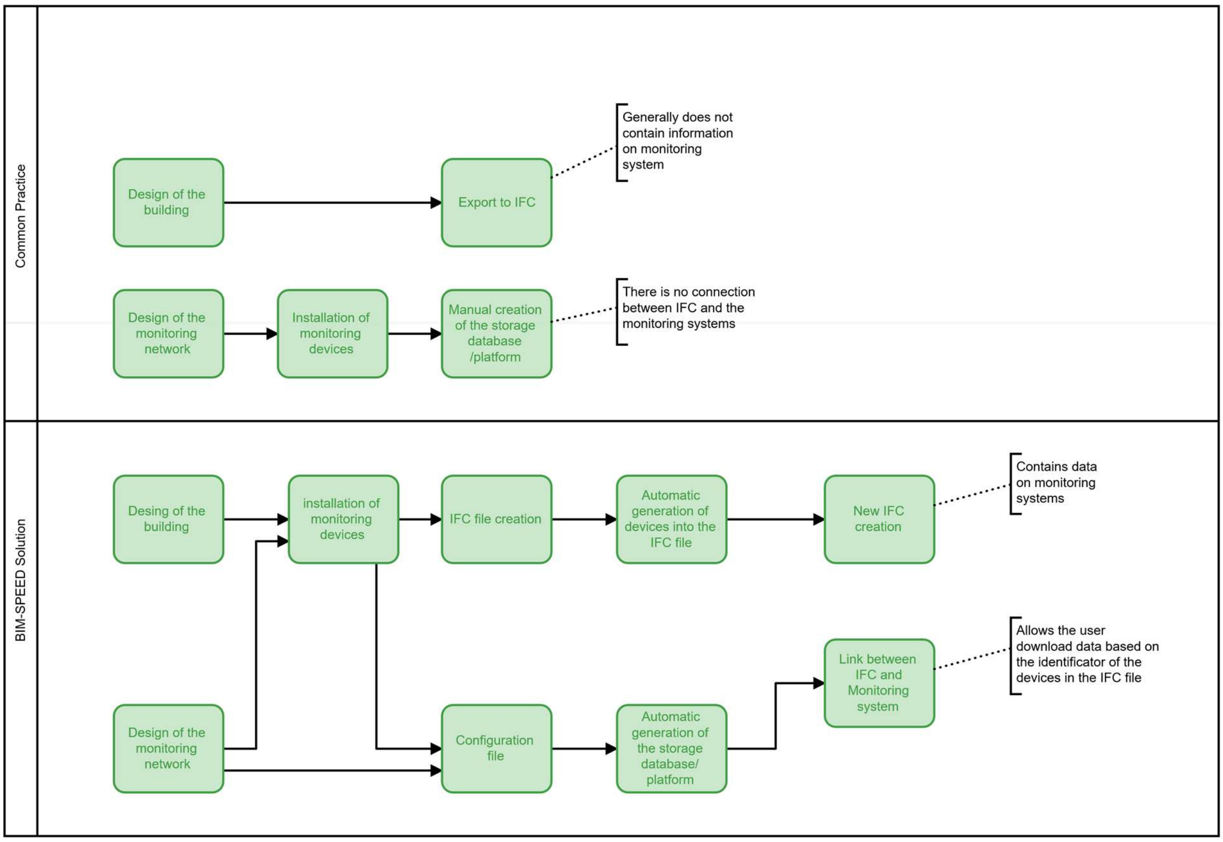


Figure 29 Comparison of common practice with BIM-SPEED approach

The use case demonstrates the following objectives:

- Time reduction: Less time is consumed to download data from different sources
- Updated BIM: IFC models are updated including information from the monitoring systems installed in buildings

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2388/en

The use case was implemented in demonstration project: #1 Apartment blocks in Vitoria, Spain.

3.2.4 Use case #3: Historical Weather Data Collection for Building Energy Modelling

In renovation projects, in addition to an as-built model for the development of design alternatives, the as-is situation of weather that the building has been subjected to is also necessary, particularly when calibrating the building energy models to real weather data. The Mereen weather service developed within the BIM-SPEED project enables retrieval of these real weather datasets. The Mereen service is integrated into the BIM-SPEED platform and can be accessed from there. Users are firstly required to select the exact location of the building from the IFC file or on a map. Upon selecting the location, the time period and format in which the weather data is required are selected. After exporting, the selected weather file can be reached on the BIM-SPEED platform, which can be downloaded. The output of this process consists of a combination of EPW files of the selected period followed by json files of the weather station and weather parameters. This forms the input for the calibration of the energy model.

The benefits of using Mereen weather service are:

- Accuracy: The accuracy of calibration of building energy models are significantly increased upon retrieving accurate datasets of historic real time data
- Time reduction: The time required for collecting such data is reduced by introducing a plug-and-play solution instead of using several other online sources for retrieval of these datasets. A qualitative analysis of time reduction of conventional and BIM-SPEED solutions for historic weather data collection is shown below:

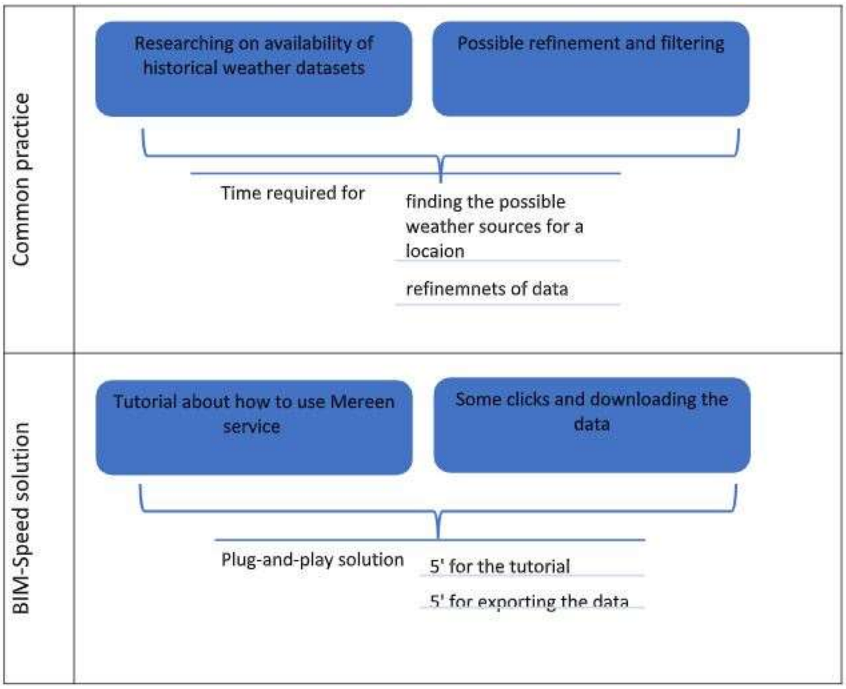


Figure 31: Common practice versus BIM-Speed approach for historical weather data collection

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2687/en

The use case was implemented in following demonstration projects: #1 Apartment blocks in Vitoria, Spain; #2 Apartment blocks in Berlin-Lichtengrade, Germany; #6 Multi-family dwellings Malko Tarnovo, Bulgaria; #9 Semi-detached building Gdynia, Poland; #11 Mixed used building Berlin-Tempelhof, Germany.

3.2.5 Use case #4: Site analysis and planning

In renovation projects, it is essential to collect information about the surrounding of the construction site to plan in advance how to access the site and how to proceed to the next stages of the project. The site analysis and planning use case defines the limitations and opportunities in the construction site which helps for an appropriate development outcome if known prior to the designing phase of the project. Site analysis and planning in building renovation refers to all the analysis and decisions made before the building data collection phase. This analysis can be performed via collecting surrounding geospatial and environmental data in a specific radius around the building under renovation. These geospatial datasets can be visualized in a GIS software, and after creating relevant maps, the construction site can be evaluated by the project team. The mentioned geospatial data can be retrieved from open access Web Feature Services (WFS) and downloaded in Shapefile format which represents vector data in 2D dimension. They also can include 3D surrounding buildings in CityGML format if available. This use case provides information for further use cases in the next stages of building renovation as well. The comparison of common practice and BIM-SPEED solutions for site planning and analysis is shown in Figure 30.

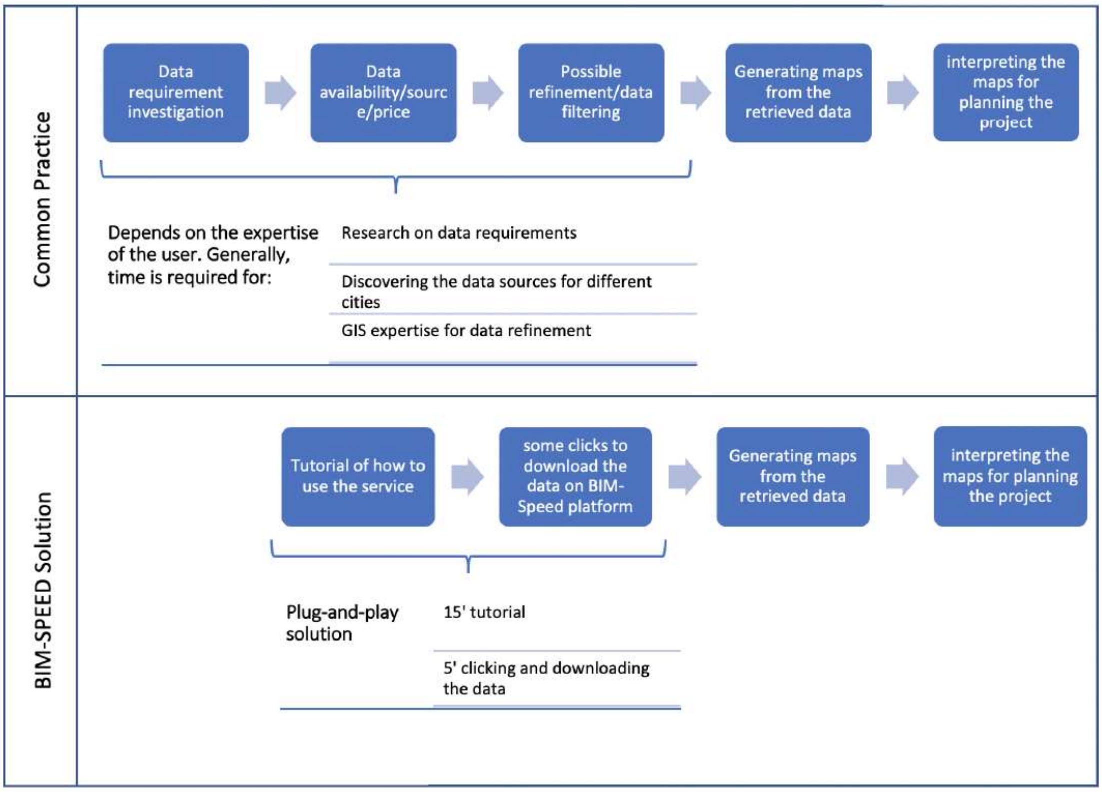


Figure 30 Comparison of Common practice with BIM-SPEED approach for Use case: Site analysis and planning

The benefits of BIM-SPEED solutions for site planning and analysis are:

- The time for this procedure has been reduced by using the 'GIS data provider service', because the user can extract relevant datasets only by selecting the demonstration site and downloading the relevant datasets in the BIM-SPEED platform.
- The added value of using BIM for renovation is the retrieving of exact location of the building directly from the IFC file stored in the BIM_SPEED platform.
- Within the development procedure of the tool, a set of standardized protocols for obtaining GIS environmental data namely Web Feature Service (WFS) has been used

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2333/en

The use case was implemented in demonstration project: #2 Apartment blocks in Berlin-Lichtengrade, Germany.

3.2.6 Use case #5: Retrieving BIM data for acoustic comfort calculation

An IFC file of a building model consists of building geometry and data. In order to retrieve the data required for acoustic comfort calculation, a ETL (Extract, Transform, Load) has been developed to retrieve specific data required for the acoustic assessment of the building. This tool has been embedded onto the BIM-SPEED Platform and can be used to retrieve acoustic comfort calculation related data which is then used for the Acoustic Comfort tool developed by UNIVPM. The process includes generating the IFC model of the building with ETL pre-requirements. Upon launching the Ifc4Acoustic Parser ETL from the BIM-SPEED platform, the ETL extracts the relevant information, which is then parsed into the JSON file that is the input to the acoustic tool. The Acoustic Comfort tool calculates the acoustic assessment and the ETL stores the results on the BIMSPEED platform.

The validation of the BIMSPEED Objective of 30% reduction in time followed by a qualitative comparison of conventional and the BIMSPEED solution for the same use case.

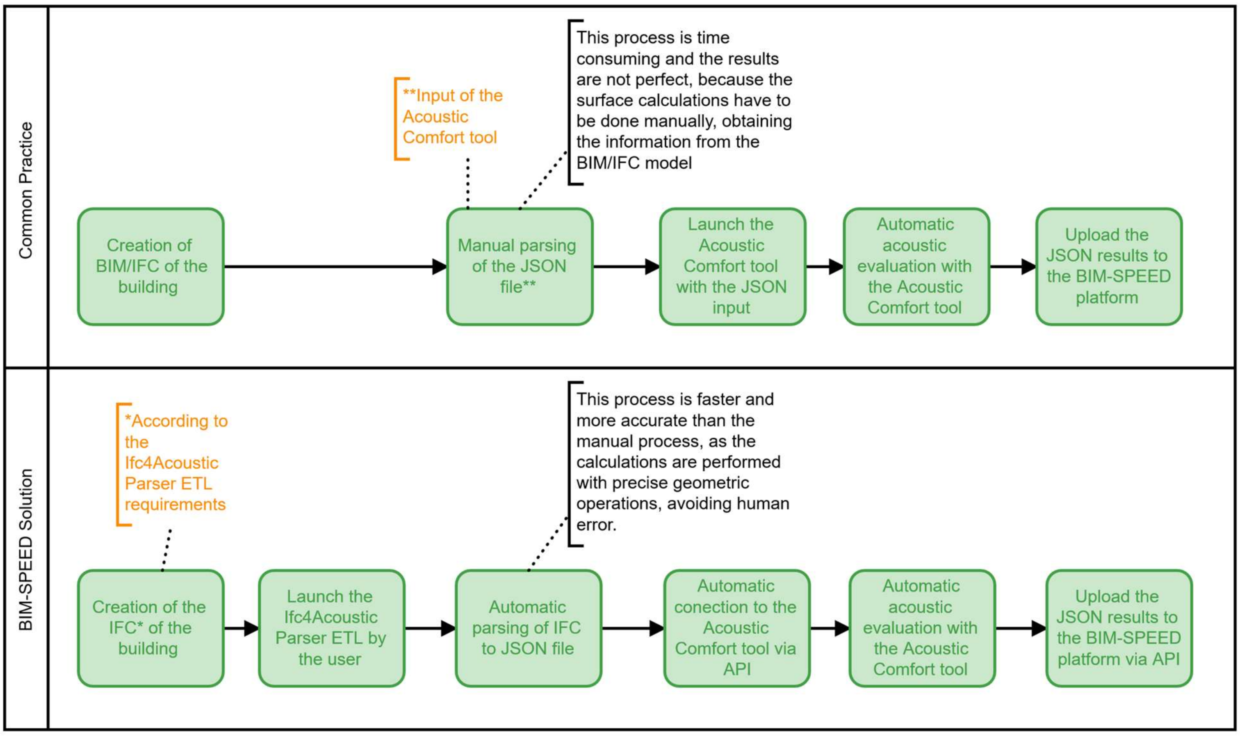


Figure 31 Comparison of Common practice with BIM-SPEED approach for Use case: Retrieving BIM data for acoustic comfort calculation

The BIM-SPEED solution demonstrated through demonstration project #1 Apartment blocks in Vitoria (Spain) assessed the developed solution to enable reduced time and increased accuracy of results by reducing user iteration for obtaining necessary data, and more precise geometric operations for acoustic comfort performance calculations.

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2818/en The use case was implemented in demonstration project: #1 Apartment blocks in Vitoria, Spain.

3.2.7 Use case #6: Crowd data collection

Inhabitant's input of comfort is a pre-requisite for developing renovation design alternatives. This is often encountered as a challenge, given the amount of work required to collect the information in addition to privacy related concerns surrounding occupant related information retrieval. In order to collect occupant related information, a user-friendly application has been developed as a part of the BIM-SPEED project, which facilitates and speeds up the process of data collection from inhabitants while involving them in decision making processes. Prior to the collection of user related data, the relevant needs of user relevant information are identified such as analysis, simulations, calibrations etc., and based on this the relevant questions are formulated, which are added to the app. The app proves beneficial not only in the design phase, to assess the as-is situation of comfort, but also is implemented as a part of the operation and maintenance phase to collect information from occupants for further evaluation and assessment of defects in building systems, perceived comfort while also recording wishes, needs and preferred renovation scenarios from occupants. The comparison between conventional practices and the solution developed by BIM-Speed is shown in the figure below.

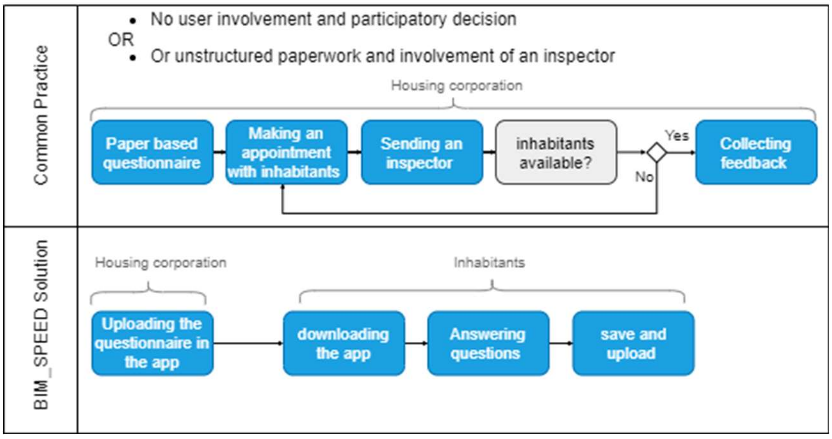


Figure 32 Comparison of Common practice with BIM-SPEED approach for Use case: Crowd Data Collection

The benefits of the "Inhabitant App" are as follows:

- Digitalization of the process of occupant data collection and analysis
- Reduce in cost and time involved in outsourcing the inspection activities of inhabitants
- Involving inhabitants in the decision-making process by collecting their needs and preferences
- Streamline and standardize the process by uploading the results to the BIM-SPEED platform.

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2379/en

Implementation of this use case was foreseen for #10 Multi-family dwellings in Warmond, the Netherlands. . For the tool participation of inhabitants is a key aspect. In consultation with the housing corporation that manages the building, the actual implementation is postponed for a time when the mobile app of the tool is ready for iPhone as there was no guarantee that all the participants will have Ipad. This is in line with the exploitation plan of DEMO partner and the interest of the housing corporation in this product and their willingness to test and eventually use it as commercial product.

3.2.8 Use case #7: Geometrical verification of as-built BIM models by deviation analysis

3D BIM models of existing buildings are often derived from 2D plans and laser scans. The 3D BIM models thus developed, need to be checked for geometrical correctness in order to use the model for further renovation related use cases. The geometrical verification use case ensures correctness of the 3D BIM model with the as-is situation of the existing building. The process of deviation analysis includes performing laser scans of the existing buildings, followed by importing the purged and registered point cloud into the software to perform deviation analysis, while importing the mesh of the existing 3D BIM model into the software. Upon manual alignment of the mesh and point cloud and assigning tolerance limits to carry out the analysis, the deviation of the as-is situation and the 3D BIM model is analyzed and necessary action is undertaken to optimize the 3D BIM model. The implementation of the use case is to ensure reliability of the as-built geometry in the 3D BIM model, which also saves time as further use cases are executed on a reliable as-built 3D BIM model. The benefits realized from the implementation of the use-case are:

- Carrying out design based on verified as-built model
- Spotting errors which might have occurred during the construction phase and incorporation of the reliable as-is situation of the building
- Time reduction in defining a well-defined as-is model for further implementation of use cases

This use case is under preparation and will be published soon. The use case was implemented in demonstration project:
#10 Multi-family dwellings in Warmond, the Netherlands.

3.2.9 Use case #8: Thermal Comfort and Indoor Air Quality Analysis

In order to assess thermal, indoor air quality, a dashboard for KPI review has been developed in order to assess IEQ performance based on common standards, to compare building performance before and after renovation, as well as to support the design team, stakeholders and inhabitants to select the most optimal renovation solution. The process involved includes installation of the 'Comfort Eye' sensors in the building before renovation, while also extracting data from BIM about geometry. IEQ is assessed before renovation, development of the renovation scenarios, followed by an assessment after renovation, after which IEQ is validated. The Comfort Eye is an innovative IoT BIM based system developed for thermal comfort and indoor air quality assessment. The assessment of indoor air quality allows to plan interventions in order to improve air quality after renovation. The methodology to assess KPI regarding thermal comfort includes deployment of sensitivity analysis in order to identify the parameter that causes discomfort, so that it can be enhanced in the renovation alternatives to improve building performance. The comparison between common practice of IEQ assessment and the BIM-SPEED solution, namely Comfort eye is shown below.

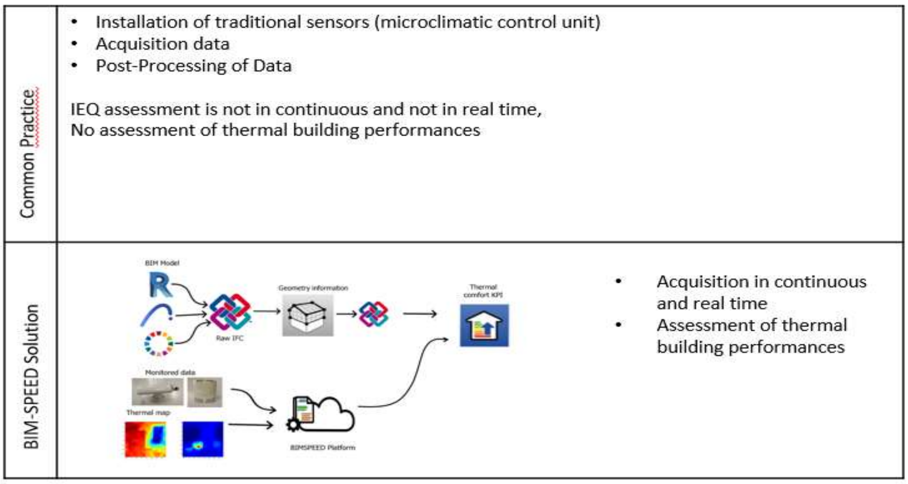


Figure 33 Comparison of Common practice with BIM-SPEED approach for Use case: Thermal Comfort and Indoor Air Quality Analysis

The objectives of the 'Comfort Eye' aligned with the objectives of the BIM-SPEED project allows:

- A framework and methodology for holistic building performance assessment, including comparison of building performance before and after renovation
- A dashboard for KPI review of support the design team to identify most optimal renovation solution.
- Continuous and real time acquisition of data for thermal building performance assessment

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2439/en

The use case was implemented in demonstration project: #10 Multi-family dwellings in Warmond, the Netherlands.

3.2.10 Use case #9: Lighting and Visual Comfort Analysis

For efficient design and utilization of space, the functionality is optimized by assessing it for lighting performance as one among the steps the relevant factors in spatial design. Within the BIM-SPEED project, workflows have been developed to evaluate the visual comfort of an existing building, multifamily midrise dwelling to assess lighting and visual comfort. The workflow assesses as built and renovation daylight performance, aid in development of renovation strategies with industry standard requirements along with cross platform interoperability within the tools used within the workflow. The workflows include two commonly used tools namely Rhino and Revit in order to achieve speed and cost-efficiently pre and post renovation achieved from implementation of both these workflows. By demonstration of these workflows integrated within the BIM-SPEED platform, exhibited optimization of performance by Revit in the IFC import and simulation preparation while the workflow with Rhino exhibited a higher level of customization for parameter definitions.

The benefits of these workflows are:

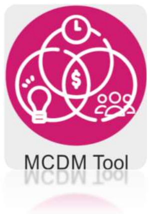
- Facilitating designer's understanding of daylight performance in the process of design
- Seamless workflow for assessing comfort performance and designing simultaneously
- Reduction of time by limiting contact with an external consultant

- Reducing cost by performing comfort analysis in-house
- Industry standard (LEED, WELL, BREEAM) validation for building credits and certification

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2437/en

The use case was implemented in demonstration projects: #1 Apartment blocks in Vitoria, Spain and #6 Multi-family dwellings Malko Tarnovo, Bulgaria.

3.2.11 Use case #10: Decision-making in residential building renovation



This use case addresses the selection of renovation solutions by involving several stakeholders and preferred individual criteria. It enables stakeholders to define general objectives, establish a criteria to evaluate multiple alternatives, capture the preferences of stakeholders and rank the renovation design alternatives based on several criteria. The multi-criteria decision making tool developed relies on pairwise comparison and TOPSIS methods. The process involves the definition of specific objectives that are intended to be obtained by renovation, which is selected from the pre-defined set of economic, environmental, and social objectives defined within the framework. The next step involves capturing the preferences of the stakeholders, for which a weighting method is implemented, to allow stakeholders to represent their preferences in a transparent way, upon which the value of each criterion is quantified. The weights and results from this stage are then aggregated to obtain the final ranking of renovation alternatives based on their performance to the chosen criteria. This will support the decision-makers to analyse the set of alternatives available and make decisions in a transparent and inclusive manner. The image below shows a comparison of conventional procedure of decision making to the framework developed as a part of the BIM-SPEED project.

