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Report on BIMERR pre-validation activities

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Acronym	Meaning
AEC	Architecture Engineering Construction
API	Application Programming Interface
AR HMD	Augmented Reality Head Mounted Display
ARIBFA	Augmented Reality Enabled In-Situ Building Feature Annotation
BICA	Building Information Collection Application for Building Residents
BIF	BIMERR Interoperability Framework
BIMERR	BIM-based holistic tools for Energy-driven Renovation of existing Residences
BIM-MP	BIM Management Platform
BRG	B-Rep Generation
CBIP	Common Boundary Intersection Projection
EPD	Environmental Product Declaration
ETL	Extract, Transform, Load
GED	Geometric Error Detection
GUI	Graphic User Interface
HVAC	Heating Ventilation Air Conditioning
H & S	Health and Safety
IFC	Industry Foundation Classes
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MEP	Mechanical, Electrical and Plumping
MVD	Model View Definition
NZEB	Near Zero Energy Building
PRUBS	Profiling Resident Usage of Building System
PWMA	Process & Workflow Modelling And Automation
RenoDSS	Renovation Decision Support System
TLS	Terrestrial Laser Scanning
VRF	Variable Refrigerant Flow
WoT	Web of Things
WSN	Wireless Sensor Network
2LSBs	2nd Level Space Boundaries

EXECUTIVE SUMMARY

This document, Deliverable (D8.6), reports the pre-validation activities that took place regarding Task 8.4 "BIMERR ICT System Pre-Validation" and it will be drafted as initial input for Task 10.3 which will document best practice examples.

Within BIMERR, the workflow involves the generation of an Industry Foundation Classes (IFC) file either by using the Scan to BIM tool or by using the BIM Authoring tools. The IFC data are then checked and enriched with all the necessary information by the BIM Management Platform in order to be used on site by the ARIBFA tool and to generate renovation scenarios exploiting the RenoDSS tool. At the same time, the BIMERR Middleware tool performs data exchange and management across the BIMERR sub-systems and ensures collection of the complete data set. This deliverable analyzes the arisen issues on the pre-pilot sites and points out the applied practices to overcome these issues.

As it was already mentioned, this deliverable provides a documentation regarding the activities that took place in the pre-validation sites of the BIMERR and consequently a valuable feedback for the next tasks of the project. A detailed description of the deployment of the relevant BIMERR tools and modules, the verification and tests performed at this stage is the core of this deliverable.

The last part of this deliverable presents a brief conclusion regarding the lessons learned from the tests and verifications during the pre-validation phase. The conclusion is presented for each related BIMERR tool independently.

1. INTRODUCTION

1.1 SCOPE AND OBJECTIVES OF THE DELIVERABLE

The main goal of this deliverable is to present a thorough report of the pre-validation activities. During the pre-validation phase two Greek sites were used for testing the BIMERR tools under operational conditions; KRIPIS SmartHome of CERTH and a residential building of CONKAT.

During this phase, the BIMERR toolkit's deployment was planned and executed. The tools for digital model creation were rigorously tested and compared against existing building models. In addition, renovation options, that can significantly improve the energy efficiency of the building, were showcased based on the real building characteristics. To ensure successful pre-validation, the tools were installed and operated on site, focusing on their individual characteristics. In addition, manual verification of the BIMERR tool outputs was performed to assess their operational effectiveness and results accuracy. Therefore, based on the experience gained from the tools' usage in near-real-life conditions, we concluded in a valuable report for the BIMERR tools. This report will aid the further deployment to pilot sites and un/semi-supervised use by relevant stakeholders. Furthermore, the tested use cases, the examples and the results derived from this deliverable will set the basis for the documentation of best practice examples at the next stages of the project.

Deliverable D8.6 "Report on BIMERR pre-validation activities", main outcome of T8.4 "BIMERR ICT System Pre-Validation", aims at providing a general documentation of all the tests, deployments and activities that have taken place for the evaluation and verification of the BIMERR tools on the pre-validation sites.