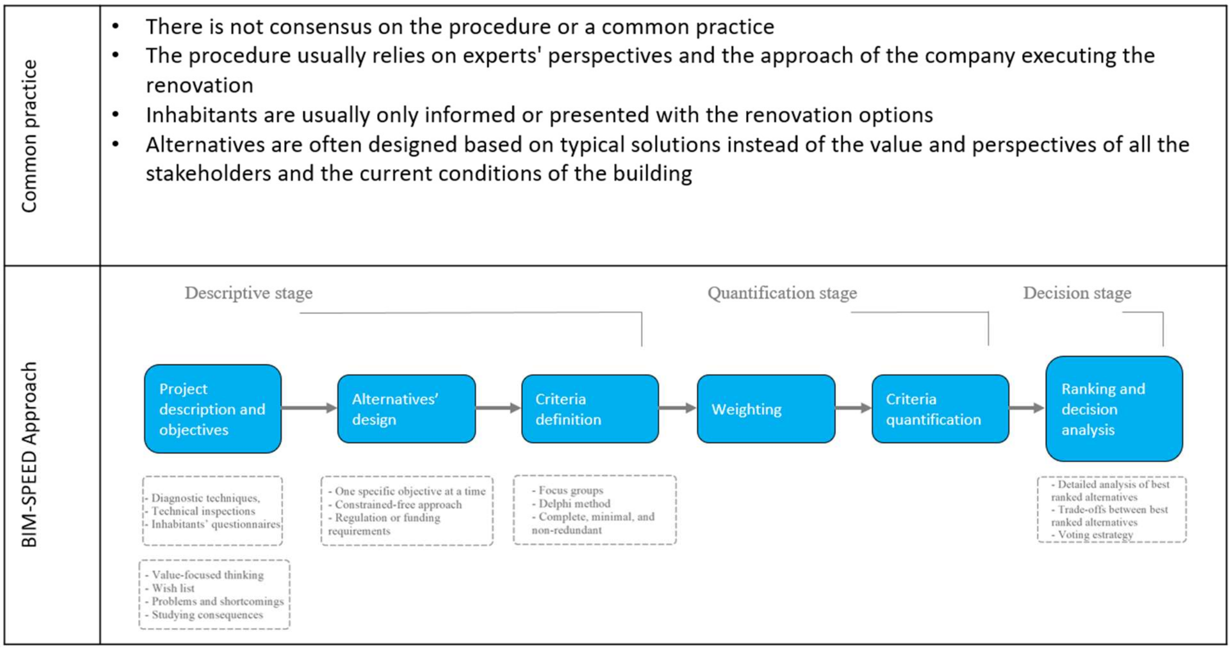


Figure 34 Comparison of Common practice with BIM-SPEED approach for Use case: Decision making for residential building renovation

Objectives of the developed framework include:

- Engagement of different stakeholders in the decision-making process of renovation projects.
- Implementation of a sustainable assessment criteria considering environmental, social and economical aspects
- Ability to capture preferences of different stakeholder groups and their roles in the decision making process
- Gather and present results from several different analysis like energy simulations, cost analysis, comfort studies, for the assessment of design alternatives
- Identify renovation alternatives based on preferences and criteria assigned in a transparent manner.

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2431/en

The use case was implemented in following demonstration projects: #1 Apartment blocks in Vitoria, Spain; #2 Apartment blocks in Berlin-Lichtengrade, Germany; #3 Apartment block Warsaw, Poland; #4 Care point for homeless people in Warsaw; #5 Multi-family dwellings Barlad, Romania; #7 Historical residential building Varna, Bulgaria; #8 Historic Residential building in Frigento, Italy; #9 Semi-detached building Gdynia, Poland; #10 Multi-family dwellings in Warmond, the Netherlands; #11 Mixed used building Berlin-Tempelhof, Germany; #12 Apartment blocks in Antony, France.

3.2.12 Use case #11: Semantic Design rules and tool for deep renovation design

Building regulations, when translated to machine readable form can be used by data experts to automatically check model elements for compliance. This is the motivation for the development of semantic design rules which denote the elements and relationships between these elements. The purpose of the checking process is to warn the users of possible failures and to propose alternative renovation objects that are compliant to building regulations and can be efficiently integrated to their design. Within the scope of the BIM-SPEED project, the design rules focus on typical elements of renovation, including building envelope, HVAC systems, and other building elements like stairs and corridors. The overall objective of design rules developed in line with the BIM-SPEED project is to check if the 3D model complies with semantic design rules and if yes, it can proceed on the BIM-SPEED speedway. In order to achieve specific checking, additional property sets are imported and subjected to the model checker, upon which a report is generated, to check if the objects comply with the design rules.

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2514/en

The use case was implemented in demonstration project: #1 Apartment blocks in Vitoria, Spain.

3.2.13 Use case #12: Estimation of time required for the completion of renovation scenarios using 4D BIM

Conventional scheduling of construction activities in a project are most often lengthy, unorganized, and overwhelming. The workflow was developed and implemented as a part of the BIMSPEED project for the assessment of the time required for the execution of renovation works, to determine the criteria for the selection of the optimum renovation design alternative. The process includes importing the 3D BIM model and activities are identified and automated. The schedule generated upon assigning costs is optimized for activity durations. The objective of the use-case developed from the workflow is to determine the optimum renovation design along with identifying the optimum workflow of tasks to be performed to reduce the time for execution of the renovation work.

This time schedule is also used as input for further cost analysis and improves interoperability while having a single source

3D BIM model for all use cases. This automation of tasks also helps improve the reliability of the schedule obtained. This use case is under preparation and will be published soon. The use case was implemented in demonstration projects: #1 Apartment blocks in Vitoria, Spain; #3 Apartment block Warsaw, Poland; #4 Care point for homeless people in Warsaw, Poland; #8 Historic residential building Frigento, Italy; #9 Semi-detached building Gdynia, Poland; #10 Multi-family dwellings Warmond, the Netherlands#11 Mixed used building Berlin-Tempelhof, Germany.

3.2.14 Use case #13: Cost estimation and budget analysis

Cost estimation of the execution of a particular renovation scenario is one of the criteria which determines the optimal renovation scenario to be selected. For 5D analysis, various costs are required for a renovation scenario such as material cost, labour cost, transportation cost, machinery cost, etc. In addition to having all of the costs, it is also of the utmost importance to have local rates for these costs from the region of the project. For this project, Construction price generator (provided by consortium partner CYPE) was used as the source of cost estimation. The aim is to provide a standardized approach to assess the demo case 5D – Cost scheduling of the different renovation scenarios to:

- Obtain an accurate cost schedule of each scenario and use this as input for MCDA (BIM Speed goal: reduce execution cost), to plan cost workflows
- Reduce costs of building's renovation by obtaining an accurate and reliable cost workflow

This use case is under preparation and will be published soon. The use case was implemented in demonstration project: #1 Apartment blocks in Vitoria, Spain.

3.2.15 Use case #14: Model Checks for compliance testing and design coordination

BIM implementation across various life cycles of existing buildings requires a consistent model with requirements for interoperability of all related BIM use cases. For this purpose, the outcome of model checks defined in this use case aids regional and/or standards verification-based compliance testing and ensures a well-defined model which is also used for geometrical checks of coordinated design and geometrical accuracy. The process of model checks includes collecting design rules which are interpreted into a format suitable for automated checks followed by evaluating the results generated by these checks. The verified 3D BIM model can be used to provide a basis for decisions on whether further BIM use cases based on this model can be performed. The process of automated model checks aids in improving time reduction of the process, followed by the possibility of a BCF file export which allows the BIM author directly to each issue within a CAD or viewer software, which enhances the process of coordination and verification of errors in addition to having a verified model for geometrical checks. The comparison of conventional practices and BIM-SPEED solution is shown below:

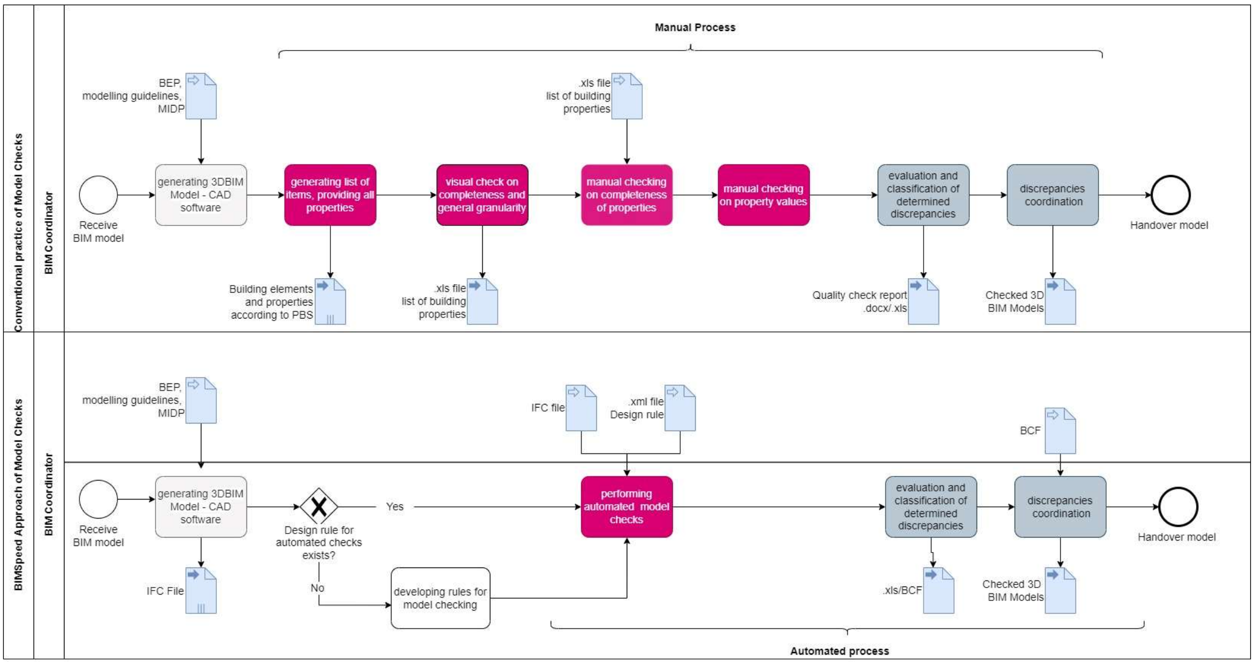


Figure 35 Comparison of Common practice with BIM-SPEED approach for Use case: Model Checks for compliance testing and design coordination

The benefits of BIM-SPEED solutions for Model checks are:

- Verified 3D BIM models for national/region specific/ other standard, naming/semantic informational requirements
- Time reduction by automated model checks

This use case is published, and it is available under link: https://ucm.buildingsmart.org/use-case-details/2826/en

The use case was implemented in demonstration project: #1 Apartment blocks in Vitoria, Spain.

3.2.16 Use case #15: BIM-BEM approach

The BIM-BEM process comprises modelling in BIM, model schema exchange format, and the BEM software. Often interoperability issues are encountered between BIM and BEM which hinders the whole process, which has been reported as a loss of information and inaccurate translation of data from BIM models to BEM. Several comparative studies results have shown that there is information loss in the exchange of information from BIM models to BEMs and a lack of a standard. The 'CYPETHERM Procedure' provides a BIM-BEM workflow, starting with BIM models and optimizing the interoperability between BIM and BEM. The output of the implementation of the UC is a BEM required to perform building energy performance analyses. The process starts with the creation of a new project on the BIM Server center upon uploading the .ifc file. The next step includes creating an analytical model of the building using the OpenBIM Analytical Model tool and defining the relevant thermal properties using the Open BIM Construction System tool. Several other properties of the model like occupancy, operating schedules, HVAC systems, and thermal zones using Cypetherm EPlus.

The BIM-BEM use case satisfies the following objectives:

– Reducing time for the BEM creation: Automated translation of certain model data like geometry and other energy analysis necessary data has contributed to a reduction in time for the whole process. Transfer of available data from the BIM model to the BEM model significantly reduces the need for collecting and input of data necessary for energy analysis into the energy simulation platform. Certain other inputs like material thermal specifications, HVAC system data, and occupancy and operational parameter schedules need to be entered manually which remains the same as traditional processes. The results show a time reduction of about 44%, which is accounted largely to automated geometry and related other data required for energy analysis directly from the BIM model.

- Retrieving geometry and other data directly from the already available BIM model, avoiding direct measurement and the construction of a 3D model from the beginning: The Open BIM Analytical Model solves the problem of lack of geometric accuracy and heterogeneity of definition of IFC files generated by different major BIM tools (Revit, ArchiCad, Allplan, etc). From any IFC containing the geometric definition of spaces, this application is able to recalculate its geometry and redefine all the edges and vertices of all the enclosures of the model received as input so that it is ready to be calculated by subsequent thermal analysis tools.
- The models are synchronized, and a change within the IFC will then be read also in the final BEM: The automation process enabled with a standard interoperable file format like IFC enables models to be synchronized thereby also reducing coordination complications. This has been identified as an advantage of using BIM to translate changes within all relevant analysis and stages of models throughout the building life cycle to integrate processes and information for efficient project delivery.

This use case is published, and it is available under the link: https://ucm.buildingsmart.org/use-case-details/2428/en

The use case was implemented in the following demonstration projects: #1 Apartment blocks in Vitoria, Spain; #3 Apartment block Warsaw, Poland; #4 Care point for homeless people in Warsaw, #5Multi-family dwellings Barlad, Romania; #8 Historic residential building Frigento, Italy; #9 Semi-detached building Gdynia, Poland; #11 Mixed used building Berlin-Tempelhof, Germany.

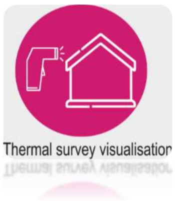
3.2.17 Use case #16: BIM-SPEED library

The BIMSPEED was developed to offer construction industry stakeholders, a catalogue of BIM objects for renovation design, which consists of parameters containing the information required for energy performance and sustainability assessments. The database consists of a set of parameters and a set of files. The parameters can be divided into four packages: the info package, the energy package, the LCA package, and the LCC package. The data collected for energy performance assessment vary based on the component categories. Files include object ifc files, technical sheets, and other product-specific information. The database is aimed for use by producers who want to add their products to the database as well as by users who can log in, visualize and download the objects for use. The database has the possibility of being enriched with different types of input files from external libraries, project demo sites, or other partners uploading objects from existing or completed projects. Specific APIs allow the connection of the database with external services aiming to use the objects present in the BIMSPEED database. The database forms an input to the achievement of larger objectives of time and cost reduction within the BIMSPEED project.

This use case is published, and it is available under the link: https://ucm.buildingsmart.org/use-case-details/2606/en

The use case was implemented in demonstration project: #8 Historic Residential building in Frigento, Italy.

3.2.18 Use case #17: Creation of thermal 3D Model



Visualization of 3D thermal models allows better usability than the use of direct 2D thermal scans. Higher visibility reduces the number of errors that will need to be fixed along with improving communication among stakeholders. The texture of the thermal scans indicates the thermal situation of the building, thereby allowing easier comparison of existing buildings. This use case allows the development of a 3D thermal model that bundles the necessary data, which can be moved and rotated, and analyzed as an object in hand. This allows the stakeholders to visualize the model and thereby reduce further errors. The use case defines two methods – one by thermal photogrammetry and the other by thermal texturing of CAD. The model produced by thermal texturing exhibits higher accuracy but is slower to produce, along with geometrical accuracy being greater from the CAD model instead of photogrammetry. Better visualization enhances the accuracy which also enhances time reduction in the process, which is one of the objectives of the BIM-SPEED project.

This use case is published, and it is available under the link: https://ucm.buildingsmart.org/use-case-details/2692/en

The use case was implemented in the following demonstration projects: #1 Apartment blocks in Vitoria, Spain; #6 Multi-family dwellings Malko Tarnovo, Bulgaria; #7 Historical residential building Varna, Bulgaria.

3.2.19 Use case #18: Holistic Evaluation

This use case supports the holistic evaluation of possible renovation scenarios in the context of residential buildings. It collects results from mostly specialized tools and processes and aggregates them in an overall performance dashboard. It thereby enables consideration of multiple objectives in a decision-making process to select from a multitude of possible renovation scenarios.

The analysis of renovation scenarios often includes a wide range of different considerations with multiple objectives. In addition to calculations on energy performance, this can include parameters on comfort, costs, sustainability, or other stakeholders' evaluations. Much of this information comes from different, usually very specialized, tools, calculations, and evaluations. Their results must be combined for a holistic view with multi-criteria objectives. This is done in a common dashboard. In the Holistic Performance Dashboard, results from simulations, calculations, expert assessment, and other Decision-making processes are combined. This is done both for the unrenovated as-is state and for each potential renovation scenario. The dashboard is integrated into the BIM-SPEED platform: The results of the individual tools are transmitted to the platform. Depending on the tool, this can be automated, semi-automated, or manual. The partial results are bundled automatically, and the dashboard can be accessed via the BIM-SPEED platform.

In the dashboard itself, there are various display options for comparing the potential remediation variants with each other:

(i) Group views as table-view or card-view: Filter settings can be used here to further restrict the display.

(ii) Detailed views of individual variants: The properties and KPIs results of a selected scenario are displayed.

(iii) In Pareto graphs: Several variants are represented as a point cloud with respect to two target parameters.

The application of this use case is particularly recommended if there are many possible renovation scenarios and if several tools, calculations, and evaluations are used. The use case addresses planners and decision-makers as the primary actors involved in the decision-making process for selecting a renovation option to be implemented. This use case is under preparation and will be published soon. The use case was implemented in the following demonstration projects: #8 Historic Residential building in Frigento, Italy; #10 Multi-family dwellings in Warmond, the Netherlands; #12 Apartment blocks in Antony, France; #13 Apartment block in Massy, France.

3.2.20 Use case #19: Remote Simulations of Building Renovation Scenarios by Holographic Twinning

Visualization is a key aspect of implementing several use cases on BIM models. Remote simulations of buildings by holographic twinning obtain a realistic impression and a dynamic experience of the renovation project. The renovation scenarios can also be visualized for better decision-making. Remote possibilities of visualization of such holograms, based on the 3D models allow stakeholders to make decisions and enhance as well as provide the users with a dynamic experience of moving through the real spaces of the building. The use case implements mixed reality solutions in order to obtain the remote dynamic simulation experience. The process includes preparing the BIM or photogrammetric model of the renovation building along with the renovation alternatives proposed. The 3D models in the existing condition are imported onto Unity, and are exported from the MR application and imported onto the device to be viewed from. The benefits realized from the implementation of this use case on demonstration sites within the BIM-SPEED project includes:

- Time reduction: Remote simulations avoid traveling time, along with enhanced visualization including dynamic experience
- Credibility: The 1:1 visualization of the model allows users the as-is representation of visiting the building on site.
- Enhanced collaboration due to better visualization.

This use case is under preparation and will be published soon. The use case was implemented in demonstration project:
#6 Multi-family dwellings Malko Tarnovo, Bulgaria.

3.2.21 Use case #20: BIM based Life Cycle Cost analysis

In renovation projects aimed at energy efficiency across Europe, a systematic decision-making process involves the analysis of several factors including energy efficiency, and analysis of monetary and environmental consequences of the renovation alternatives. One of the challenges currently faced within the AEC industry is to have tools, methods, or frameworks for quickly estimating costs, benefits, and expected Return of Investments which also influences the tendering process of projects. "Payback time" is calculated in order to make informed decisions regarding the feasibility of the project. With this problem definition, the Life Cycle Cost (LCC) analysis use case proposes a systematic approach to a quick LCC calculation in order to be able to compare different renovation strategies. The process of LCC analysis includes the creation of a BIM model, followed by enriching the model with the required cost data. The analysis scope and cost categories in the tool, along with the recurring incomes and expenses. This allows for calculating the total cost over the entire lifecycle of the building. The use case is implemented in the design stage where the optimal renovation alternative needs to be decided, along with the outline feasibility of execution of renovation works.

The LCC analysis use case allows an insight to the following questions raised on the renovation project:

- Will the future expenses for maintenance and management considering the capital cost related to a renovation investment be in balance with the rental benefits?
- If there is not a good cost/benefit balance will that then be compensated by an increased market value?

- Is a renovation investment needed and what will the effect be on the future market value by the end of the lifecycle?
- Will the quality of the real estate stay on a level, during the life cycle, which can facilitate refinance of the outstanding loans?
- Is it worthwhile to invest or better to just maintain? Is it better to sell now or to wait and do that later?
  These questions in turn determine the possibility for cost reduction as well as improving the determination of financial performance (KPI) of a renovation scenario, which is one of the objectives of the BIMSPEED project.

This use case is published, and it is available under the link: https://ucm.buildingsmart.org/use-case-details/2865/en

The use case was implemented in demonstration project: #10 Multi-family dwellings in Warmond, the Netherlands.

3.2.22 Use case #21: Clash Detection

Collaboration among several trades within a project is a time-consuming task and requires careful planning. Independent design of building trades creates room for error, where elements of different trades can clash. Such clashes should be identified prior to site execution and finalized design in order to ensure time reduction and accuracy in the design process. Clash detection, as defined within this use case, is a procedure for detecting geometrical collisions between model elements of different disciplines. Within the BIM-SPEED project and the scope of this use-case, an automated process has been developed to check for collisions and to classify them based on specific rules and tolerances so that necessary action can be taken to rectify the design before site execution. The process of the automated clash detection developed includes obtaining the IFC model files followed by developing clash rules and tolerances, and the relevant clashes are reported and communicated to the relevant disciplines. Upon performing clash detection, the following benefits are realized:

- Ensuring compatibility between several models and disciplines, which leads to efficient coordination
- Keeping a project on schedule by preventing further delays in the design and construction phase.
- Efficient communication of clashes through issue management tools

This use case is published, and it is available under the link: https://ucm.buildingsmart.org/use-case-details/2729/en

The use case was implemented in demonstration project: #4 Care point for homeless people in Warsaw, Poland.

3.2.23 Use case #22: Indoor acoustic comfort calculator

The use case assesses the occupant's indoor acoustic comfort to perform the assessment in order to identify the most optimal renovation scenario. It describes a methodology to assess indoor acoustic comfort calculation based on geometrical, and material data along with outdoor acoustic level which has been obtained from noise mapping data or measured in situ. The process of implementation of the use-case includes the input of data from BIM along with strategic noise map or insitu measurement for outdoor acoustic levels, which are used for calculation of the indoor acoustic performance. The output of implementation of the use case returns an estimation of the indoor acoustic comfort range from (A to E) depending on the use of the space. Based on the obtained results, an assessment of the minimum acoustic comfort requirements is made, and the renovation scenarios that do not meet the minimum comfort requirements can be outlined.

The main purpose of the use-case is to provide:

- A methodology and accompanying tools for building acoustic comfort performance assessment
- The possibility within a framework to implement possible renovation strategies, and compare building performance pre and post renovation
- A dashboard for KPI review which allows designers, stakeholders, and inhabitants to select the optimal renovation scenario.

This use case is under preparation and will be published soon. The use case was implemented in demonstration projects: #1 Apartment blocks in Vitoria, Spain and #10 Multi-family dwellings in Warmond, the Netherlands.

3.2.24 Use case #23: Assessing operational energy costs and energy performance of buildings using measured data

The ECOtool is prepared to automatically calculate a set of indicators related to the occupation and maintenance phases of the building renovation process: Operational Energy Cost, Operational Primary Energy Demand, Global Warming Potential, and the Payback Period. The ECOtool uses static (IFC, energy bills) and dynamic data (energy consumption, energy costs) of the building. The current BIM-SPEED adapted version of the tool obtains part of the information from an excel template provided to the user. The tool can be used by the designers involved in the renovation projects and owners, who need to know the energy costs and environmental impact of the proposed renovation. The overall process for ECOtool service is presented in the Figure 36. The procedure starts with the energy data collection at the building/dwelling level by the user.

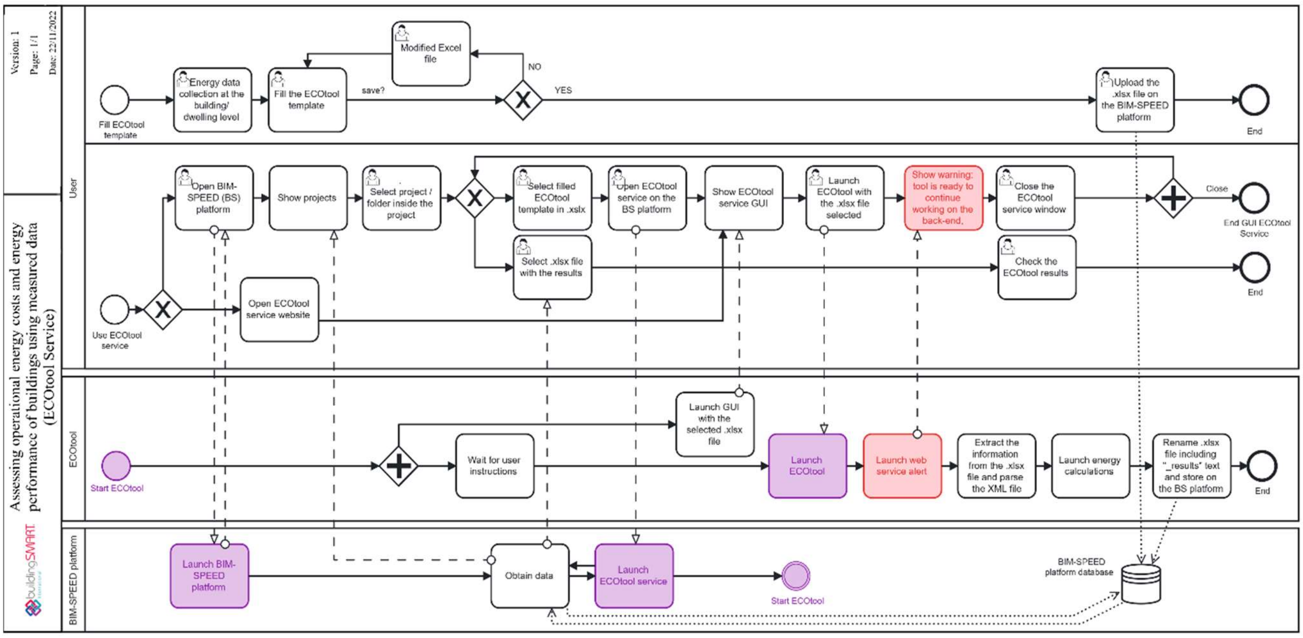


Figure 36 Main steps for the Use case: Assessing operational energy costs and energy performance of buildings using measured data

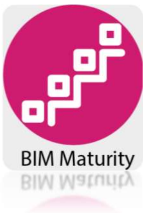
The benefits of using the ECOtool are:

– Reduced time and improved accuracy of results in renovation projects compared to traditional methods, as no user iteration is required in the calculation of the different indicators provided by the tool.

- Reduce costs, as the user can quickly check the Payback Period for different investment costs depending on the selected renovation options.

This use case is under preparation and will be published soon. The use case was implemented in the following demonstration projects: #1 Apartment blocks in Vitoria, Spain and #9 Semi-detached building Gdynia, Poland.

3.2.25 Use case #24: Determination of Stakeholder's BIM Maturity



The main aim of the use case is to give guidance to stakeholders regarding BIM implementation in the renovation projects based on their respective level of BIM maturity. This is achieved through an online tool that guides the stakeholders to BIM use cases that are tailored to their respective levels of BIM maturity. The overall benefit of using the tool lies in time and costs savings due to the better-informed user who can make appropriate decisions on their BIM usage. The process includes creating an account for the tool, entering required information regarding the stakeholder, company, and project, and reviewing the results of the project. Target users of this tool are SMEs, contractors, construction players, investors, architects, and designers that intend to check their BIM maturity level and readiness to perform BIM based renovations.

This use case is published, and it is available under the link: https://ucm.buildingsmart.org/use-case-details/2825/en

This use case was not implemented on demonstration projects, it was implemented by the consortium partners, because the tool is targeted at stakeholders (e.g., SMEs, large companies, building owners, housing associations, etc.).

3.3 Contribution to the impacts

BIM-SPEED project contributes to several impacts related to the topic[4] under which was funded:

1) A reduction of the renovation working time of at least 30% compared to current practices with the baseline. Explanation of how **selected** BIM tools contribute to time reduction is highlighted below in this chapter.
2) Acceleration of the market uptake across Europe by speeding-up industrial exploitation among construction/renovation companies. Exploitation Plan, Business Plan and Market Uptake Strategy were developed and are reported in deliverable D9.3 "Exploitation plan, business plan, market uptake strategy".
3) Creation of best practices examples for the construction retrofitting sector with benefits for the operators and associated stakeholders (architects, designers, planners, installers, builders, owners). Deliverable 8.4 "EU BIM guidelines, best practices and market uptake roadmap for renovation of residential buildings" presents main achievements and key steps of the roadmap of market uptake of BIM-SPEED project, the approach and long-term impact developed tools could have in renovation process. Also impact of 5 most promising tools: BIM-SPEED platform, Crowdsourcing app, 3D Modelling of Existing Asset Based on Point Clouds (Scan2BIM), BIM to BEM process – CYPETHERM Procedure, VR Safety Training is described.

Most renovation projects are still done based on conservative techniques without the use of BIM. As-built data collection is done by taking measurements and photos of the existing building, making an inventory of the current conditions by manual condition assessment, and studying the building archives at the local municipality. Different building professionals collect data for

[4] https://cordis.europa.eu/programme/id/H2020_LC-EEB-02-2018

different purposes, resulting in fragmentation and low accuracy. Renovation solutions are proposed by the construction firm with minimal analysis by a specialist designer, HVAC engineer, or energy expert. Basic construction drawings, technical specifications, and cost estimates are made accordingly. Coordination of renovation work is mainly done on-site with negative implications, such as ad hoc rework, delays, and disturbance for the inhabitants. After renovation, no one holds the responsibility for monitoring the real performance and comparing it against the pre-renovation level. Below we show how selected BIM based tools can contribute to the reduction of renovation time. The conclusions are based on the implementation of BIM-SPEED use cases on demonstration projects.

3D Modeling of Existing Asset Based on Point Clouds

- Currently, the conversion of point clouds into BIM models is time consuming and needs to be done manually. 3DASH tool is a specially-tailored plug-in Revit software that allows for the automatic generation of walls in BIM using point clouds as input. This facilitates the creation of as-built BIM models for buildings. Using this Scan-to-BIM tool can significantly speed up the process of creating a structural model. This can be very useful when quick information is needed from quantity take offs and there is no time for detailed modelling.
- Based on a comparison between the traditional Scan-to-BIM method and the use of the 3DASH tool, the estimated time reduction is around 75%.

Building optimizer

- The Building optimizer tool is used to analyse different types of renovation interventions. Different solutions are examined by adjusting the design variables (e.g., insulation materials, thicknesses, window types, HVAC system) between a certain range of predefined values and options. The tool uses a dynamic optimization process based on 4.080 automated year-round simulations. These are directed towards identifying technically and economically optimal building variants on a data-analytical basis.
- Within the range of building variants, 4.080 renovation scenarios are automatically simulated and assessed. This length of computation time depends on the characteristics of the project (number of thermal zones, number of options to consider, building size), considering a server cluster with 288 cores and 470 GB RAM involving server costs of approx. 50-300€. As a result, the tool provides detailed calculations of a large set of KPIs for energy, cost, comfort and sustainability for each renovation scenario. It furthermore provides visualization of the 4.080 potential renovation scenarios in pareto graphs, indicating the range of optimal solutions for pairs of target parameters.
- A comparison of two buildings with an equal total floor area shows that using the Building optimizer tool results in a 36% time reduction in comparison to the traditional process. This is the case for the projects #13 Apartment block in Massy (10.090 m^2) and #11 Mixed-used building in Berlin -Tempelhof (9.556m2), which required 19 hours of execution using Building optimizer, and 30 hours of traditional work, respectively.

- On average, in projects using Building optimizer tool 13 hours of implementation were needed, while 22 hours were needed for identifying and modelling renovation scenarios in a traditional way. Other than time savings, the Building optimizer also poses an advantage in terms of the quantity of optimal renovation scenarios that can be identified.
- Besides time saving, the Building optimizer poses two additional major advantages: (1) Data-driven: Optimal solutions can be selected from a large quantity of potential renovation scenarios. (2) Achievability insight: The whole range of achievable performance results in terms of KPIs is being evaluated.

Clash detection

- Clash detection is a critical part of the integrated BIM modelling process. It analyses project data from different trades to highlight when a potential conflict might occur. Stakeholders can then re-design or address the conflict before it becomes a more pressing and expensive issue. BIM makes it possible to create detailed clash reports during the design stage.
- Through a conventional approach to project design and management, issues/clashes may not arise until the construction phase. Since BIMs are more precise and practical than 2D models, users can spot these issues earlier. It is always easier and more affordable to solve a problem in the planning phase than it is in the execution phase. Resolving clashes is especially important for Mechanical, Electrical, Plumbing, and Fire protection components. Soft clashes are common for these systems and if they are spotted in advance, the conflicts can be resolved. Furthermore, clash detection has a positive influence on facility management in terms of installation safety. For example, a plumbing line being close to an electrical wire is a potential short-circuit hazard.
- Clash detection analysis was implemented in #4 Care point for homeless people in Warsaw, Poland. During this analysis 148 clashes were found.

4D time scheduling

- The planning and scheduling of construction projects represent an important part of the management of the construction process. It plays a crucial role in a project's success since it facilitates the allocation of resources (such as equipment, materials, and labour) to project activities over time, so as to ensure the completion of the project on time and within budget. Good scheduling enables project stakeholders (investor, engineers, management of construction sites) to check project feasibility, estimate preliminary costs, maintain safety, optimise the use of resources, and allow the project team to monitor and control progress and determine if the work is proceeding efficiently, ensuring that the client's objective is achieved. Furthermore, planning and scheduling deficiencies and poor communication among project participants have been identified as major factors that can lead to project delays and cost overruns, and ultimately to claims and disputes. The enrichment of a 3D BIM model with scheduling data has increasingly improved the quality of the construction planning process through the development and integration of several use cases such as: dynamic site analysis with temporary components including equipment movement, resource availability, management of congestion and other operational constraints, spatiotemporal analysis for health and safety management, evacuation path planning , logistics management, augmented vehicle tracking and transportation route planning, construction waste management, spatial conflict detection, workspace congestion avoidance, and the monitoring of construction progress with site layout designs Tools for 4D time scheduling enabling construction planning and operations. Such tools provide virtual support to construction, planning, and model-based workflows. Overall, based on the experience of construction companies participating in the BIM-SPEED project (Mostostal and FASADA), 4D BIM simulations can lead to a 40% of time reduction in comparison to conventional planning procedures.

BIM-BEM approach

- Currently, the BIM-to-BEM procedures are time-consuming are require many manual adjustments and data corrections. For these reasons the process to create BEM models usually starts from the scratch and not automatically involving BIM models. The BIM-BEM approach proposed constitutes a first step to overcome the lack of interoperability between the models and consolidate the process of converting BIM into BEM. It is based on the development of new tools: Open BIM Analytical Model and Open BIM Construction System that allow to improve the interoperability between the IFC format and the energy simulation tools.

- The BIM-BEM proposed approach can save time firstly because it is possible to “synchronize” the information establishing a direct bridge between the BIM and the BEM models thought the BIMserver.center Platform. Additionally, the BIM-to-BEM process gives time savings in the following steps:
  - Data collection: useful information is already included in the BIM model and can be used to characterize BEMs, without having to redo onsite data collection or document analysis
  - Building geometry generation: the Open BIM Analytical Model allows to generate automatically an analytical geometric model for the energy analysis starting from an architectural model defined through the IFC standard. The information included in the BIM model (definition of spaces and architectural element) are used to qualify elements, surfaces adjacencies
  - Building thermophysical characterization: the Open BIM Construction Systems integrates the elements defined in the BIM architectural model, it allows to establish a link between the elements and the construction systems (stratigraphies and materials properties) that have already been defined
- General, with the BIM-BEM approach proposed it is possible to benefit, more or less automatically, from the information already included in BIM models and one does not need to start from the scratch. Based on the comparison of traditional the estimated time reduction is around 41%.

Figure 37 presents contribution of selected BIM tools to time reduction impact for various demonstration projects.

TIME REDUCTION

TOOL	BIM-BEM	Building Optimizer	3DASH	4D Time Scheduling	Clash detection
#1 Apartment blocks Vitoria, Spain	42%		75%	50%	
#2 Apartment block Berlin - Lichtenrade, Germany					
#3 Apartment block Warsaw, Poland	43%			50%	
#4 Care point for homeless people Warsaw, Poland	39%		75%	50%	50%
#5 Multi-family dwellings Barlad, Romania	38%				
#8 Historic residential building Frigento, Italy	44%	36%		50%	
#9 Semi-detached building Gdynia, Poland	40%			50%	
#10 Multi-family dwellings Warmond, the Netherlands		36%		50%	
#11 Mixed used building Berlin-Tempelhof, Germany	41%			50%	
#12 Apartment blocks Antony, France		36%			
#13 Apartment blocks Massy, France		36%			
Average:	41%	36%	75%	50%	50%

Figure 37 Contribution of selected BIM tools to time reduction impact based on implementation on demonstration projects.

4. BIM to fabrication demonstration project

4.1 Introduction

One of BIM-SPEED demonstration project is related to implementation of BIM to production process (demonstration project #14 Fabrication of Plug and Play solutions, Italy). This demonstration project differs from the others, and it is focused on the analysis and improvement of the production of façade panels performed by Italian company Focchi S.p.A[5],. It is a company established in Rimini (Italy) that is very active in the curtain walling sector. The company is engaged in the full cladding process from design, manufacture, delivery, and site installation. The goal of the work was to verify how the BIM can be introduced within the process from design to production without data loss or incompatibility of the software. Focchi on the one hand designs complex glass façade solutions for several kinds of buildings, on the other hand, highly detailed production models are derived from these overall design solutions. So far, there is no direct communication or link between the software solutions for the overall architectural design, Autodesk Revit.[6], and the elaboration of the complex framing systems' geometries for production, Autodesk Inventor[7]. The design of an entire façade takes place on a macroscopic scale with the building as a system, while the production planning takes place on a microscopic scale with only one façade element as a system being remodeled according to the macroscopic model by hand. Therefore, another difficulty is, that these two separate processes design and production require entirely different levels of detail (LODs) and especially levels of geometry (LOGs). Meaning, that geometry cannot only be exported and imported, as it would be supported by several exchange formats, but must raise or reduce its LOD/LOG during the exchange process. This change requires well-defined interfaces for the data exchange.

The BIM to production concept, also referred to as BIM to fabrication, deals with the advantages and challenges coming along with a fully BIM-supported planning and production process. It must contain at least two participants. The designer, responsible for macroscopic modeling, for example, an architect, and the producer, facilitating producible units for the implementation of the designer's ideas. Automation in production in terms of deriving production documents from BIM models as well as the communication between participants are hereby big topics, current research deals with. Often, it is not clear, what kind of exchange is required to facilitate an automated BIM to production workflow. Furthermore, depending on the modeling method, a geometric exchange can become complicated, leading to a high implementation effort. Therefore, it is important to fully understand the process, before implementation can start which can lead to more efficient solutions. In the past, many studies investigated, how highly detailed production models can be based on or derived from the designer's model of higher abstraction. Case studies were conducted in several fields of the AEC sector. All these studies investigate the so-called "top-down" workflows, beginning with the designer's model and decreasing the level of abstraction by deriving production documents. By using models of higher abstraction as a base for more detailed ones, the level of detail (LOD) raises during a top-down process. No information must be rationalized to match the requirements of the target model. Nevertheless, in 2004, Sacks et al. stated, that besides the top-down approach also "bottom-up" functions are required to facilitate a BIM to the production process. Bottom-up derives less detailed models from more elaborated ones. It is often used by fabricators, to implement fabrication concerns at an early stage,

[5] https://www.focchi.it/ww/
[6] https://www.autodesk.com/products/revit/overview
[7] https://www.autodesk.com/products/inventor/overview

supplying microscopic "off the shelf" elements. These elements can then be used in a project of macroscopic scale. To investigate, if Sacks' statement is still current, a case study was conducted on a real example. It was examined whether top-down or bottom-up functions are used in current BIM to production workflows as well as if these are useful in future processes. In order to conduct the case study, a model driven architecture (MDA) approach was chosen. Interviews with participants of the BIM to the production process of the Italian façade design company Focchi S.p.A. were conducted to investigate the above-introduced topics

The Model driven architecture (MDA) allows viewing the processes of interest from different viewpoints. While the early stages are depicted from a process modeling viewpoint and therefore abstract and easy to understand, later stages are more specific, containing information from an implementation viewpoint. As part of the MDA, the process modeling viewpoints were gathered using the accessible business process model and notation (BPMN) language. In such a way, the depicted processes can be understood at an early stage by the participants, and changes or possible implementations can be openly discussed. Hence, not only information about the used approaches can be derived from the process models. By implementing the participants' requirements concerning future processes, statements about the current process can be derived. In such a way it can be stated, not only whether in the existing process specific functions can be found, but also if they are feasible and wanted by the participants. In a consecutive step, implementation oriented schematic class diagrams and use case diagrams are derived from the BPMN using the Unified Modeling language (UML). In such a way, additionally, the implementation effort can be estimated. Furthermore, these diagrams build the base for possible future implementations.

To evaluate the existing process and wishes and demands concerning a possible future workflow, meetings and workshop were scheduled with representants of Focchi company (participants of the BIM to the production process as well as the BIM management process). In order to facilitate an integrated workflow between the Technical Department and the Façade System Design Department of Focchi, six scenarios were studied and analysed.

4.2 Recommendations

By going through the consecutive steps of the Model driven architecture (MDA) process, a solution can be facilitated to fulfill the company's demands. Therefore, two directions can be further investigated. On the one hand, the process, derived from the interviews, can be implemented (Figure 38). For that, the implementation of bottom-up functions must previously be investigated. Crucial for the successful implementation of a geometric exchange interface are the two topics of level of detail (LOD) control and the transmission of the parametrization.

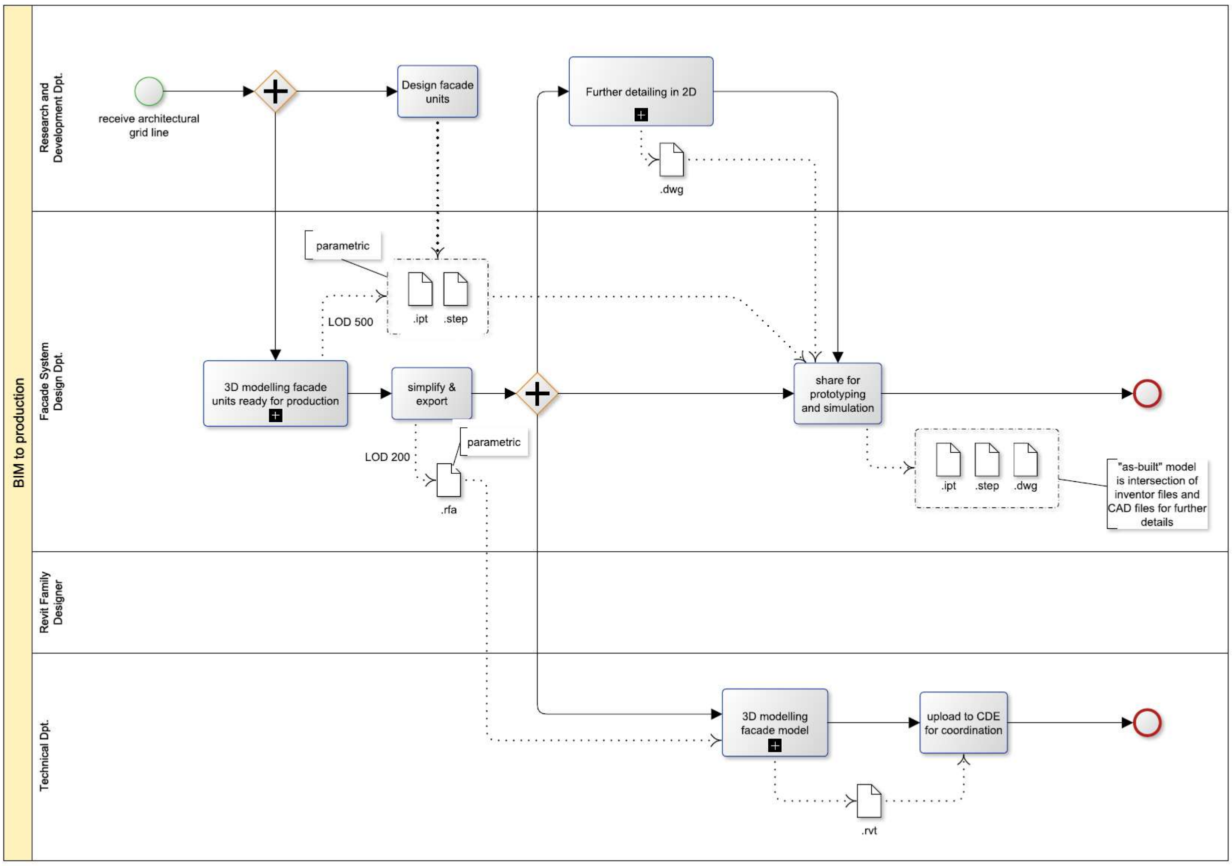


Figure 38: Scenario 6: Chronologically shifted workflow; use of implemented interface

On the other hand, the process derived from the workshop can be implemented (Figure 39). This process requires tools to export data from Revit and Inventor. In the second step, these data must be merged and accounted to generate a valid quantity determination.

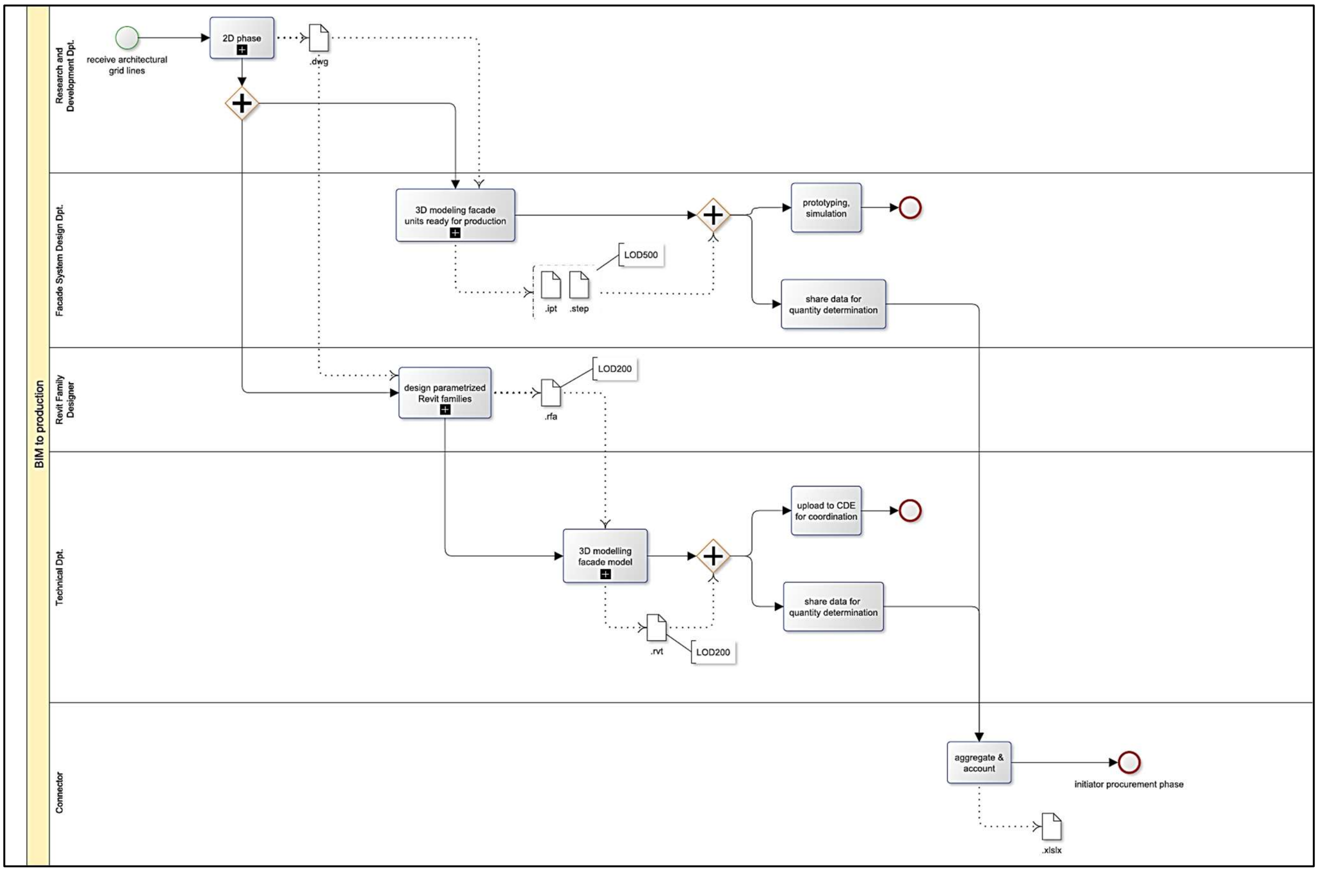


Figure 39 Project-oriented (top-down) workflow; additional connector concept

Secondly, the bottom-up functions can be further applied to the AEC sector.