It is worth mentioning that exploiting the differentiation of the two pre-pilot sites, variant tests and checks took place on site in a different level of detail. First of all, the operation of each building needed to be taken into consideration; KRIPIS operates as an office while CONKAT is a residential apartment. Therefore, the CONKAT building has the great advantage of its residential operation while some tools (such as PRUBS and BICA) could be verified and assessed only in this site because of its residential data. Subsequently, not all the applications could be tested in both of the buildings, depending on the data available and needed in each process. In addition, the CONKAT apartment had an extra step which considers to be of high importance: the installation of the wireless sensors network. It is obvious that the different level of detail at the checking process did not affect the quality and objectives of the T8.4. In most cases the KRIPIS building was exploited for developing and testing the applications, while the CONKAT building was used in terms of verification and evaluation of the functionality of the apps. Nevertheless, there can be no doubt that each pre-validation site contributed in a different way within BIMERR.

1.2 Relation to Other Tasks And Deliverables

T8.4 "BIMERR ICT System Pre-Validation" and therefore D8.6 "Report on BIMERR pre-validation activities" is connected to other BIMERR deliverables as follows:

- the functionalities and uses cases of the tools, that were tested in the pre-validation activities, are described in the BIMERR system Architecture (WP3; Deliverables D3.5 and D3.6);
- the BIM Management Platform (BIM-MP) tool is described in the deliverables "Prototype of Enhanced BIM Platform 1" and "Prototype of Enhanced BIM Platform 2" (WP5; Deliverables D5.1 and D5.2);
- the Scan-to-BIM tool is described in the deliverables "Innovative Scan-to-BIM tools for Automated BIM generation 1" and "Innovative Scan-to-BIM tools for Automated BIM generation 2" (WP5; Deliverables D5.3 and D5.4);
- the Building Information Collection Application (BICA) tool is described in the deliverable "Building Information Collection Application for building residents 1" (WP5; Deliverable D5.5);
- the Augmented Reality Enabled In-Situ Building Feature Annotation (ARIBFA) tool is described in the deliverables "AI-enabled tools (hardware & software) for in-situ digital building model annotation via smart-glasses 1" and "AI enabled tools (hardware & software) for in-situ digital building model annotation via smart-glasses 2" (WP5; Deliverables D5.9 and D5.10);

- the Renovation Decision Support System (RenoDSS) tool is described in the deliverables “Integrated BIMERR Renovation Decision Support System 1” and “Integrated BIMERR Renovation Decision Support System 2” (WP7; Deliverables D7.9 and D7.10 and Deliverables of RenoDSS sub-components);
- the Profiling Residents Usage Building Systems (PRUBS) tool is described in the deliverables “Building resident energy-related behaviour profiling framework 1” and “Building resident energy-related behaviour profiling framework 2” (WP5; Deliverables D5.7 and D5.8);
- the BIMERR Middleware is described in the deliverable “BIMERR Middleware prototype” (WP8; Deliverable D8.2);
- the BIMERR Interoperability Framework (BIF) is described in the deliverables “Integrated BIMERR Interoperability Framework 1” and “Integrated BIMERR Interoperability Framework 2” (WP4; Deliverables D4.8 and D4.9);
- the deliverables “BIMERR Information Collection & Enrichment Tool 1” and ““BIMERR Information Collection & Enrichment Tool 2” (WP4; Deliverables D4.6 and D4.7), which describe the process for collecting, processing, storing, and indexing building-related data to be available to all authorized BIMERR applications;
- the Process & Workflow Modelling and Automation (PWMA) tool is described in the deliverables “Renovation process simulation tool 1” and “Renovation process simulation tool 2” (WP6; Deliverables D6.4 and D6.5);
- the deliverables describing the on-site interaction of workers with the digital twin of the reconstruction process, i.e., the deliverables “Smart glass application for on-site renovation worker support 1” and “Smart glass application for on-site renovation worker support 2” (WP6; Deliverables D6.8 and D6.9); and
- the deliverables describing the mobile application for on-site support of the residents, i.e., the deliverables “Renovation progress monitoring & alerting application for residents 1” and “Renovation progress monitoring & alerting application for residents 2” (WP6; Deliverables D6.10 and D6.11).

1.3 STRUCTURE OF THE DELIVERABLE

To address the aspects relevant to the scope of T8.4, Section 1 introduces the work performed, the scope and objectives of this deliverable, along with its relations to other BIMERR tasks and deliverables, as well as the deliverable's structure.

A brief review of the functionality of the BIMERR tools and modules that should be validated in real world conditions is presented in Section 2.