5. Conclusions

The selection of a suitable renovation solution in the context of residential buildings is a challenging task due to the participation of multiple stakeholders, lack of clear decision-making procedures, and diverse effects resulting from the renovation alternatives. Residential renovation projects encounter different scenarios and particularities that require a better-structured decision-making approach to select suitable renovation solutions that fulfil the requirements of the project and stakeholders involved. A decision support framework for this field should enable the participation of multiple stakeholders and support the definition of objectives and criteria, promote the analysis of not only economic and environmental aspects, and integrate stakeholders' preferences with the evaluation of alternatives. Having a comprehensive predefined set of objectives and criteria encourages stakeholders to implement a broader analysis of the renovation alternatives [5]. Multi-Criteria Decision Support Tool and Building optimizer (developed within BIM-SPEED project) support diverse stakeholders from the residential renovation field to select a suitable renovation solution. Implementation on demonstration project showed that Building optimizer tool allows to reduce the time around 36% in comparison to current practices.

This deliverable consolidates and presents definition and implementation of BIM-SPEED use cases associated tools on demonstration projects. BIM-SPEED project followed the BuildingSMART standardisation procedure for documentation of use cases. Developed use cases allow to exchange best practices and make them accessible to the entire Architectural Engineering and Construction (AEC) industry. Use cases are proposed for the entire process of data collection, design, construction, and operation. Each use case details the information workflow between the respective project participants enabling collaborative and efficient work. For this moment 17 use cases are published within the Use Case Management Service of buildingSMART and can be accessed here: https://ucm.buildingsmart.org/use-cases?lang=en".

Most renovation projects are still done based on conservative techniques without the use of BIM. This deliverable presents benefits for the actors of the renovation process (building owners, architects, engineers, investors, construction companies) of BIM tools. Utilization of various BIM based tools allows to speed up different part of the renovation process: As-built data acquisition, renovation design, performance engineering and execution of construction works, this approach was validated and proved on various demonstration projects.

6. Literature

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[4] Pinzon Amorocho, J. A., & Hartmann, T. (2020). BIM-SPEED D7.1 Multi-criteria decision making method and tool for housing renovation projects. https://doi.org/10.14279/depositonce-10659

[5] Pinzon Amorocho, J. A., & Hartmann, T. (2022). A Multi-criteria Decision-Making framework for Residential Building Renovation, conference paper, https://www.sbe22.berlin/

[6] Sacks, Rafael ; Eastman, Charles M. ; Lee, ghang: Parametric 3D modeling in building construction with examples from precast concrete. In: Automation in Construction 13 (2004), S. 291–312

7. Appendix: Example of three BIM-SPEED use cases

Use case #1: 3D Modeling of Existing Asset Based on Point Clouds (Scan2BIM)

Use case #10: Decision-making for residential building renovation

Use case #14: Model Checks for compliance testing and design coordination

Use Case

3D Modeling of Existing Asset Based on Point Clouds (Scan2BIM)

3DASH4Scan2BIM

Publisher:	BIM Speed
GUID:	e4541133-68bc-40b2-b634-b5b5e0a049fe
Published on:	2022-02-15
Last change:	2022-02-15
Life Cycle Stage:	ISO 22263
Maturity level:	Outlook

Use Case

Management Summary

This document aims at describing '3D Modeling of Existing Asset Based on Point Clouds' use case which is implemented as part of BIM-SPEED EU Horizon2020 project, under grant agreement No. 820553, using the 3DASH Tool. https://www.bim-speed.eu/en. This use case allows to obtain the As-Built BIM model of the building based on the 3D point cloud obtained on site in the first phase of the renovation process.

Use Case Definition

USE CASE DESCRIPTION	
Title	3D Modeling of Existing Asset Based on Point Clouds (Scan2BIM)
Goal	The proposed use case aims at reducing time and cost, as well as increase the accuracy to obtain the As-Built BIM model of a building based on point clouds
Description	The use case provides a procedure which makes easier the generation of the BIM model of the building based on the 3D point clouds using the 3DASH Tool, a plug-in for REVIT programmed in C++ and supported by Point Cloud Library (PCL)
Input data	3D point-cloud (PLY, PTS or PTX format)
Sequence of actions	1. Obtain the point clouds; 2. Installation of the 3DASH Tool; 3. Automatic generation of the elements from point clouds by using the 3DASH Tool; 4. Extraction of the results by exporting the generated BIM model to IFC and loading the information into the BIM-SPEED Platform;
Output data	BIM model of the building in REVIT (.rvt) and/or IFC file (.ifc)
Primary actors	The 3DASH tool can be used by the designers involved in the renovation projects, who need to create the 3D modeling of the existing buildings using point clouds as input.
Secondary actors	Other experts in 3D modelling
Pre-conditions	• The building needs available space to obtain the point cloud by laser scanning or photogammetry systems. • 3DASH add-in (BimSpeed.addin available to download from the BIM-SPEED platform).
Trigger	As-Built data acquisition and BIM modeling
Post-conditions	POST-1. The final walls automatically generated by the tool must be checked by the user to edit/ join some elements or add properties to some of them.
Frequency of use	Before the renovation starts. Every time a building renovation process starts.
Support planned for	BIM-SPEED
UC Created by	CARTIF Technology Centre

Aim and scope

The '3DASH Tool' implemented as part of BIM-SPEED project is developed with the need for the objectives set by the BIM-SPEED Project. It helps in:

Time reduction in the generation of walls in BIM from point clouds.

Accuracy in the generation of walls from point clouds due to the fact it is a mathematical process based on algorithms.

Objectives

A tool that supports the creation of As-Built models using point clouds as data for the generation of BIM models using REVIT software with these users benefits:

- Time reduction: both to generate As-Built models and to compare with previous existing models, or to generate these models if you do not have previous documentation.
- Accuracy: the tool gives a high accuracy since it is a mathematical process based on algorithms for the detection and generation of walls using point clouds, compared to the manual process that would be for the user to generate the walls using as a template the point clouds, as it would never have the same accuracy in the selection of the points.

Limitations

The tool needs a manual process by the user to check and edit the types of walls generated in case there is any overlap between them, but even so, this time would be less than the time it would take to manually do the whole process.

References

- Autodesk Revit Website. Available online: https://www.autodesk.es/products/revit/overview.
- BIM-SPEED (2021) *1: Methods for architectural, structural, thermal 3D data acquisition of existing buildings*. BIM-SPEED Consortium, Berlin, Germany. See https://www.bim-speed.eu/en/results (accesed 08/07/2021).
- BIM-SPEED (2021) *2: BIM Connectors for interoperability between different BIM tools and with the BIM-SPEED Platform*. BIM-SPEED Consortium, Berlin, Germany. See https://www.bim-speed.eu/en/results (accesed 08/07/2021).
- BIM-SPEED training materials area. Available online: https://www.bim-speed.eu/en/training-materials

Abbreviation

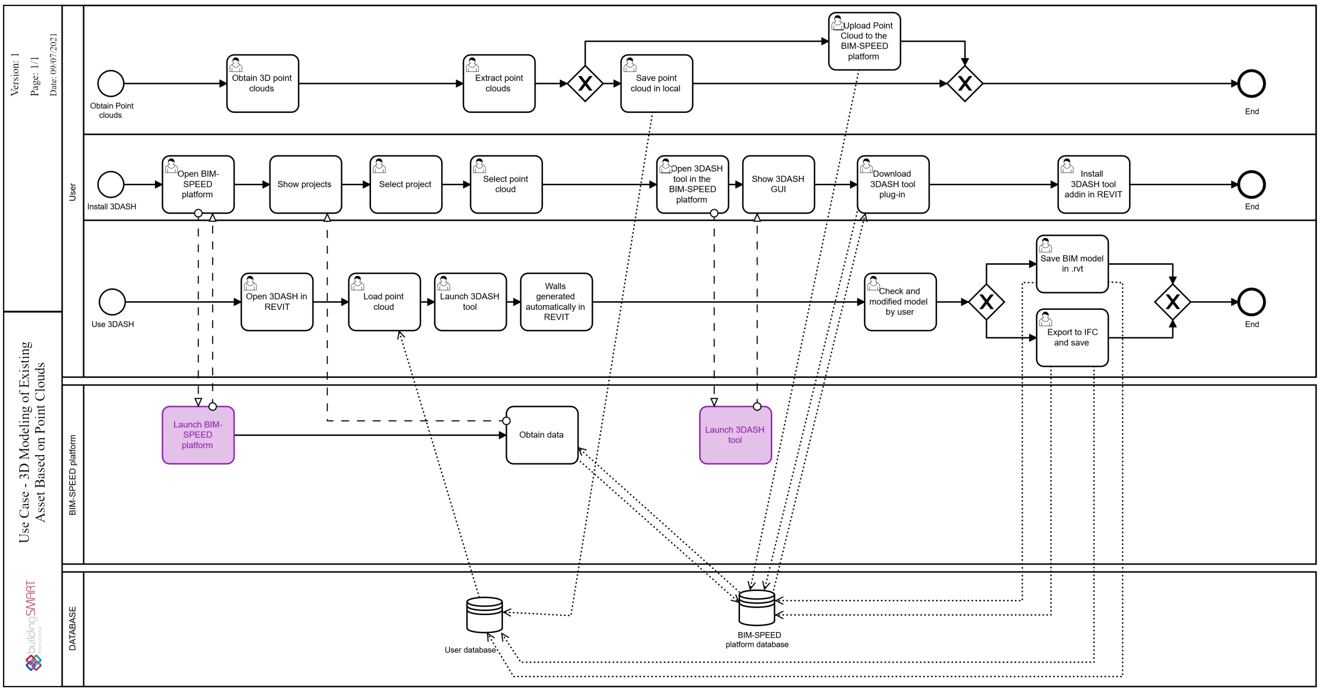
- **3DASH:** 3D Modeling Based of Existing Asset based on Point Clouds
- **BIM**: Building Information Modeling
- **GUI**: Graphical User Interface
- **IFC**: Industry Foundation Classes

Process Definition

Overall process

Description

The overall process for 3DASH Tool is presented in the figure below. The procedure starts with collecting the 3D point clouds by the user acquired by laser scanning or photogrammetry systems. The overall process is further explained through its implementation on two demonstration sites.



As shown in the image above, there are three different parts involved in the process: the user, the BIM‑SPEED platform and the databases:

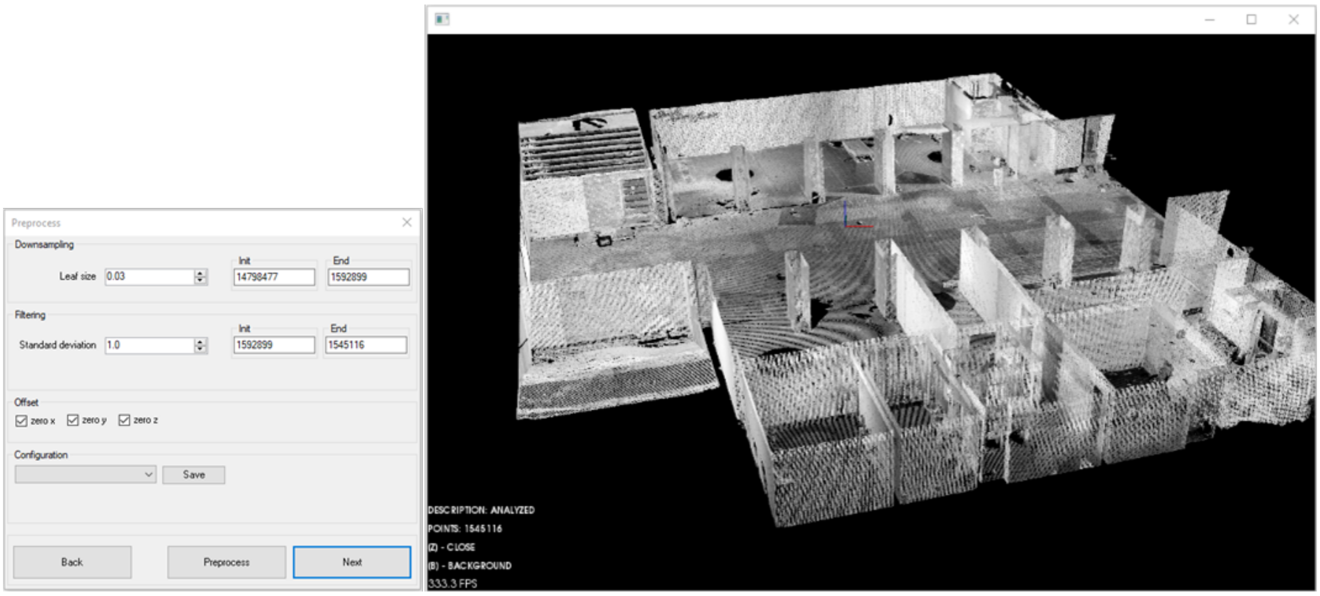
- The user has to start three different process if it is the user's first time using the tool:
    1. Obtain Point Clouds: First, the user has to obtain the 3D point clouds and transform them to PLY, PTS or PTX format.
    2. Install 3DASH plug-in: The user has to launch the 3DASH Tool in the BIM-SPEED platform to download the 3DASH add in and install the add in in REVIT.
    3. Launch the 3DASH Tool in REVIT.
- BIM-SPEED platform: The BIM-SPEED platform allows to launch different services hosted on it, being able to launch the 3DASH GUI (Graphical User Interface) from the platform following the user's commands.
- Databases: There are two different databases in the process:
    1. User database: The user can save the data in its local database.
    2. BIM-SPEED platform database: The user can upload and download data from BIM-SPEED platform.

The details of the implementation of this tool in two demonstration cases are covered in the next section.

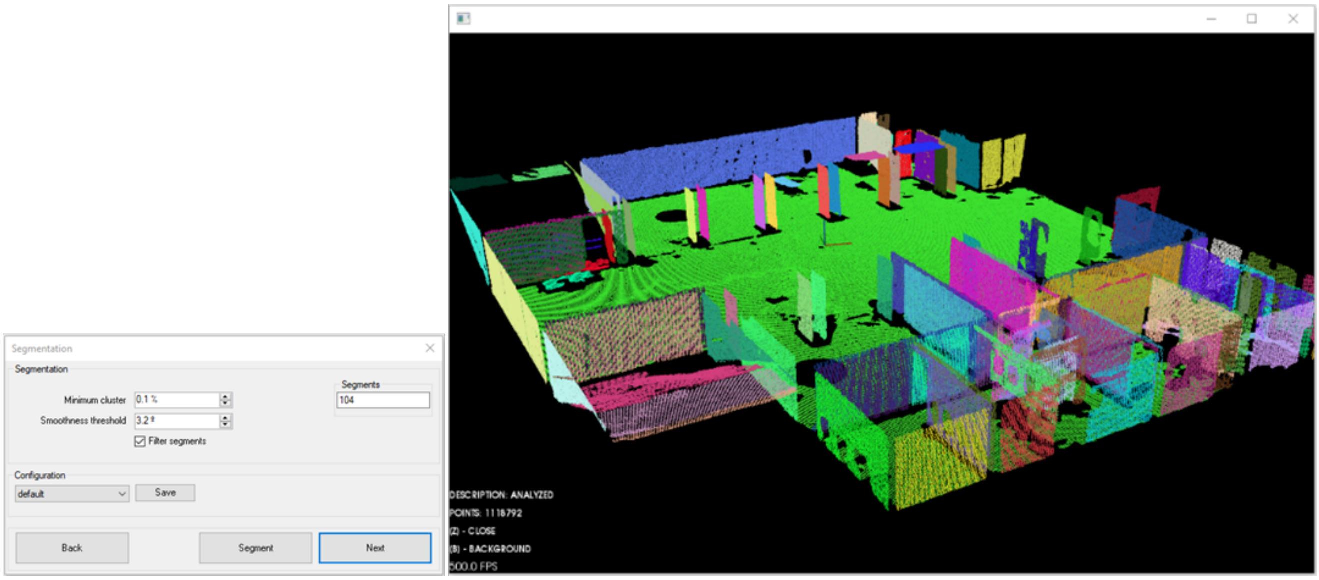
DEMONSTRATION SITE – Jazdy Konnej, WARSAW, POLAND

The demonstration site is located in Warsaw, Poland. The building is an underpass. The point clouds upload to the tool in the first step 'Analyzed' is shown in the image below:

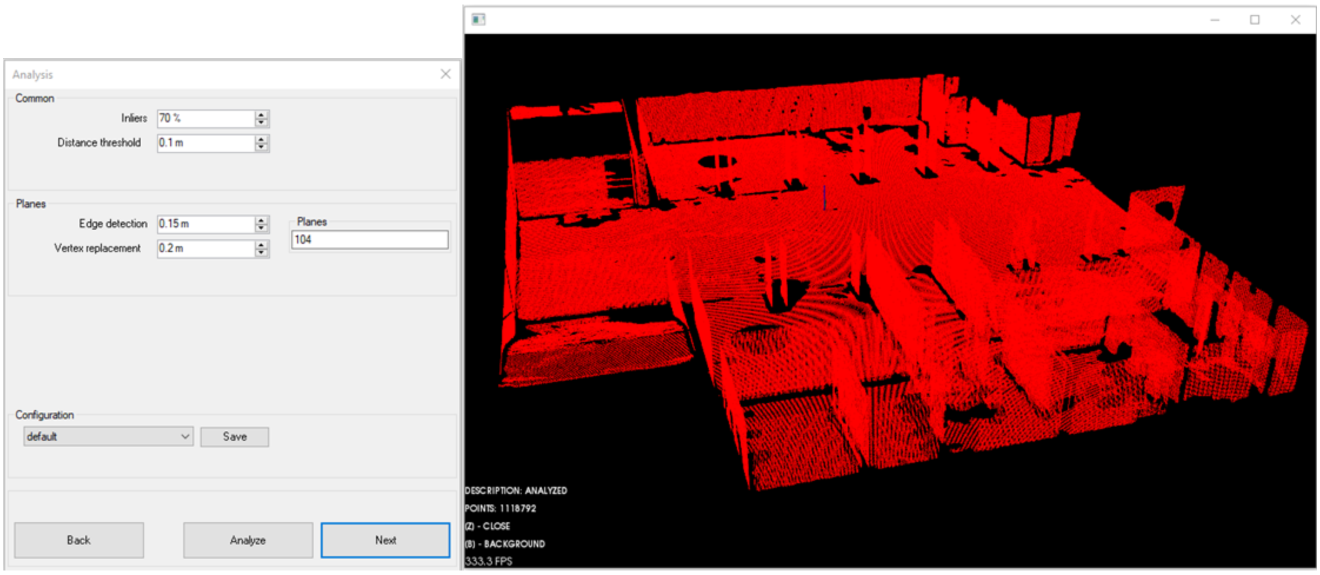
The second step is the pre-processing process where several parameters are selected, the results of which is shown in the following image:



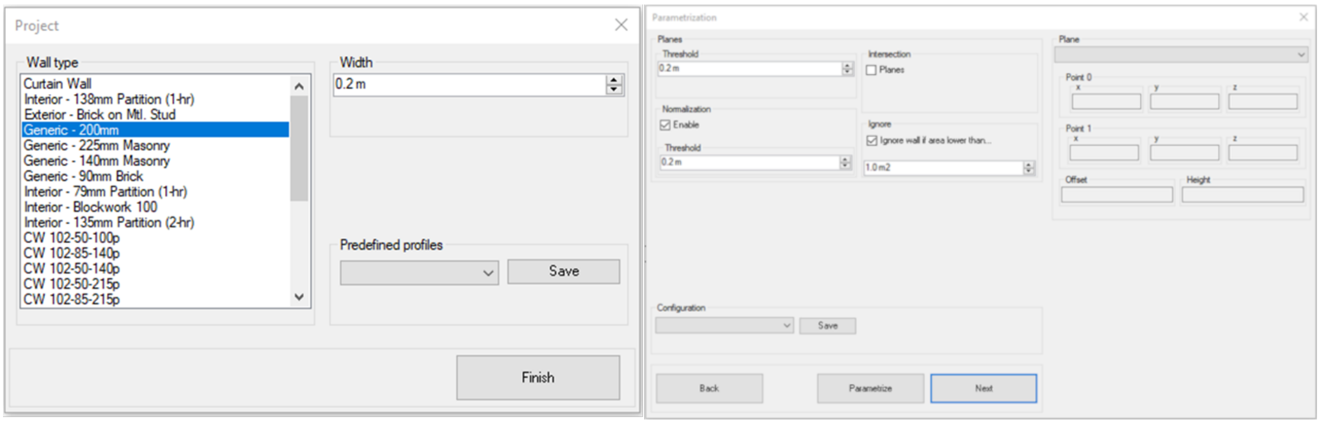
In the segmentation step, the user can modify different parameters such as the smoothness threshold which indicates the maximum deviation between the normals of the neighboring points. The results for the Warsaw demo is shown below:



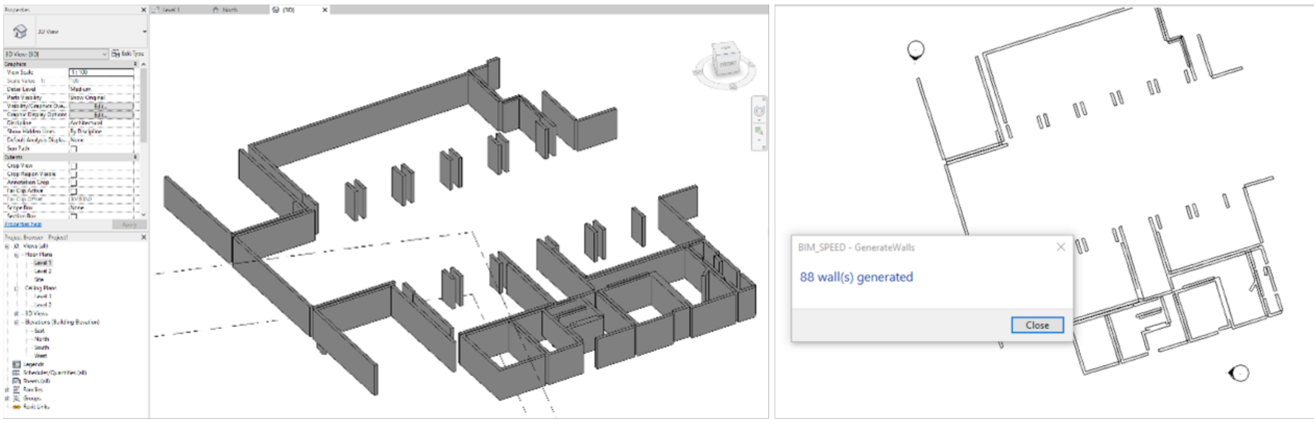
The analysis step makes it possible to determine, among other parameters, the maximum distance between a point and the virtual plane to which it belongs. The results for the parameters selected in the Warsaw demo are shown below:



Finally, the user can select the wall type to be applied in all the walls generated by the tool, as shown in the following images:



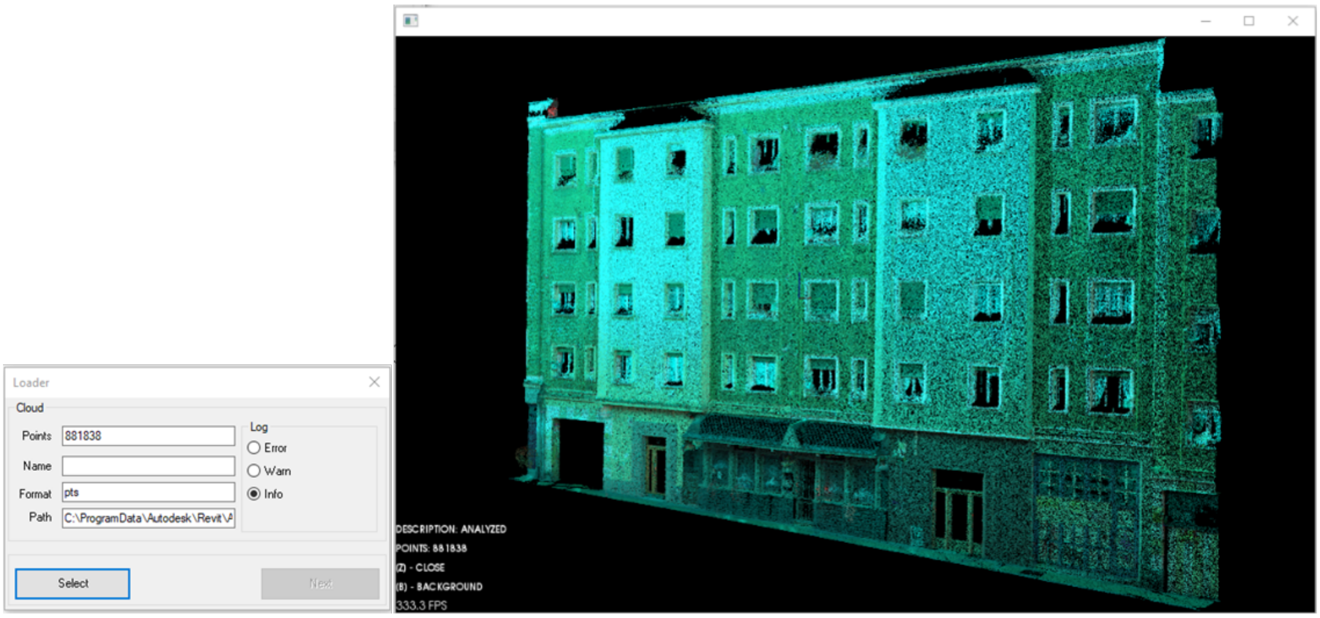
With the options selected by the user in all the process, 88 walls have been generated and the time spent for the automatic generation was 77 seconds (excluding the time spent by the user in selecting parameters). The final result obtained for the Warsaw demo is show below:

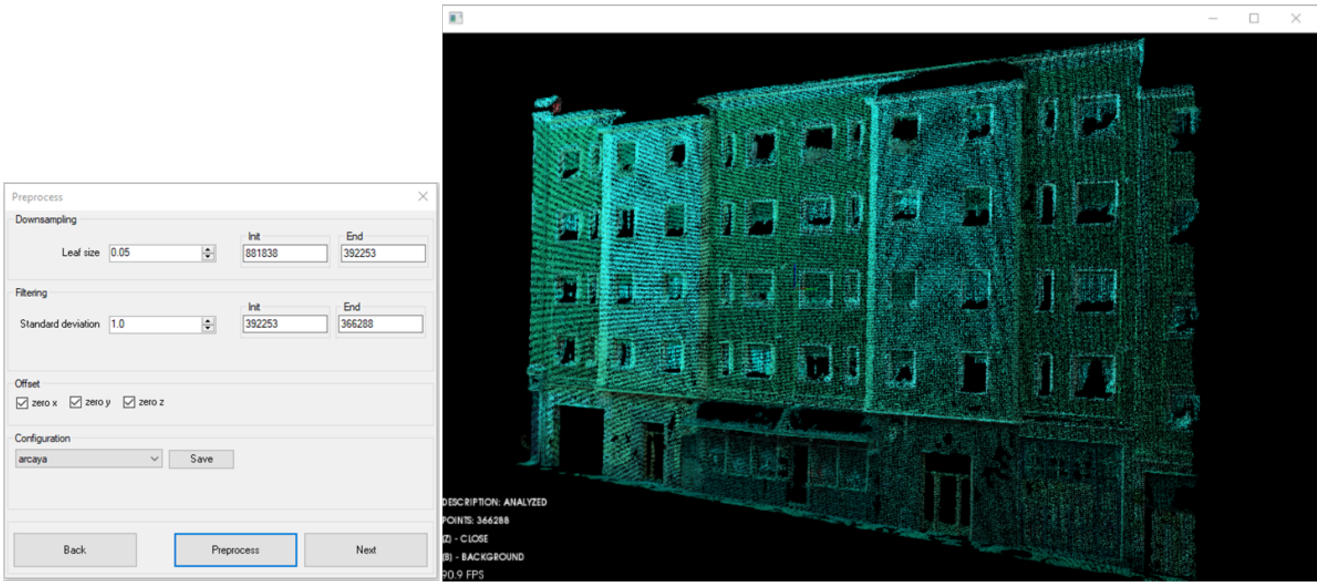


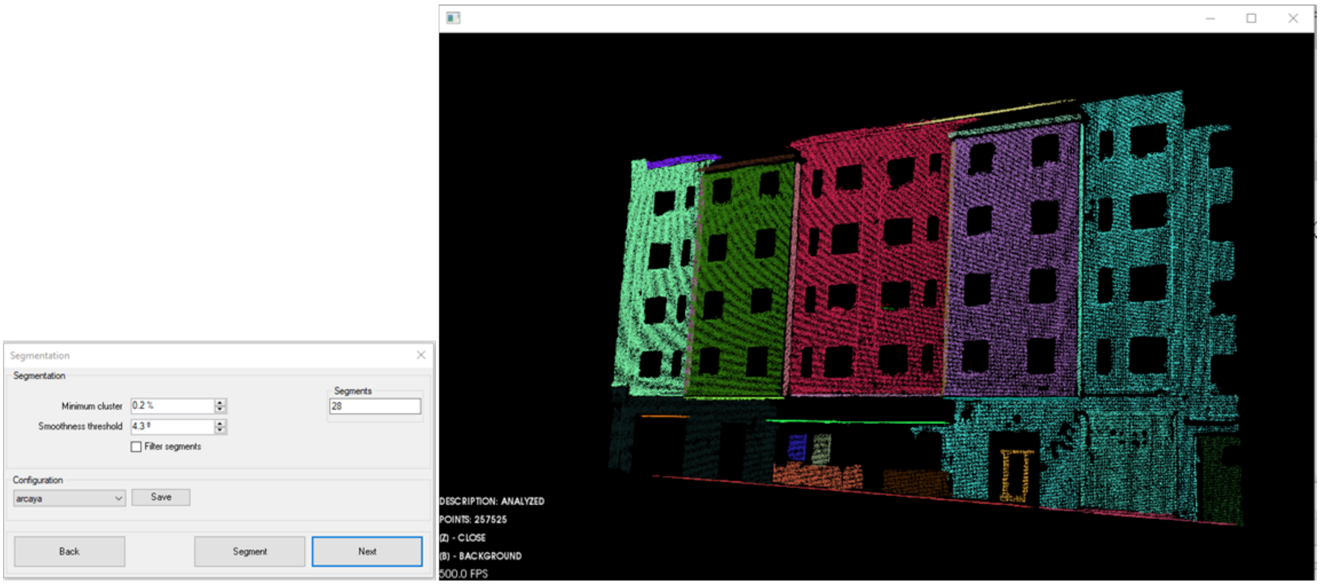
More information about this demonstration can be found in the training area of the BIM-SPEED website https://www.bim-speed.eu/en/training-materials and in the YouTube channel https://youtu.be/pJB1pGj1I34.

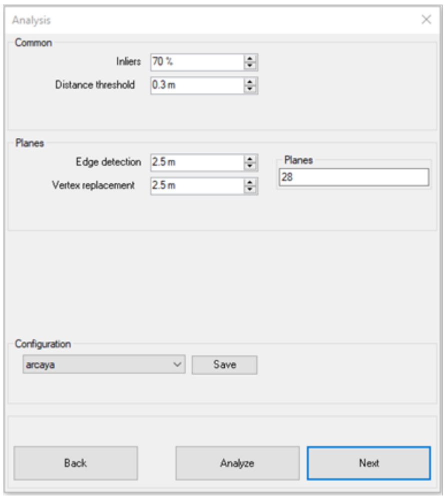
DEMONSTRATION SITE – ARCAYA 5, VITORIA, SPAIN

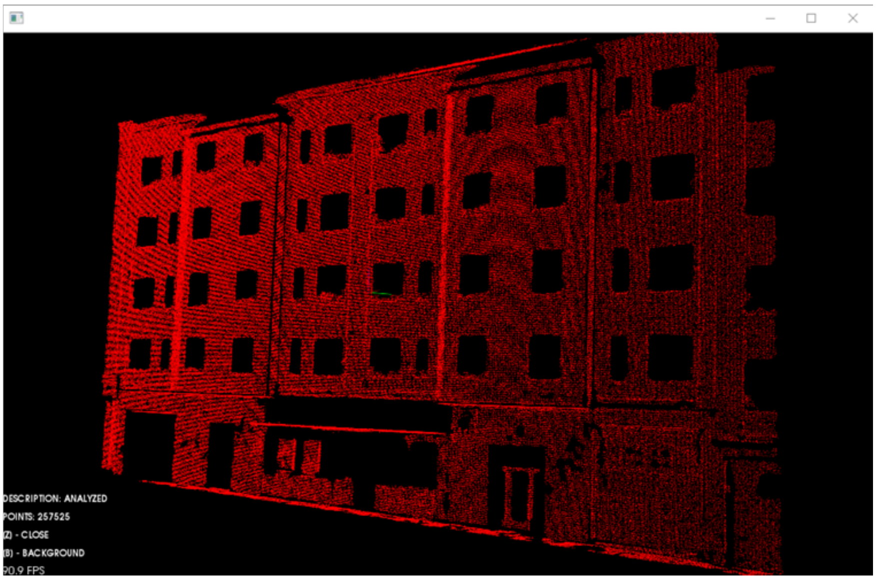
The second demonstration site of the use case 3DASH4Scan2BIM process has been carried out with the Vitoria demo, the building ARCAYA5. This demo is a residential building located in the city of Vitoria-Gasteiz, Spain. The steps are the same as those identified in the previous demonstration, so only the results are shown below:

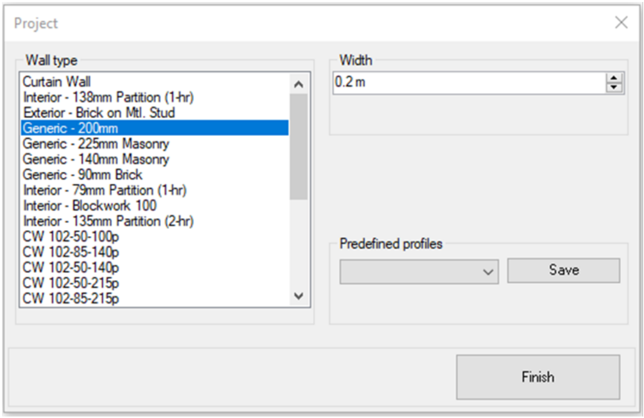


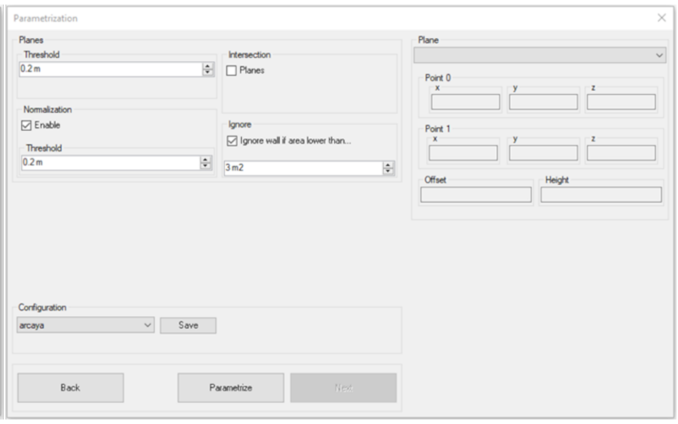

Preprocess
Downsampling
Leaf size 0.05
Init 881838
End 392253
Filtering
Standard deviation 1.0
Init 392253
End 366288
Offset
zero x
zero y
zero z
Configuration
arcaya
Save
Back
Preprocess
Next
DESCRIPTION: ANALYZED
POINTS: 366288
(Z) - CLOSE
(B) - BACKGROUND
90.9 FPS

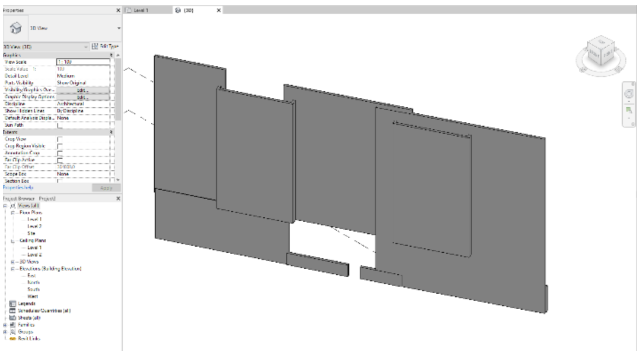

Segmentation
Segmentation
Minimum cluster 0.2 %
Smoothness threshold 4.3 º
Filter segments
Segments
28
Configuration
arcaya
Save
Back
Segment
Next
DESCRIPTION: ANALYZED
POINTS: 257525
(Z) - CLOSE
(B) - BACKGROUND
500.0 FPS

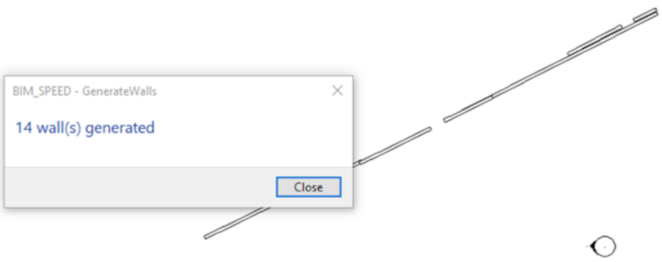

Analysis
Common
Inliers 70 %
Distance threshold 0.3 m
Planes
Edge detection 2.5 m
Vertex replacement 2.5 m
Planes
28
Configuration
arcaya
Save
Back
Analyze
Next


DESCRIPTION: ANALYZED
POINTS: 257525
(Z) - CLOSE
(B) - BACKGROUND
20.9 FPS


Project
Wall type
Curtain Wall
Interior - 138mm Partition (1-hr)
Exterior - Brick on Mtl. Stud
Generic - 200mm
Generic - 225mm Masonry
Generic - 140mm Masonry
Generic - 90mm Brick
Interior - 79mm Partition (1-hr)
Interior - Blockwork 100
Interior - 135mm Partition (2-hr)
CW 102-50-100p
CW 102-85-140p
CW 102-50-140p
CW 102-50-215p
CW 102-85-215p
Width
0.2 m
Predefined profiles
Save
Finish


Parametrization
Planes
Threshold
0.2 m
Intersection
Planes
Normalization
Enable
Threshold
0.2 m
Ignore
Ignore wall if area lower than...
3 m2
Plane
Point 0
x
y
z
Point 1
x
y
z
Offset
Height
Configuration
arcaya
Save
Back
Parametrize
Next




BIM_SPEED - GenerateWalls
14 wall(s) generated
Close

In this case, the point cloud of the building was only of the main façade, obtaining 14 walls with the 3DASH tool. The time spent for the automatic generation was 18 seconds (excluding the time spent by the user in selecting parameters).

Attached Images

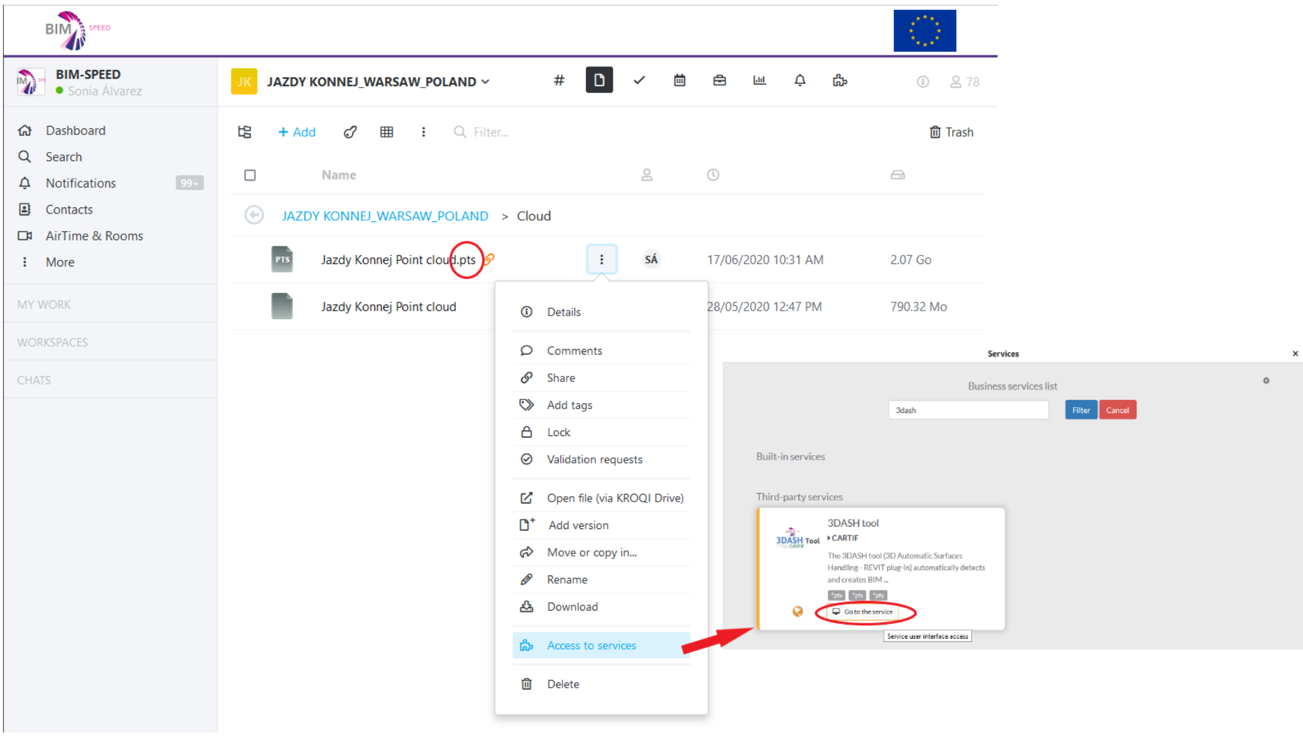
- 3DASH_BPMN_BSI.png
  (20211215110950-3DASH-BPMN-BSI.png , 476.07 KB)

ISO 22263

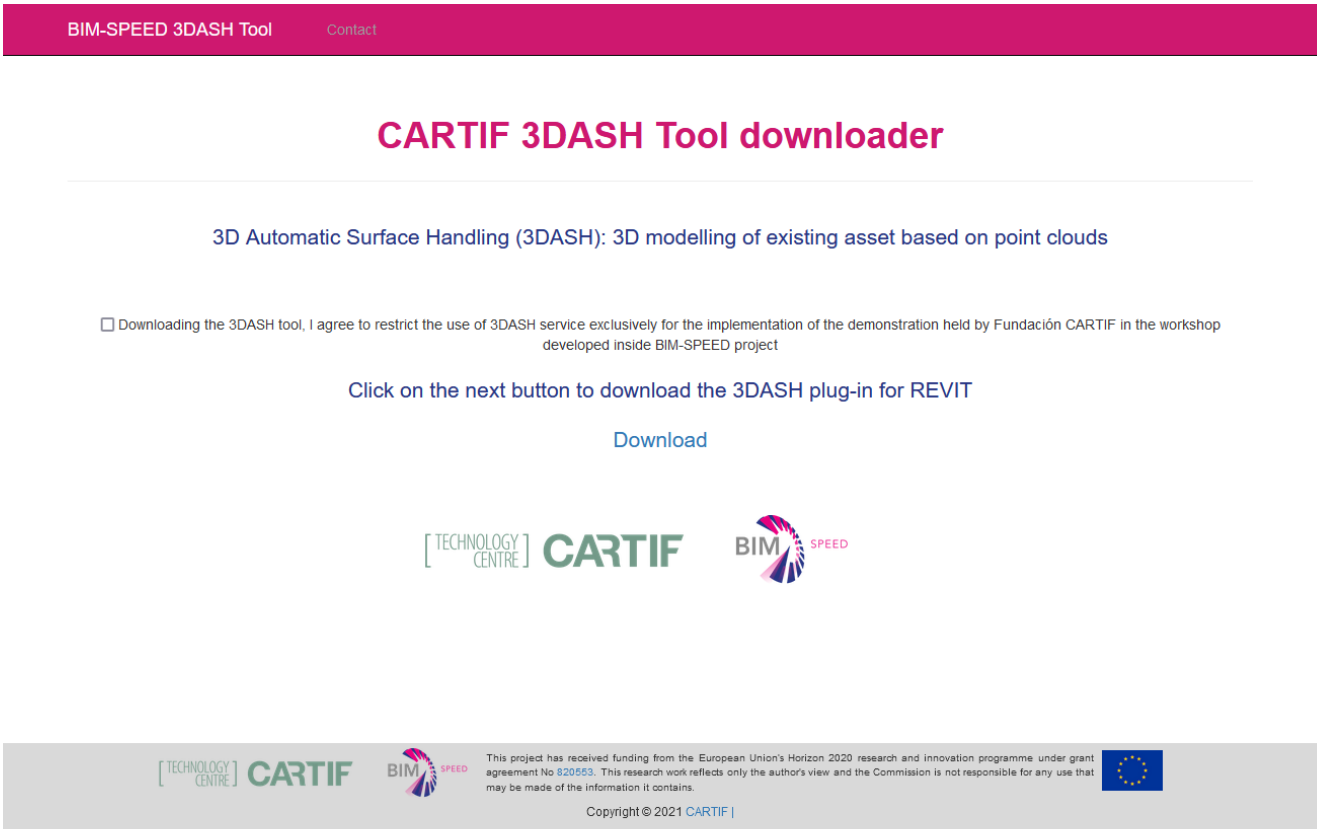
Stage - 2 Outline feasibility

Description

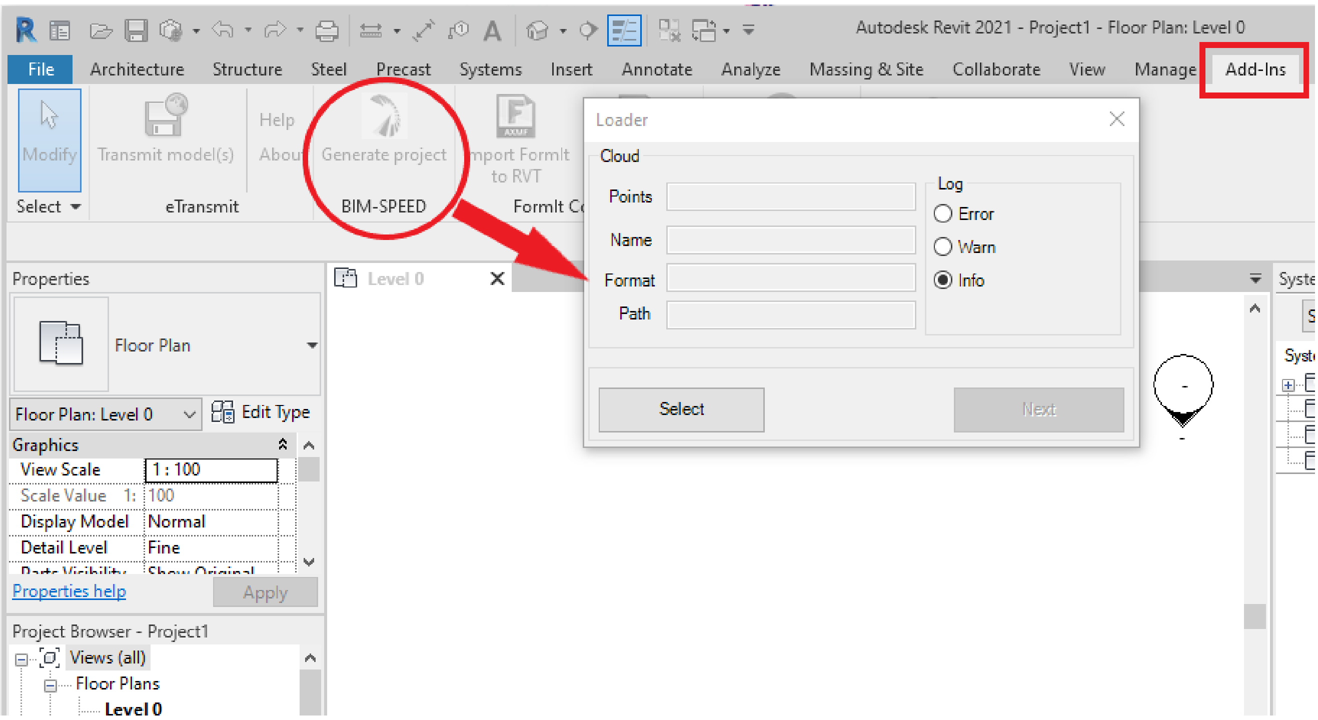
The 3DASH Tool service is integrated into BIM-SPEED platform and accessible from there. The service is available in the platform if there is a point cloud available in .ptx, .pts or .pty format.



After launch the 3DASH Tool service, and before to download the pug-in, the user must accept the terms and conditions of use of the tool in the GUI (Graphical User Interface).

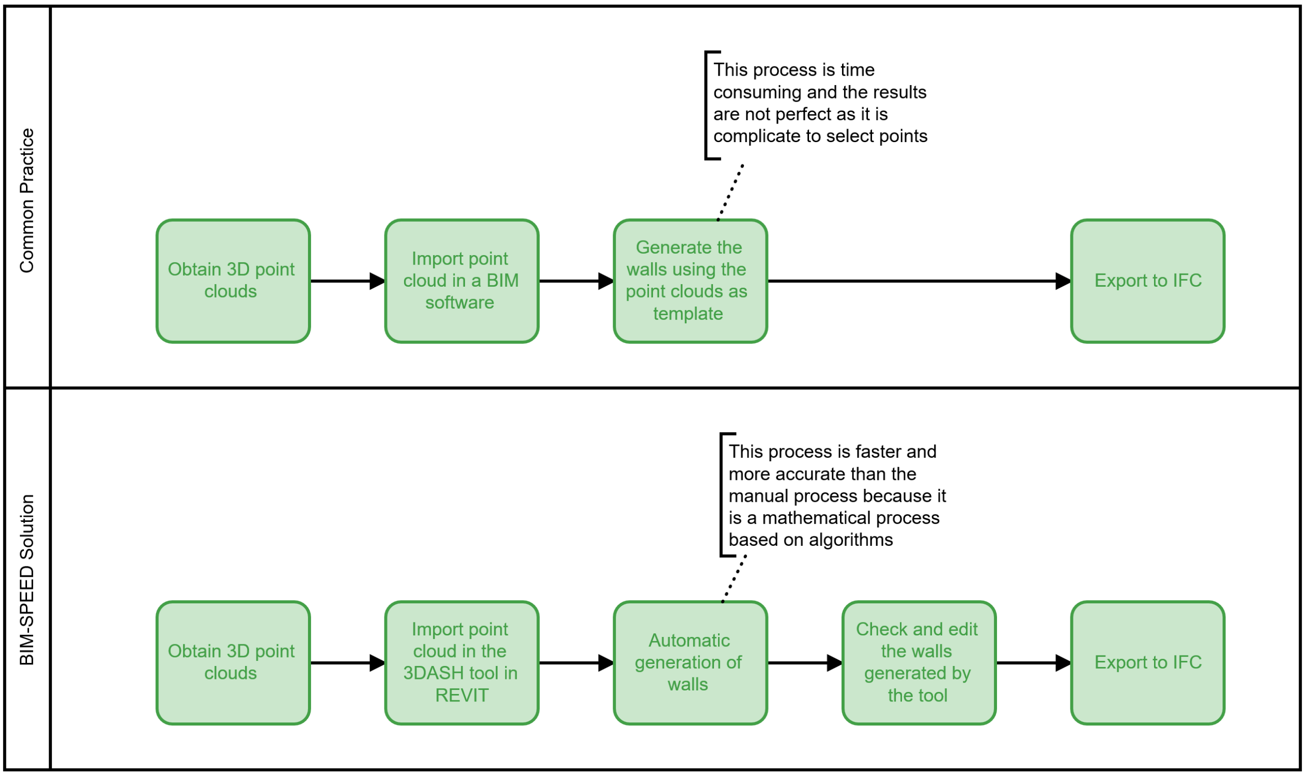


Once the plugin is installed, from REVIT you can launch the tool and follow the instructions that will appear.