In Section 3, the related activities that took place in the KRIPIS SmartHome pre-validation site are presented. Firstly, the architecture of the building, the construction materials, its fenestration as well as the installed HVAC system and its MEP components are described. Additionally, information about the wireless sensor network and the overall building monitoring is provided. Furthermore, the application of the tools responsible for the IFC creation, validation and enrichment is analyzed. In addition, the on-site operations, as well as the renovation scenarios' process and KPIs' calculations are described. Finally, in the last part of the section, the monitoring and alerting of the renovation progress is presented.

Section 4 follows the same structure and presents the activities of the BIMERR tools that took place in the pre-validation site of the CONKAT building.

Finally, Section 5 summarises the lessons-learnt based on valuable feedback provided by the BIMERR tools during the aforementioned testing activities in the pilot sites.

1.4 COVID IMPACT IN THE PRE-VALIDATION ACTIVITIES

As per T8.4 description, the tools should have been tested/used on site. However, due to the Covid-19 pandemic and the restrictions that were imposed it was difficult for the BIMERR tools' developers to visit the sites, install and operate the tools, as necessary depending on their individual characteristics. Overall, it is obvious that most of the construction projects facing delays, disruptions and uncertainty of completion due to the Coronavirus pandemic and usually the business plan is adjusted. In our case, due to all the aforementioned factors, while trying to be adapted to reality and to overcome the pandemic obstacles too, many of the BIMERR tools were tested on site firstly at the KRIPIS pre-validation site to assess their operational effectiveness and results accuracy. Unfortunately, due to Covid-19 restrictions, we did not manage to totally exploit the residential operation of the CONKAT building; it was occupied only specific periods during the pre-validation phase of the project. Therefore, issues were arisen regarding the residential data gathering process from the building and subsequently the CONKAT pre-validation site in many cases operated supplementary to verify the functionality of the tools and applications. To conclude, each pre-validation site had an important but different contribution within BIMERR. The results, experience and lessons learned from both sites will aid the further deployment to pilot sites and un/semi-supervised use by renovation professionals.

2. BIMERR Tools And Modules Related to Pre-Validation Activities

In this section, a brief review of the BIMERR tools and modules that needed to be validated in real world conditions is presented.

2.1 BIMERR Middleware

The middleware design reflects the requirements of the project associated with secure and standardized information exchange among the various BIMERR components. Respectively, the middleware is designated for identity and sensor data management in the BIMERR project. The identity management is to maintain user and application profiles and authenticate the identity of resource owners. The sensor data management is a collection of functionalities to extract, maintain, annotate, and expose sensor data for building data collection and residential profiling applications. The middleware follows a microservice architecture which can be customized and deployed tailored to the applications' needs. The BIMERR project deployed a central set of components on the cloud and various instances of components on low-powered gateway devices in pilot sites. All middleware functionalities went through in-depth testing as part of pre-validation activities. The details of such efforts are described in the chapters dedicated to each pre-validation site. The description of the middleware is available in D8.2 - BIMERR Middleware prototype [1].

2.2 Scan-to-BIM

The Scan-to-BIM tool assists BIM modelers in the production of semantic building models. It semi-automatically generates BIM models, according to the Industry Foundation Class (IFC) standard, from 3D point clouds obtained by terrestrial laser scanning (TLS) devices. The Scan-to-BIM tool can be divided into three sub-components: Structural, which automatically identifies and models structural entities (e.g. walls, slabs and openings); MEP to automatically detect, classify, and model Mechanical, Electrical and Plumbing (MEP) objects installed in the building (i.e. radiators and air conditioning units); and Editor, which is employed to manually add non-visual information, such as materials and properties, to the entities previously modelled by Structural and MEP as well as classifies spaces into zones (or apartments). These sub-components are integrated into an umbrella piece of software with Graphical User Interface (GUI) that: (1) enables the user to run the three subcomponents mentioned above; (2) connects to the BIMERR material and components database and downloads its content to populate the IFC file; and (3) connects to the BIF, via the platform's API, to upload the generated file [2].

2.3 BIMERR Interoperability Framework (BIF)

The Building Interoperability Framework (BIF) aims to deliver a collaborative working environment acting as a central cloud-based information point for the various applications/tools and AEC stakeholders involved in the same renovation/construction project while also ensuring the seamless and secure building data exchange among them. BIF delivers appropriate data management and integration functionalities based on widely adopted industry standards and design principles that enable any construction technology application to obtain and provide semantically coherent data for efficient collaboration.