Performance requirement

The Scan to BIM method defines in this document allows to achieve a reduction of time in the generation of walls from point clouds, compare with the conventional practices. This process also improves the accuracy in the generation of walls from point clouds due to the fact it is a mathematical process based on algorithms. The image below shows this comparison with the conventional practices to obtain BIM models from Point Clouds.


Common Practice
This process is time consuming and the results are not perfect as it is complicate to select points
Obtain 3D point clouds
Import point cloud in a BIM software
Generate the walls using the point clouds as template
Export to IFC
BIM-SPEED Solution
This process is faster and more accurate than the manual process because it is a mathematical process based on algorithms
Obtain 3D point clouds
Import point cloud in the 3DASH tool in REVIT
Automatic generation of walls
Check and edit the walls generated by the tool
Export to IFC

Exchange Requirements

Description

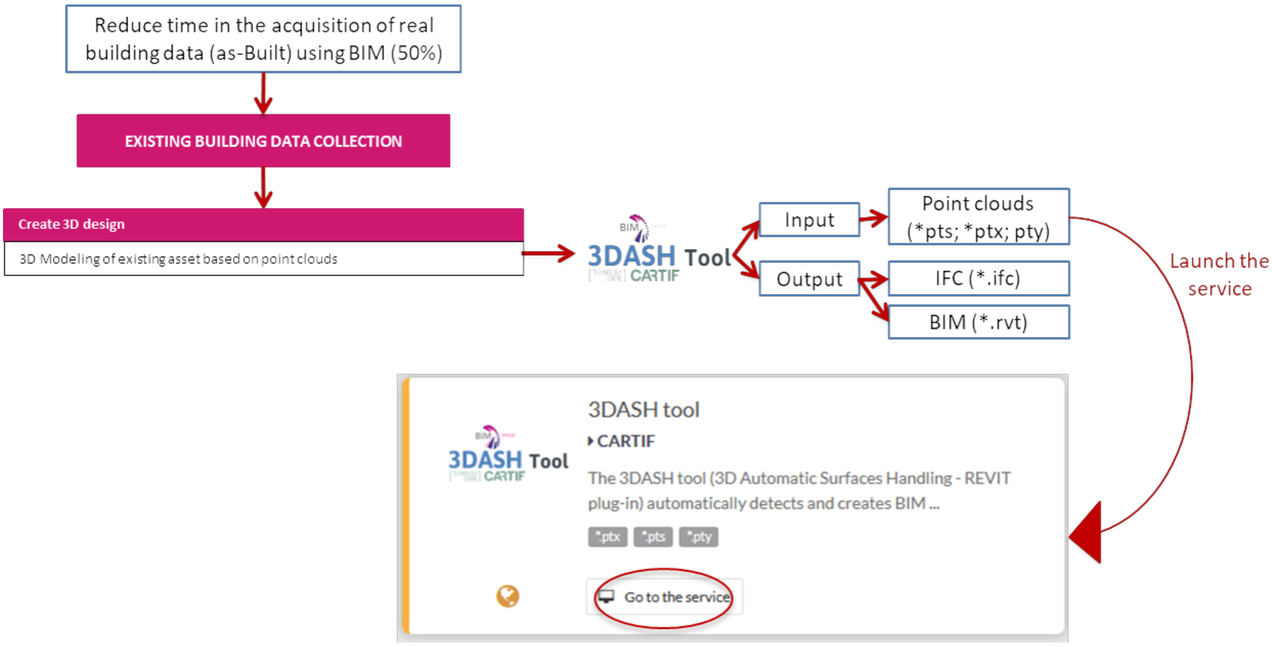
The exchange requirements of the 3DASH are explained and shown in the image below:

INPUTS:

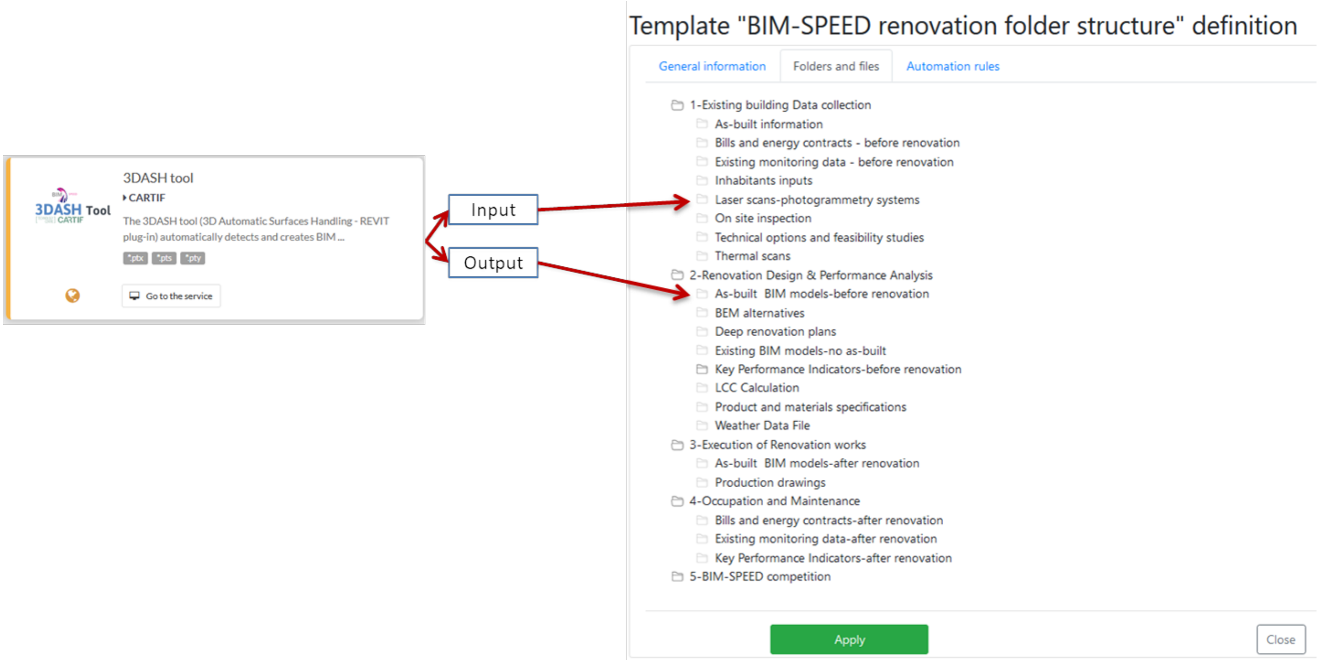
1. To launch the tool you need to download the 3DASH add-in file, and to install it in REVIT following the instruction of the Readme.txt file included.
2. Obtain point clouds: The extension of the point clouds must to be .ply/.pts/.ptx.

OUTPUTS:

1. REVIT file: the walls created in a .rvt file.
2. IFC file: The IFC can be created with the REVIT IFC exporter.



These exchange requirements will be included in the folder structure defined in the BIM-SPEED platform, as shown in the image below:



Imprint

Project Group

- Álvarez-Díaz, Sonia (CARTIF Technology Centre)
- Román-Cembranos, Javier (CARTIF Technology Centre)

Publisher

BIM Speed

Restriction and handling

These documents do not claim to be complete. Nor are they to be understood in the sense of a recommendation or guideline that is generally valid from a legal point of view, but are intended to support the client and contractor in applying the BIM method. The use cases must be adapted to the specific project requirements. The examples given here do not claim to be complete. Information is based on practical experience and should therefore be regarded as best practice and not generally applicable. As we are in a phase in which definitions are only just emerging, the publisher cannot guarantee the accuracy of individual contents.

Use Case

Decision-making for residential building renovation

This use case supports the selection of suitable renovation solutions in the context of residential buildings. It enables stakeholders to define general objectives, establish the criteria to evaluate multiple alternatives, capture the preferences of diverse stakeholders involved in the decision, and to obtain a final ranking of the alternatives according to their performance on the multiple criteria. The use case relies on the Pairwise comparison and TOPSIS methods.

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Life Cycle Stage:	ISO 22263
Maturity level:	Outlook

Use Case

Use Case Definition

USE CASE DESCRIPTION	
Title	Decision-making residential building renovation
Goal	To provide stakeholders with a structured approach to select a renovations solutions considering multiple criteria and stakeholders perspectives
Description	It enables stakeholders to define general objectives, establish the criteria to evaluate multiple alternatives, capture the preferences of diverse stakeholders involved in the decision, and to obtain a final ranking of the alternatives according to their performance on the multiple criteria. The use case relies on the Pairwise comparison and TOPSIS methods.
Input data	Stakeholders and roles Objectives and criteria Renovation alternatives Stakeholders preferences Results from different tools that calculate the performance of alternative according to the criteria
Sequence of actions	1. Project description and objectives 2. Alternatives design 3. Criteria definition 4. Pairwise comparison and weighting 5. Criteria quantification 6. Decision analysis
Primary actors	Owners, tenants, architects that participate in the decision-making process to select the final renovation solution to be implemented in the project
Secondary actors	External experts who carry out the calculations and estimations of the criteria
Pre-conditions	The diagnosis and inspection of the current conditions of the building should have been performed. BIM, BEM, and other models for the different renovation alternatives should be available
Trigger	Building renovation planning
Post-conditions	The final ranking with the evaluation of the different renovation alternatives and the final criteria weights used for the analysis are stored in a spreadsheet containing the diverse information of the process.
Frequency of use	During the renovation design stage
Support planned for	BIM-SPEED
UC Created by	TU Berlin

Aim and scope

Aim:

By providing the stakeholders with a structured procedure to characterize the project goals, capture their perspectives, analyze multiple renovation options, and obtain a final ranking the aim of this use case is to improve the quality, availability, accessibility of information by the different stakeholders involved; it also supports the involvement of end-users such as tenants and owners. Having a structure approach to analyze renovation alternatives and involve the different stakeholders at different stages also contributes to reduce the time compared to the conventional practices.

Scope:

The use case supports the stakeholders through the process to select a suitable renovation solution.

1. Multi-criteria definition: In the first stage of the framework, specific objectives for the renovation project are defined. The stakeholders select the specific objectives they intend to achieve within the renovation, from a predefined set of economic, environmental, and social objectives proposed by the framework. Once these objectives are defined, a suggested criteria tree for the specific project will be presented, including only criteria related to the specific objectives selected by the stakeholders. For instance, if one of the specific objectives is to maximize indoor comfortable conditions, the criteria Indoor air quality, Acoustic comfort, Visual comfort, and Thermal comfort are included in the tree.
2. Criteria and preferences quantification: Once the stakeholders agree on the objectives and criteria that would be included in the criteria tree, it is necessary to capture the preferences of the diverse stakeholders over those criteria. To do this, a weighting method is implemented. The aim is to allow the stakeholders to identify and represent their preferences in an easy and transparent way. Then, for each alternative, the value of each criterion is quantified.
3. Decision analysis: The weights and results for the criteria from the second stage will be aggregated to obtain a final ranking of the renovation alternatives showing their performance regarding the criteria. This will support the decision-makers to analyse the set of alternatives available and select, in a transparent and inclusive way, the one that should be implemented, taking into account the preferences of the different stakeholders. The overall process section describes each stage in detail.

Objectives

- To engage different stakeholders in the decision-making process in renovation projects;
- To implement a sustainable assessment approach considering environmental, social, and economic aspects;
- To capture the preferences of different stakeholders' groups considering their roles in the decision-making process;
- To identify which renovation alternatives are more suitable according to the objectives and preferences of the different stakeholders, in a transparent way;
- To gather and present the results from different analysis such as energy simulations, cost analysis, comfort studies, performed during the assessment of design alternatives.

Decision-making approaches are intended to provide stakeholders with a structured framework to address the process of making decisions, especially when multiple and conflicting objectives and criteria can appear. As presented below, the approach proposed by BIM-SPEED provides clear steps to conduct the decision-making process. Having the structure procedure to make the decision can reduce the time to select the final renovation solution. Since the stakeholders involved in the project are requested to perform specific actions at different stages, they can engage in the renovation, facilitating the process. Capturing the stakeholders' perspectives through the weighting method and integrating them with the alternatives' performances enable a transparent way to make the decision. The general decision tree included in the frameworks comprise social, economic, and environmental elements to encourage stakeholders to establish a more comprehensive evaluation.

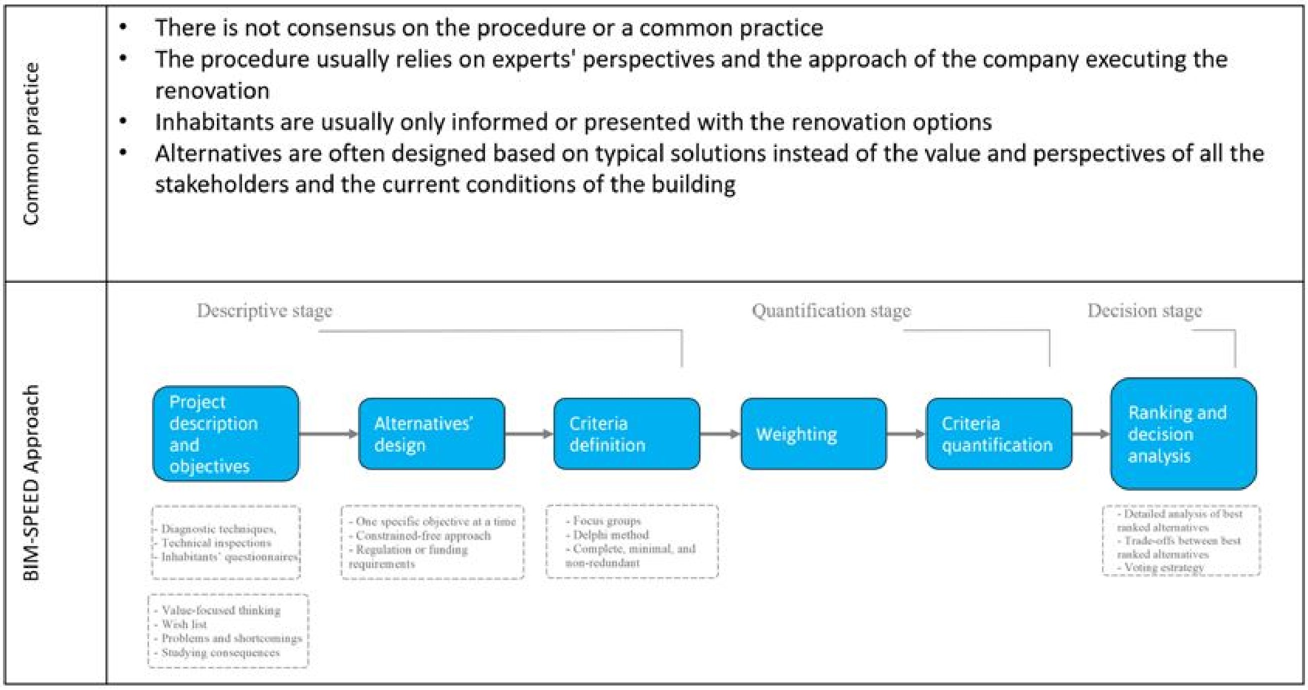

Fig: Comparison between common practices and BIM Speed approach in decision making

Limitations

- The tool supporting the use case allow the participation of five stakeholders' groups, this could be a constraint in cases involving more groups
- The consistency of the matrixes for the pairwise comparison method can be difficult to reach in some specific cases
- The number of required comparisons increases according to the number of objectives and criteria included in the decision tree

References

- BIM-SPEED D7.1 - Multi-criteria decision-making method and tool for housing renovation projects
- The tool supporting the use case can be download in http://dx.doi.org/10.14279/depositonce-10659

Attached Images

- comparison.PNG
  (20211208012321-comparison.PNG , 109.88 KB)

Process Definition

Overall process

Description

General description of Overall Process:

The users should follow six steps. The first three steps correspond to the Multi-criteria definition stage where the stakeholders should:

- Make a general description and characterization of the project.
- Define the potential renovation alternatives they would like to evaluate.
- In the third step, the different stakeholders should discuss and define the criteria that will be used to evaluate those alternatives.

The Criteria and preferences quantification stage includes steps four and five

- in step four, different groups of stakeholders provide their preferences according to the criteria that were established. The criteria weights are calculated according to the input of the users.
- In step five, the performance of the alternative according to each criterion are quantified.

At the last stage, Decision analysis,

The results from the criteria quantification and the preferences of the stakeholders are combined to rank the alternatives and identify which are the alternatives that perform the better on the criteria, and at the same time capture the preferences of the different stakeholders.

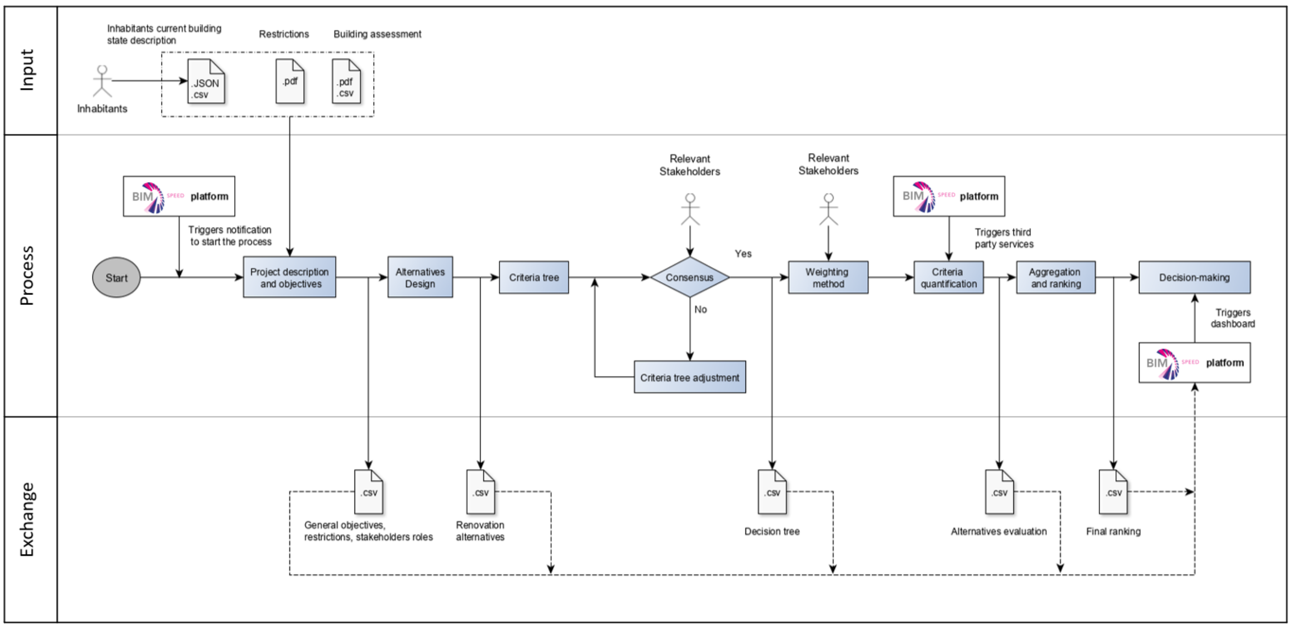

Figure 1: Decision-making procedure

The implementation of the use case in one demonstration case of the BIM-SPEED EU project is presented to illustrate the application of the proposed workflow.
Multi-criteria definition stage:
• Description and characterization of the project.
The building to be renovated corresponds to one of the dwelling units of a duplex residence unit (two-family) constructed in 1961 and located in Gdynia, in the North of Poland. The external walls of the building are made of full brick and have a thickness of 56cm, the building is partially insulated with expanded polystyrene. It is connected to the natural gas and the heating system is based on the gas boiler. The reasons for the renovation are: very low building condition, the age of the building, low energy performance and the need to rearrange and enlarge the usable area. As-built 2D drawings and BIM model are available for the building. The decision-maker of the process is the private owner of the unit.

General information	
Location	Gdynia (Poland)
Use category	Single family household (half of duplex)
Building type	Multi-storey building
Construction year	1961
Renovation year	---
Number of floors	3
Number of apartments/units	1 dwelling

Table 1: General information

- Define potential renovation alternatives.

Table 2 summarizes the renovation scenarios considered for the building:

	ETICS	Ventilated	Roof insulation	Windows replacement	Second window	Floors insulation
Renovation Scenario 1	EPS 032 Insulation XPS 200-036 (basement)	----	EPS 032 insulation	PVC triple-glazed windows	---	EPS 100 Insulation EPS 036 (basement floor)
Renovation Scenario 2	---	EPS 032 insulation	---	---	PVC triple-glazed windows	EPS 100 Insulation (basement floor)
Renovation Scenario 3	EPS 032 Insulation XPS 200-036 (basement)	---	EPS 032 insulation	PVC triple-glazed windows	---	EPS 100 Insulation (basement floor)

	Lighting	Radiators	Piping	Boilers	Ventilation	Thermal solar
Renovation Scenario 1	LED 7-60W	---	PVC triple-glazed windows	Gas condensing boiler	---	Evacuate-tube collectors
Renovation Scenario 2	LED 7-60W	Panel 917-1072W	---	---	Decentralized mechanical ventilation	---
Renovation Scenario 3	LED 7-60W	---	---	---	---	---

Table 2: Overview of Gdynia renovation scenarios

1. In Renovation scenario 1, the following interventions has been analysed:

ETICS – All facades above the ground were insulated with 0,12m thic EPS 032 with λ=0,032W/mK, bacement external walls were insulatet with 0,12m thic XPS 200-036 with λ=0,036W/mK
Roof insulation – roof insulated with 0,12m thic EPS 032 with λ=0,032W/mK

Windows were replaced with triple-glazed windows. The frames are made of polyvinylchloride (PVC). The U-value of 0,90 W/(m2 K) of the windows was used.
Floor insulation – floors between storeys were insulated with 0,04m thic EPS 036 with λ=0,036W/mK, bacement floor were insulated with 0,10m thic EPS 100 with λ=0,036W/mK
Lighting – all light sources were replaced by LED technology
Piping – all pipes in system were replaced with new ones
Boilers- boiler was replaced with gas condensing boiler Thermal solar was installed

2. In Renovation scenario 2, includes:
Ventilated facade – all walls insulated with 0,12m thic EPS 032 with λ=0,032W/mK and with 0,03m air gap
Second window - triple-glazed windows. The frames are made of polyvinylchloride (PVC). The U-value of 0,90 W/(m2 K) of the windows was used
Floor insulation – floors between storeys were insulated with 0,04m thic EPS 036 with λ=0,036W/mK, bacement floor were insulated with 0,10m thic EPS 100 with λ=0,036W/mK
Radiators- radiators were replaced with 917-1072W panel radiators
Decentralised mechanical ventilation was installed

3. In Renovation scenario 3,
ETICS – All facades above the ground were insulated with 0,12m thic EPS 032 with λ=0,032W/mK, bacement external walls were insulatet with 0,12m thic XPS 200-036 with λ=0,036W/mK
Roof insulation – roof insulated with 0,12m thic EPS 032 with λ=0,032W/mK
Windows were replaced with triple-glazed windows. The frames are made of polyvinylchloride (PVC). The U-value of 0,90 W/(m2 K) of the windows was used.
Floor insulation – floors between storeys were insulated with 0,04m thic EPS 036 with λ=0,036W/mK, bacement floor were insulated with 0,10m thic EPS 100 with λ=0,036W/mK
Lighting – all light sources were replaced by LED technology
Piping – all pipes in system were replaced with new ones
Boilers- boiler was replaced with gas condensing boiler
Thermal solar was installed

• Objectives and criteria setting.
The private investor renovating their house is aware of the risks caused by global warming and pollution, diverse economic, social and environmental aspects are relevant for them. In a sessions with the architect responsible for the project, the owner defined the objectives and criteria for the project, they indicated multiple aspects that they wanted to consider during the evaluation of the renovation alternatives. Figure 2 depicts the final decision tree for this case.

Environmental	**To reduce Primary energy**	**Operational primary energy**
	To reduce Energy demand	**Total energy demand**
		Energy savings
	To reduce Environmental impacts	**Global warming potential**
Social	**To improve Indoor conditions**	**Visual comfort**
		Indoor air quality
		Thermal comfort
	To increase social acceptance	**Aesthetics**
	To increase social technical benefits	**Renovation time**
		Durability
Economic	**To reduce Cost**	**Investment cost**
		LCC Cost
	To reduce O&M Cost	**Maintenance cost**
		Operational energy cost

Figure 2: Decision tree for Gdynia

Criteria and preferences quantification stage:

• Criteria weights.
The owner of the apartment indicated their preferences on the different criteria included in the decision tree following the pairwise comparison method, the results are summarized in Table 3. The most important criteria are the investment cost (23,15%), thermal comfort (15,68%) and global warming potential (15,15%).

Criteria	Weights
Operational primary energy	3,03%
Total energy demand	2,53%
Energy savings	12,63%
Global warming potential	15,15%
Visual comfort	3,14%
Indoor air quality	3,14%
Thermal comfort	15,68%
Aesthetic	2,96%
Renovation time	1,40%
Durability	7,02%
Investment cost	23,15%
LCC cost	4,63%
Maintenance cost	4,63%
Operational energy cost	0,93%

Table 3: Weighting criteria for Gdynia

- Alternatives' performance.

To study the different renovation scenarios, energy simulations were performed directly on EPlus, modifying the BEM model in the .idf file according to the components included in each of the scenarios. The performance of the renovation scenarios according to other criteria was calculated using different methods. The results are presented in Table 4. The best performances are indicated with bold font.

Alternative	Operational primary energy [kWh/m²·year]	Total energy demand [kWh/m²·year]	Energy savings [kWh/m²·year]	Global warming potential [years]
Baseline	---	180,3	---	---
Renovation scenario 1	**88**	**124,1**	**56,2**	20
Renovation scenario 2	117,42	156,6	23,7	**28**
Renovation scenario 3	101,51	**124,1**	**56,2**	18

Alternative	Visual comfort [-]	Indoor air quality [-]	Thermal comfort [-]	Aesthetics [-]	Renovation Time [-]	Durability [years]
Baseline	---	---	---	---		
Renovation scenario 1	3.5	**4,7**	4,4	3	2	**12**
Renovation scenario 2	5	4,4	4,7	**5**	1,5	**12**
Renovation scenario 3	**4,8**	4,2	**4,8**	3,3	**1**	9

Alternative	Investment cost [€]	LCC cost [€]	Maintenance cost [€]	Operational energy cost [€]
Baseline	---	---	---	---
Renovation scenario 1	33500	369000	**3240**	**1390**
Renovation scenario 2	30500	381000	3590	1510
Renovation scenario 3	**25500**	**365000**	3770	1620

Table 4: Renovation scenarios for Gdynia, general results

Decision analysis.
After analyzing the data, the decision-making framework implemented on the Excel spreadsheet generated a ranking of the most suitable solutions based on the scores allocated to each criterion. According to the results, renovation scenario 3 is the most suitable solution. It is the most complete renovation strategy that will bring benefits in terms of investment cost, thermal comfort and global warming potential. This renovation alternative performs the best according to thermal comfort and investment cost, which are two of the three most important criteria. This scenario performs similar to scenario 1 in terms of criteria such as energy savings, durability, and total energy demand. However, scenario 3 performs the best in other aspects such as LCC cost, visual comfort, and renovation time. Figure 2 presents a screenshot of the model including the final renovation solution for the building.

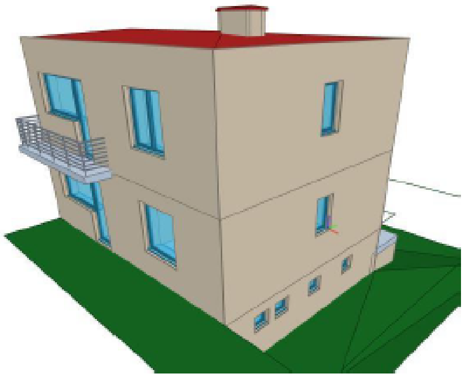

Figure 3: Final renovation solution for Gdynia

Attached Images

- finalprocess.PNG
  (20211203110000-finalprocess.PNG , 159.29 KB)

ISO 22263

Stage - 1 Conception of need

Description

At this stage, the proposed use case encourages the evaluation of the existing conditions of the dwelling unit/s, identification of potential restrictions, general objectives for the renovation project, and the role of the different stakeholders. In the first step of the proposed framework, stakeholders are requested to characterize the project, start a discussion regarding expectations, current problems encounter by the inhabitants, restrictions due to budget, time, and regulations. The results from this process are essential for the design of potential renovation alternatives that fulfill the objectives of the project, comply with the applicable regulation, are compatible with the existing conditions of the building, and meet additional requirements. Furthermore, the relevance and ease of implementing a structured decision making process is also detailed in the description and objectives section of the use-case.

Performance requirement

As a pre-requisite to start the implementation of the use case at this stage, the following are required:

- An assessment of the current state of the building and/or Inhabitants current building state description
- Restrictions around the dwelling units and the context of the project

Stage - 4 Outline conceptual design

Description

At this stage, the proposed use case supports the stakeholders to select the final renovation solution to be implemented on the project. Once the stakeholders' preferences and the performance of the different alternatives are integrated to obtain the final ranking, stakeholders can analyze the options, main design elements of them, and trade-off between different aspects to make the final decision. The final renovation solutions is the starting point for the conceptual design and planning stages.

Performance requirement

As a pre-requisite to start the implementation of the use case at this stage, the following are required:

- The preferences of stakeholders on the decision tree for the weighting method
- Detailed description of the renovation alternatives to be evaluated
- If BIM-based tools are used to quantify criteria, dedicated BIM models for each renovation alternatives are required
- Depending on the criteria selected to evaluate the renovation alternatives, different models for the alternatives would be required, e.g. Building Energy Models, Acoustic models

Exchange Requirements

Description

The main exchange activities are performed between the spreadsheet supporting the decision-making framework and the BIM-SPEED platform as presented in figure below. The main elements exchanged are in the form of .csv files. The information collected through the decision-making framework can be transferred to the platform where it can be leveraged by external services. For instance, one of the planned services is a dashboard to display the information in a user-friendly interface to support the stakeholders to make the final decision. The characterization of the project, the decision tree with objectives and criteria, the preferences of the stakeholders, the performance of the alternatives and the final ranking can be gathered and displayed together to facilitate stakeholders to make the final decision. Additional exchanges occurred between external services and the platform at the criteria quantification stage. The format and data exchanged at this step depends on the criteria selected to evaluate the alternatives. Some examples are presented in the figure below.

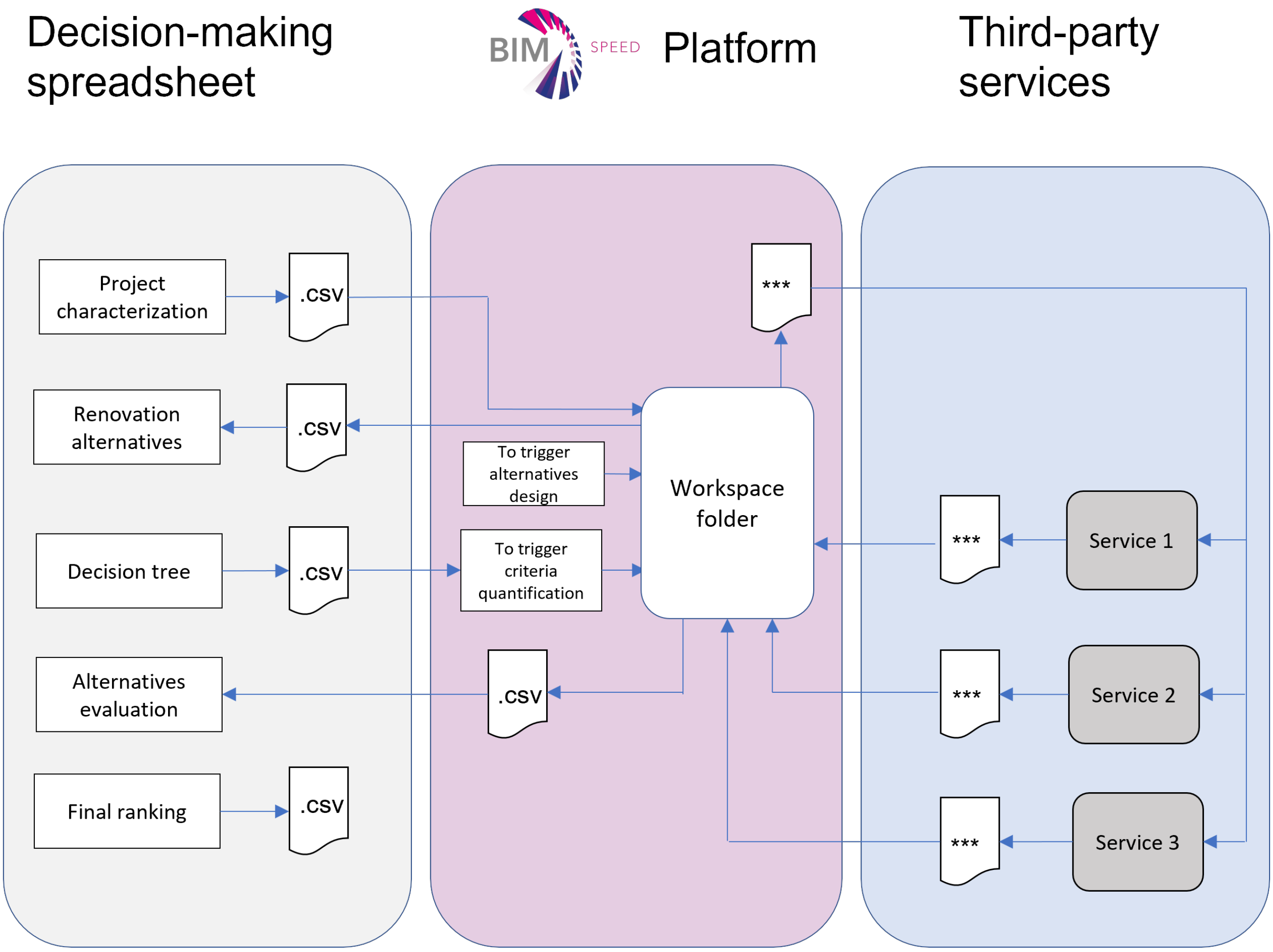

Fig: Exchange requirements

Attached Images

- exchange.png
  (Exchange-Requirements/20211203111026-exchange.png , 227.63 KB)

Imprint

Project Group

- Magdalena Dzik-Bogucka
- Rafał Łukaszewski

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BIM Speed

Restriction and handling

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Use Case

Model Checks for compliance testing and design coordination

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Identifier:	BIMSPEED_UC10_HTV
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Last change:	2022-08-25
Life Cycle Stage:	ISO 22263
Maturity level:	Outlook

Use Case

Management Summary

This document aims at describing the use case 'Model Check for compliance testing and design coordination', which is implemented as part of the BIM-SPEED EU Horizon 2020 project.

Use Case Definition

The implementation of BIM has been carried out over several uses across life cycle of existing buildings in the BIM-SPEED Project. As the structures to be modelled are existing buildings, the 3D BIM models are modeled based on as-built documentation and enriched with information and data relevant for the renovation project.

To reach the aimed goals of a specific project, several BIM use cases will be performed. These BIM use cases require a 3D BIM model which is consistent to all requirements. The verification of this 3D BIM model needs to be assured to guarantee the interoperability for all needed BIM use cases.

The aim of this use case is, to ensure that the above requirements for the 3D BIM model are fulfilled by implementing and performing model checks. The outcome of these checks aids regional regulations and/or standards verification based compliance testing and ensures a well-defined model which captures accurate information for further geometrical checks for coordinated design and geometrical accuracy.

USE CASE DESCRIPTION	
Title	Model Checks for compliance testing and design coordination
Goal	The use case aims to ensure the semantic and numerical definition of elements of a 3D model for compliance testing and design coordination.
Description	The use case explains the process to perform a model check. This process ensures that the model is valid and checked to guarantee the use of the model to perform the needed use cases to reach the aimed project goals.
Input data	• EIR (Exchange Information Requirement) / BEP (BIM Execution Plan) • 3D BIM model • Naming conventions • National/regional standards, Design rules • Model Element Matrix
Sequence of actions	• Collect the design rules to be considered and interpret them to a format for using in suitable model checking software • Evaluating the results of semantical and numerical checks
Output Date	Evaluate the results of semantical and numerical checks and providing a verified 3D BIM model, so that a decision can be made on whether further BIM use cases based on this model can be performed.
Primary actors	BIM author, BIM coordinator
Secondary actors	Designer of the renovation workflow
Trigger	Building Renovation Design
Post-conditions	The checked and verified 3D BIM models are to be handed over for geometrical checks
Frequency of use	Every time within a building renovation project, a data drop to deliver a status of the 3D BIM model is required.
Support planned for	BIM-SPEED
UC Created by	HOCHTIEF ViCon

Aim and scope

The aim of the BIM-SPEED project is to:

- **reduce the time** of deep renovation projects
- develop **affordable tools** and integrate them into the BIM-SPEED platform
- **standardize procedures** for implementing renovation solutions

The general objectives of a model check are to ensure the following:

- **Safety** - that all relevant information is available and that the geometry of the 3D BIM model corresponds to the inventory
- **Guarantee** - that further work steps based on the 3D BIM model can be processed correctly and without data loss
- **Reliability** - that all relevant information can be accessed correctly
- **Correctness** - of the calculated results (no incorrect calculations)
- **Time saving** - due to automated checking and predefined workflows

With regard to BIM-SPEED project, the specific aim is to ensure that 3D BIM models can be made accessible on the BIM-SPEED platform such that users have access to 3D BIM models that have already been verified.

Objectives

One of the main objectives of the BIM-SPEED project is to reduce the time of deep renovation projects by 30%. The implementation of model checks makes a major contribution to this, through automated and standardized model check processes, errors in the model can be detected at an early stage and efficiently corrected. Following picture shows the difference between the conventional way performing the checks and effort reduction by implementing automatic model checks. More details follow below.

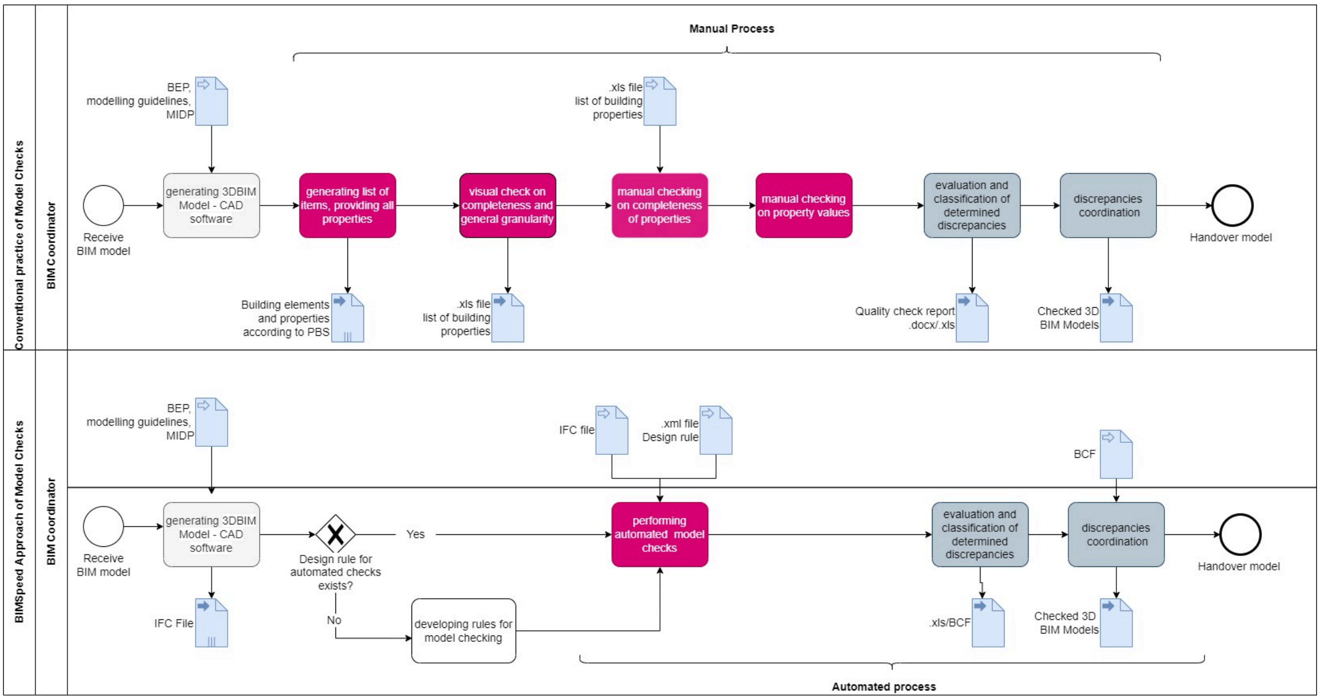


Figure1: Comparison between conventional and BIM-SPEED approach to model checking

Rather obvious is the reduction of working time to perform the model checks.

Assuming to setup and define model checks for a 3D BIM model LoD (Level of Detail) 400 to 450 of a common residential building with 4 levels and approx. 300m² living space as reference, the time required cumulated is (based on experience):

- Conventional: 5-7 working days
- BIM-SPEED: 2-3 working days

The picture above highlights the inclusion of several manual process steps in the workflow of checking a 3D BIM model in conventional way, while the BIM-SPEED approach clearly outlines the consolidation of all these steps into a single automated process step. This accounts for impactful reduction in time, along with avoiding errors by providing standardized check templates. Furthermore, the possibility to export issues as BCF files, directs the BIM author directly to each issue within his own CAD or viewer software, which enhances the process of verification by avoiding communication errors.

In the course of the model checks,

- Semantical checks on one hand verify the consistence of the elements. That includes checking of the nature of the elements as it might be, that some of the shown elements in the model are not real solid 3D elements. Additionally the existence of all needed parameters will be verified and finally compliance to all the naming conventions (file/ elements/ levels/ layers/ properties etc.) will be confirmed.
- Numerical Checks on the other hand guarantee the evaluation of numerical information provided within the properties. Given values will be safeguarded as well as the correctness of selectable or calculated values.

Combining both types of model checks in the end will assure compliance to national/ regional specific/ other standards and verify ranges along with naming/semantic/other informational requirements for further BIM uses. One main focus is, to ascertain the handover to geometrical verification procedures, like clash detection and/or deviation analysis. These aids avoiding errors in geometrical accuracies and saving costs and time by identifying clashes of different disciplines already in project execution stages.

Limitations

- The success of the model checks is based on well-defined project-specific requirements in terms of the aimed BIM use cases to be performed. In addition the resulting modeling specifications need to be described in a clear and coherent way.
- The success of the properties testing, on the other hand, depends exclusively on the detail of modeling specifications, which have to be regarded when generating the 3D BIM model. The quality of the model checks can only be as good as the predefined model specifications are. The overall goal is, to create a model and project independent syntax, based on standardized modeling specifications, which makes it possible to test different 3D BIM models with the same procedure.

Advantages

Standardizing Model Requirements, country-specific features excluded, as basis for the 3D BIM Model generation, will allow to develop a generalized workflow for verifying 3D BIM models in terms of geometry and provided information within the model elements, which can be applied to different models and different projects.

Attached Images

- Conventional vs BIMSPEED.jpg
  (20220825022425-Conventional-vs-BIMSPEED.jpg , 152.4 KB)

Process Definition

Overall process

Description

The basic process of a model check is not changed within the scope of the BIM-SPEED project, it is only adapted based on the BIM-SPEED specific requirements.

In order to illustrate the importance of the individual model checks for the design coordination process, an overview is given in the following process map. The complete design coordination process requires further approval (e.g. also approval of the 2D Drawings, etc.) but this pictures shows the part of the process to assure an approved 3D BIM model to be handed over for further coordination tasks within the complete process.

The process of the individual model checks is explained in more detail in further sections

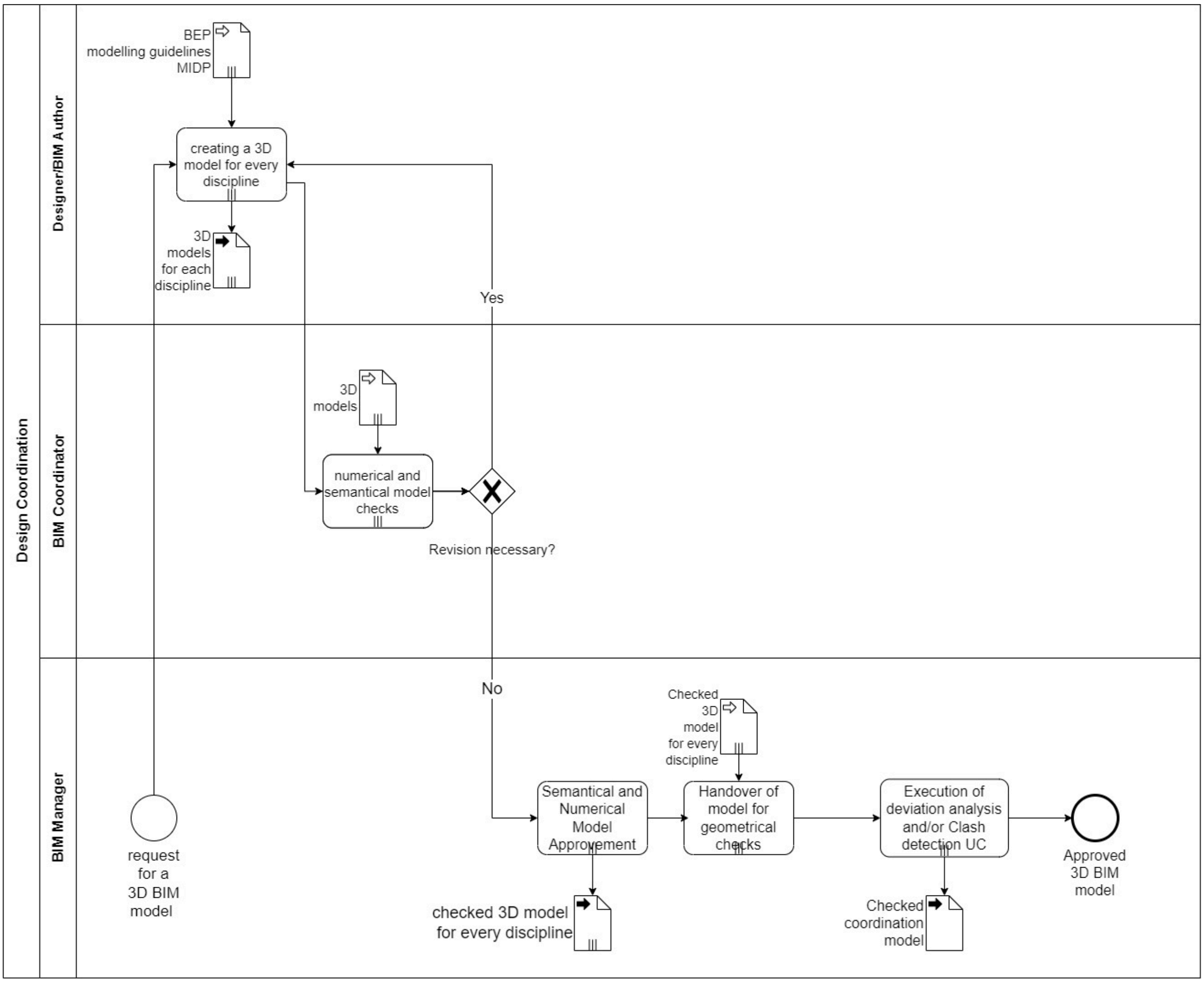


Figure2: Extract of Design Coordination Process

In the general process, the BIM author generates the 3D BIM model including other information and design related requirements coming from project standards like BEP, Modelling Guidelines and MIDP and generates the corresponding required 2D Drawings out of it. Upon creating the 3D BIM model, this is handed over to the BIM coordinator who carries out numerical and semantical checks based on the model requirements. Upon carrying out these checks, the discrepancies are realized, classified and shared with the BIM author who then has to update the 3D BIM model accordingly.

The following process map gives breakdown of the specific process steps for semantical and numerical model checks.

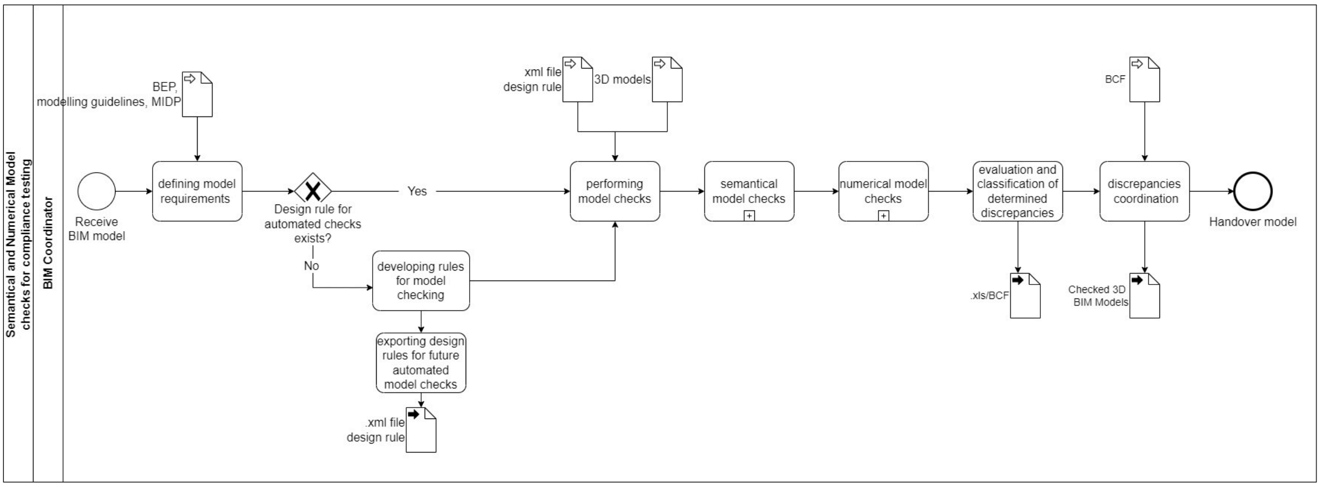


Figure 3: Semantical and Numerical model checks process

The process of semantical and numerical checks consists of initially defining model requirements which forms the basis for the process of model checking. Within the scope of BIM-SPEED Project automated checks have been implemented to reduce the time required for carrying out these checks. Upon identification of design rules, the existence of pre-defined templates for these design rules is checked. If this exists, such rule is imported to carry out automated checking of the 3D BIM Model. If such pre-defined automated rule does not exist, it has to be developed (the process can be referred to the section of demonstration case).

Semantical Check

Semantical model checks verify the consistence of the elements. Therefore, each model element is checked regarding its nature, because only elements that are created as 3D volumes can processed smoothly in further activities. For example, 2D elements can lead to miscalculation in quantity take off or in energy calculations and may be ignored, when performing a clash detection. Semantical model checks approve whether the properties assigned to a model element match the corresponding naming convention. Compliance with naming convention is a pre-requisite for a 3D BIM model, particularly automated model checking to be evaluable by software solutions for further BIM use cases. The naming convention needs to be defined at the beginning of each project.

Numerical Check

The existence and compliance of all needed properties are already verified by the semantical checks. Following on this, the numerical checks verify the values of all properties for each element, regarding project specific requirements and accordance to predefined, selectable or calculated values.

Discrepancies resulting from semantical and numerical model checks, are classified and reported to the BIM author to be corrected and verified. Report format in this case is the BCF format, which allows automated guidance to relevant issues within the authoring software.

The following section gives a demonstration of the operation process described in the process map and its results.

Demonstration Case

The 'Vitoria demonstration site' in Spain, is a residential building located in the city of Vitoria-Gasteiz. Several design rules have been identified such as country specific standards and project specific requirements. A list of mandatory properties has been collected (attached) and translated to single xml files, to be imported while carrying out these checks. A total of 59 semantical and numerical checks were derived which can also deal as templates and can be enhanced based on requirements.

BIMSPEED Properties					
Model Element/ IfcEntity	**Country**	**BIMSPEED General**	**BIMSPEED Country Specific**	**Type**	**Value**
IfcBuilding	General	BIMSPEED_Building	BIMSPEEDCountry	STRING	Spain; Germany; Netherlands; Poland; Romania; Bulgaria; Italy
IfcBuilding	General	BIMSPEED_Building	BIMSPEEDOccupancyType	STRING	MultiFamily; Single Family
IfcBuilding	General	BIMSPEED_Building	BIMSPEEDNumberOfStoreys	INTEGER	Number of Storey
IfcBuilding	ES	BIMSPEED_Building	ES_BIMSPEEDClimateZone	STRING	α; A; B; C; D; E
IfcBuilding	IT	BIMSPEED_Building	IT_BIMSPEEDClimateZone	STRING	α; A; B; C; D; E; F
IfcZone	General	BIMSPEED_Zone	BIMSPEEDPubliclyAccessible	BOOLEAN	Truth; False
IfcZone	General	BIMSPEED_Zone	BIMSPEEDNetAreaPlanned	INTEGER	[m^2]
IfcZone	NL	BIMSPEED_Zone	NL_BIMSPEEDFireCompartment	BOOLEAN	Truth; False
IfcZone	BG	BIMSPEED_Zone	BG_BIMSPEEDHandicapAccessible	BOOLEAN	Truth; False
IfcZone	NL	BIMSPEED_Zone	NL_BIMSPEEDHeight	INTEGER	[m]
IfcZone	NL	BIMSPEED_Zone	NL_BIMSPEEDGrossArePlanned	INTEGER	[m^2]
IfcZone	NL	BIMSPEED_Zone	NL_BIMSPEEDDistanceToExit	INTEGER	[m]
IfcSpace	General	BIMSPEEDSpace	BIMSPEEDCategory	STRING	Kitchen; Bathroom; WC; Auxilary Room; Corridor; Hall; Stairs; Living Room; Bedroom
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

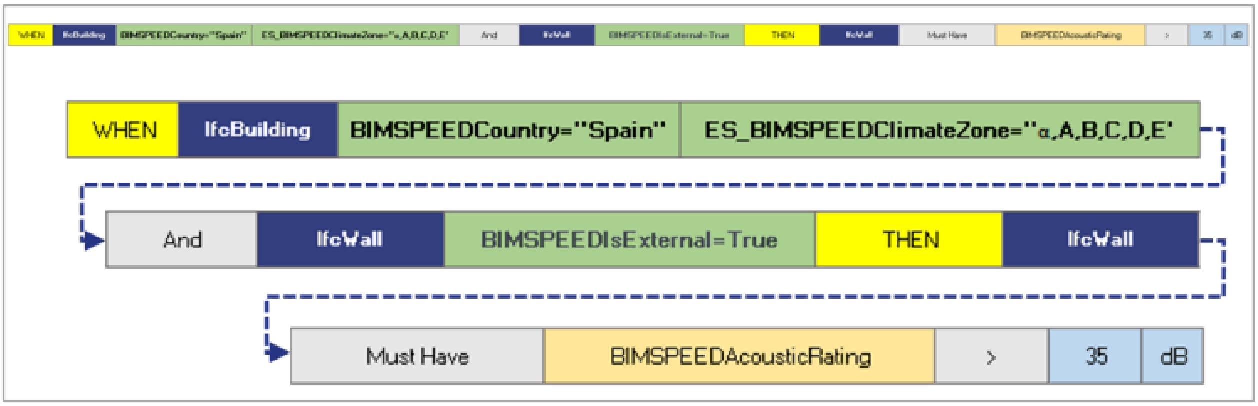
The table above gives a glimpse to some properties defined from which design rules and checking criteria are derived.

Following an example workflow to define model checks based on existing design rules:

One textual design rule for a Spanish Construction project, identified within this project says:

"In Spain in climate zone A-E, each external wall needs to have an acoustic rating of more than 35dB"

This textual design rule now is translated to a logical syntax, as shown in the image below. Doing this enables to identify required Entities and Properties to set ab the script based model check.



This rule can be explained in words as:

If there is a geometry model of a building, then there will be an entity "IfcBuilding". When there is an entity "Ifc Building" and the general attribute "BIMSPEEDCountry" provides the value "Spain" as well as the country specific attribute "ES_BIMSPEEDClimateZone" provides one of the values "α, A, B, C, D or E", AND if the entity IfcWall can by identified as external wall using the attribute "BIMSPEEDIsExternal" providing the value "True", then this entity of "IfcWall" must have the attribute "BIMSPEEDAcousticRating" with a value bigger than 35,00db.

This is translated to the code (as shown below) and exported as an xml file for automated checks:

```
  <?xml version="1.0" encoding="UTF-8"?>
- <filterrules xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  - <preconditions>
    - <frset name="newPreconditionGroup">
        <filter name="BIMSPEED_Building:BIMSPEEDCountry" default="1" pattern="Spain" dtype="xs:string"/>
        <filter name="BIMSPEED_Wall:BIMSPEEDIsExternal" default="1" pattern="true" dtype="xs:boolean"/>
        <filter name="BIMSPEED_Building:ES_BIMSPEEDClimateZone" default="1" pattern=""A" "B" "C" "D" "E" "α"" dtype="xs:string"/>
      </frset>
    </preconditions>
  - <attributerules>
    - <frset name="newRuleGroup">
        <filter name="BIMSPEED_Wall:BIMSPEEDAcousticRating" default="3" pattern=">35" dtype="xs:string"/>
      </frset>
    </attributerules>
  </filterrules>
```

Figure 4: XML Script for defining the model check within the model checking software

Importing the corresponding 3D BIM Model and this model check rule as xml file now into the model checking software, will enable to perform the model check.

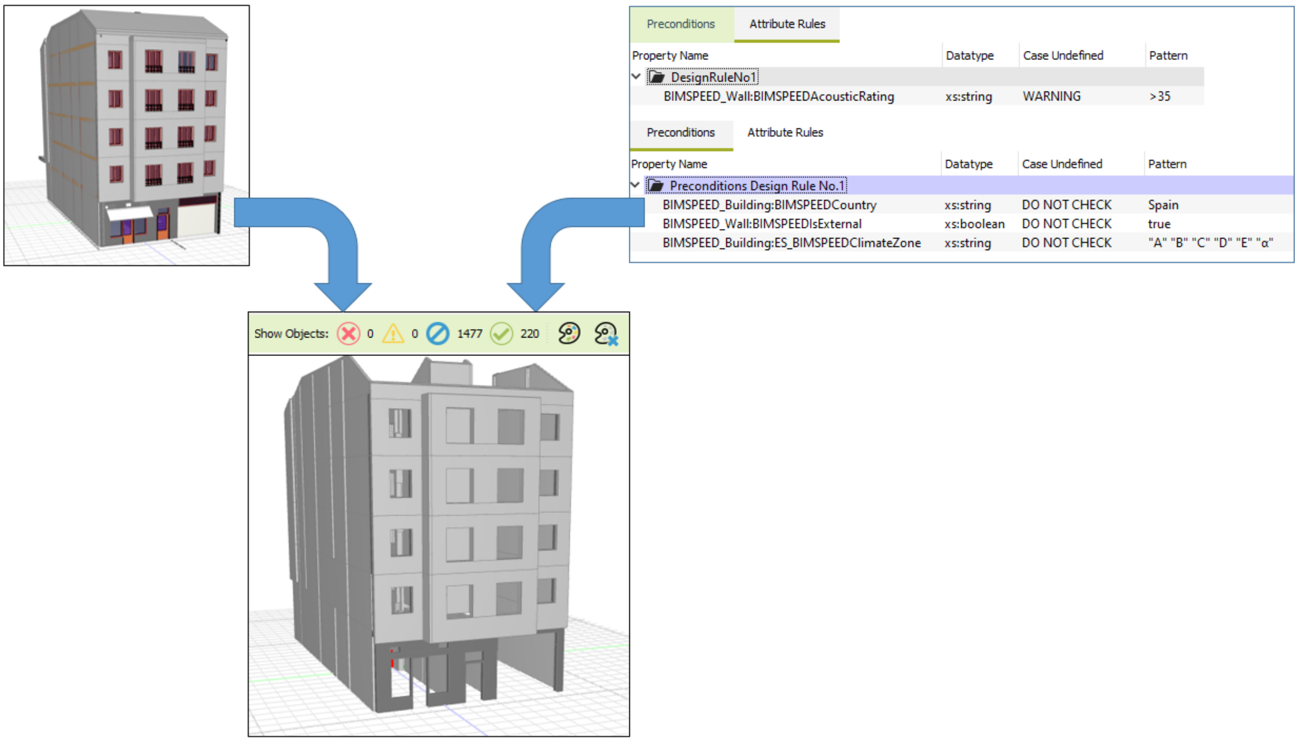
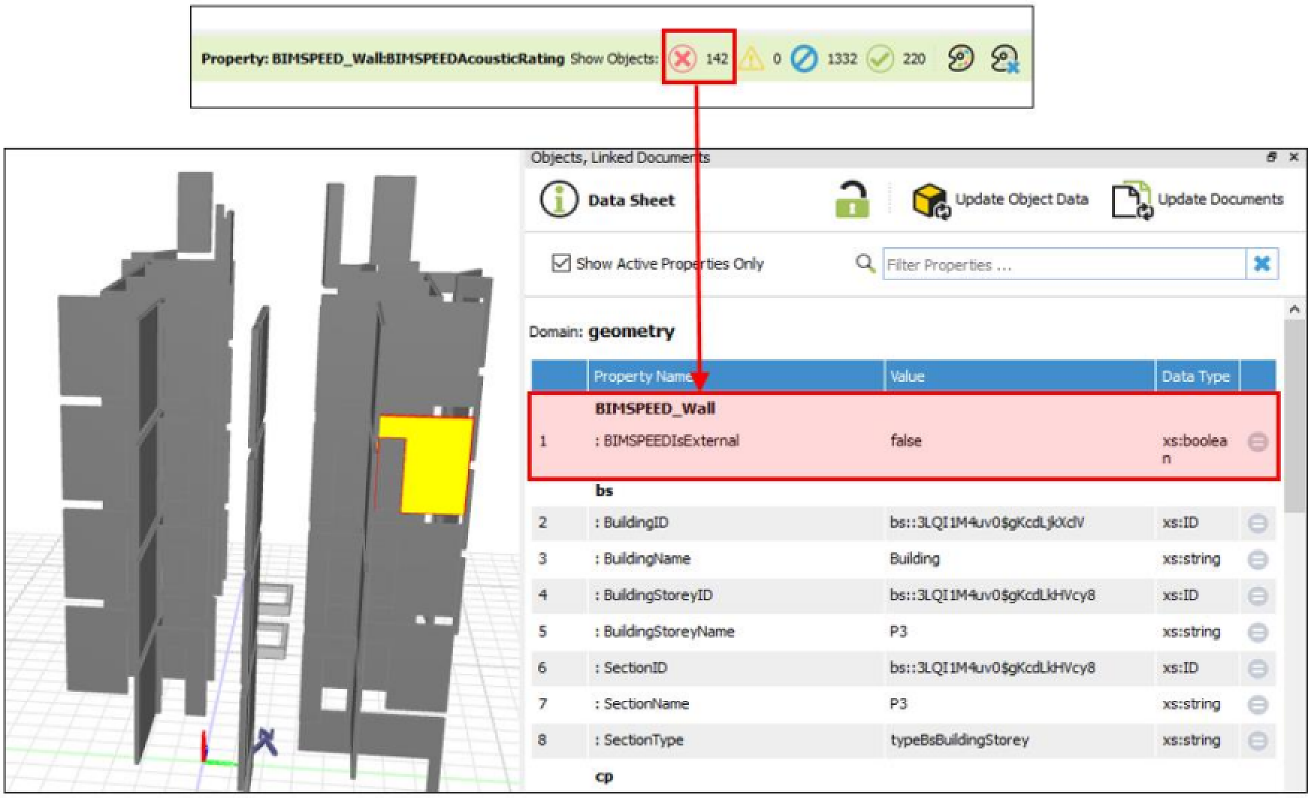


Figure 5: Evaluation of properties with regard to their numerical correctness

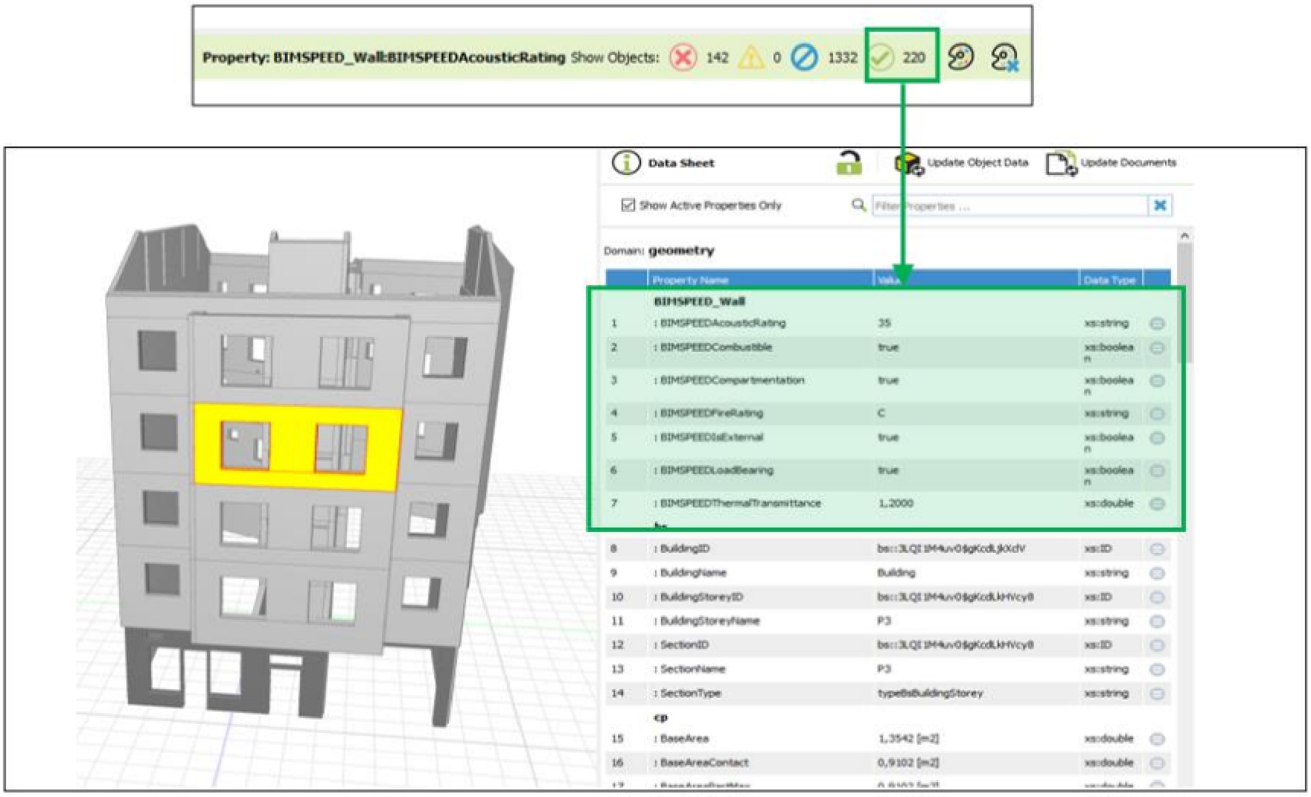
Results acquired from demonstration site:

The semantical and numerical checks carried out, that the 3D BIM model does not comply with the guidelines. The checks have identified 142 model elements, that are in fact walls, but they do not provide the required parameter BIMSpeedAcousticRating, which each model element should contain to enable the usage in the aimed BIM use cases.



***NOT COMPLY**: Property BIMSPEEDAcouticRating is missing in Pset IfcWall*

Completing interpreting the identified results, there luckily have been 220 model elements identified, that are in compliance with these requirements.



COMPLY: *Property BIMSPEEDAcouticRating is provided in Pset IfcWall*

Figure 6: Results from checks performed on 3D BIM Models

Beside the complying and not complying model elements, the performed model check also outlines, that there have been 1332 elements ignored for this specific check (see screenshot, marked in blue). These elements have not been checked at all, as in the definition of the check, there has been set a precondition to only check elements that are identified as ifcWall. All other elements can be ignored and don't need to be checked, to keep the performance within the model checking software fluid.

Attached Images

- BIMSPEED Properties.png
  (20220825024632-BIMSPEED-Properties.png , 175.42 KB)
- Compliant_model.png
  (20220825024632-Compliant-model.png , 357.09 KB)
- Non_compliant_model.png
  (20220825024632-Non-compliant-model.png , 394.53 KB)
- Overall process.jpg
  (20220825024557-Overall-process.jpg , 98.12 KB)
- Process_map_Semantic&Numericcheck.jpg
  (20220825025414-Process-map-Semantic-Numericcheck.jpg , 90.05 KB)
- Textual_design_rule.png
  (20220825024632-Textual-design-rule.png , 58.28 KB)
- XML_Script.png
  (20220825024632-XML-Script.png , 30.26 KB)

ISO 22263

Stage - 1 Conception of need

Description

Model checks, within the scope of this UC, namely semantical and numerical checks are relevant pre-requisites for several BIM use cases. Semantical checks provide the security that all relevant information is defined and integrates information in a well-defined manner. While semantical checks verify the existence and definition of all relevant IFC properties semantically, the numerical checks validate the values of properties for each element. Furthermore, automated quality checks as developed within this UC, further enhances saving of time. Both these checks also ensure that the compliance of regional regulations and standards are captured within the 3D BIM model and its relevant model elements.

Stage - 2 Outline feasibility

Description

The feasibility of implementation of this use case depends on the extent of automation of semantical and numerical model checks.

The aim of this use case is to improve the process of model checking by making the process faster and less error-prone. In cases where feasibility of automating checks does not prove feasible, the user of this UC is benefited from support related to independently implement semantical and numerical model checks for compliance testing and design coordination.

Performance requirement

- The aimed project has to be setup in a BIM conform manner, including needed project definitions like e.g. EIR, BEP, Model Element Matrix, etc.
- All naming conventions and design rules to be considered should be made clearly accessible.

Stage - 6 Coordinated design (and procurement)

Description

The model checks defined within the UC are the pre-requisites for ensuring coordination amongst design models in terms of semantical and numerical correctness. This forms the pre-requisite for carrying out further geometrical checks like clash detection, where the coordination between various design models are verified. A clash detection can only be followed correctly upon having semantically and numerically verified design models. This has also been indicated in the Overall process map in the previous section.

Performance requirement

Semantical Checks:

To perform semantical checks, the following aspects need to be taken into account:

- A list of all properties to be implemented in the model must be developed respecting country-specific and project specific requirements.
- A naming convention needs to be developed.

Numerical Checks:

To perform numerical checks, the following aspects need to be taken into account:

- An admissible value range for given values needs to be defined.
- Computation rules for automatically calculated values needs to be defined.
- Standardized check rules for the implementation of country-specific and project specific requirements needs to be developed.

Exchange Requirements

Description

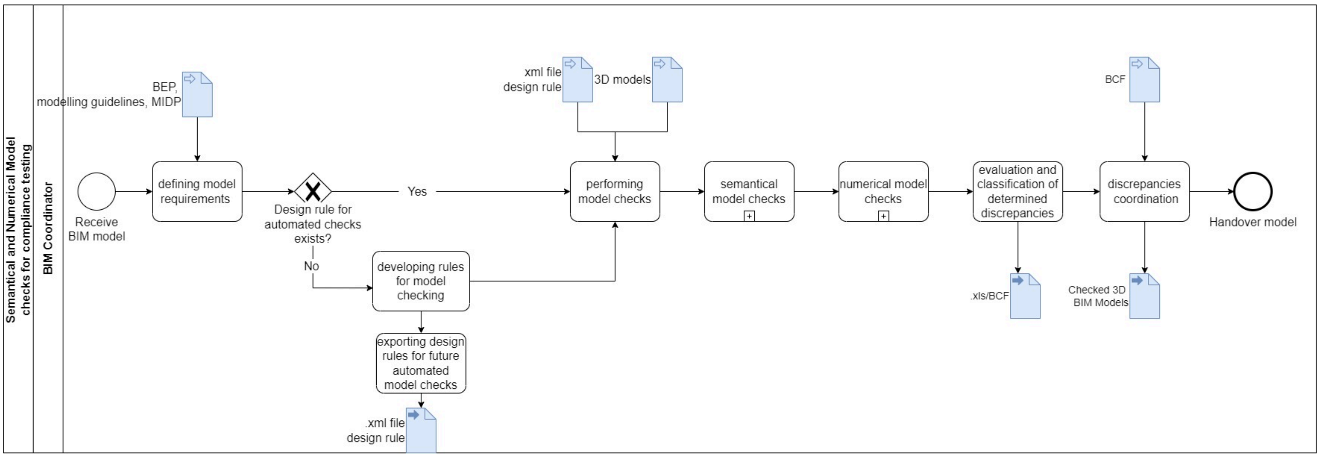


Figure 7: Illustration of file format requirements for implementation of UC

The process map above highlights the input, output data and file exchange possibilities throughout the process of the defined model checks. For the execution of the UC,

- BIM Execution plans, modeling guidelines and MIDP are used as input for defining model requirements
- .xml files are used as the file format for containing design rules which enable automated checks
- Input of 3D BIM models for checks are confined to IFC to enable the OpenBIM approach.
- Report format of identified discrepancies can be adapted to project specific needs and exporting functionalities feasible. However, discrepancies exported in BCF format can later on be imported whereby the BIM author can be directed to the identified discrepancies.

Attached Images

- ERs_Model Checks.jpg
  (Exchange-Requirements/20220825025521-ERs-Model-Checks.jpg , 91.94 KB)

Imprint

Project Group

- Jan-Derrick Braun, jan-derrick.braun@hochtief.de
- Sharon Susan Verghese, sharonsusanverghese@campus.tu-berlin.de
- David Schammler, david.schammler@hochtief.de

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