In general, the BIF comprises of four main components: 1) the BIMERR Information Collection & Enrichment component, responsible for the collection, handling and storage of building-related data, so as to be available to any authorized user and BIMERR tool/application; 2) the BIMERR Semantic Modelling component, responsible for the definition, application and maintenance of the BIMERR ontology and data model and their harmonization, ensuring semantic consistency and coherency in the building-related data exchanges; 3) the Building Information Query Builder responsible for undertaking the required data search processes though various available filtering, sorting modules that facilitate easy identification of datasets of interest and ensuring that all building-related data can be retrieved in a secure and trustful manner; and 4) the Building Information Secure Provisioning tool, which addresses the vital aspect of security in the exchange of data among different stakeholders in a multi-dimensional approach by incorporating access control mechanisms for user authentication and authorization, as well as enabling data providers to protect and share their data sets by dynamic enforcement of attributes in access policies.

Overall, trough the BIF, tools/applications involved in the same renovation/construction project, no longer need to exchange data in a direct way; since BIF acts as an intermediary, incorporating the required data models, functionalities and access-control mechanisms that allow tools/applications and AEC actors to effectively collaborate by providing and/or consume building related data in a secure centralized manner.

An in-depth description of the various components forming the BIF is provided in deliverables D4.5 -BIMERR Building Semantic Modelling tool 2 [3] and D4.7- BIMERR Information Collection & Enrichment Tool 2 [4] and D4.9 - Integrated BIMERR Interoperability Framework 2 [5].

2.4 BIM MANAGEMENT PLATFORM (BIM-MP)

BIM-MP adopts openBIM standards to provide an integrated data management solution for storing, versioning, updating and checking BIM models in the form of IFC files. It contains a set of reusable libraries to facilitate complex geometric operations such as the B-rep generation and the semantic enrichment of IFC files. Core functional algorithms such as Geometric Error Detection (GED), Model View Definition (MVD) completeness checking, Common Boundary Intersection Projection (CBIP), Automatic Space Generation (ASG), and B-rep Generation (BRG) are deployed as functional modules of BIM-MP [6].

BIM-MP also includes a model viewer with robust and stable 3D rendering capabilities of the building geometry, which is based on fast and accurate triangulation algorithm removing the dependence on externa graphics libraries and converters.

The data quality mechanisms include geometric and completeness checking operations applied on IFC input data files, to ensure that the files are suitable for BIMERR's needs. On the other hand, data enrichment services are designed to aid the BEPS model generation especially when the IFC file is originated from the BIM authoring tools or BIMERR's Scan-to-BIM tool.

2.5 Augmented Reality Enabled In-Situ Building Feature Annotation (ARIBFA)

The ARIBFA toolset aims to support the role of workers and building surveyors during the renovation process by providing recognition and registration of features in a building, while displaying information to the user through the Augmented Reality Head Mounted Display (AR HMD). More specifically, ARIBFA accepts as input the BIM model in Industry Foundation Class (IFC) format, which is a standardized, digital description of the building geometry and components, and reports user-added annotations and detected building components to BIMERR Interoperability Framework (BIF). The ARIBFA application recognizes, and registers features present in a building, using AR HMD, i.e., AR glasses, to enable the user wearing the glasses to walk through a building and (semi-)automatically annotate building characteristics on a digital building model (enhanced BIM), report issues, e.g., on structural damage, and enrich the BIM model by updating it with the registration of unrecognized or unregistered building components. The user of the ARIBFA application is a site manager, a building surveyor, or an experienced worker/foreman [7].

2.6 Profiling Resident Usage of Building System (PRUBS)

PRUBS aims to design Occupant Behaviour models that act as predictors of occupants' presence, needs (in terms of comfort) and actions. To increase the pre/post-renovation energy consumption prediction's accuracy, these models capture the dynamic data of a building energy performance simulation, and they are used as input to the BEP component of RenoDSS. PRUBS is built upon the outcomes of Annex 66, adopting obXML as its output data model. Applying Machine Learning algorithms on IoT data streams provided by Wireless Sensor Networks (WSN) that are designed for and installed in the CONKAT building and the validation sites, it generates occupant behaviour profiles that mimic the inhabitants' actions. These profiles are subsequently used to project the building system (e.g., heating/cooling) utilisation boundaries to maintain the comfort zone of the residents. PRUBS is delivered as a Software as a Service exposing APIs to interact with the BIMERR middleware and the BIMERR interoperability framework. In alignment with the BIMERR architecture, PRUBS is considered as an “as-is” building information extraction and model population tool [8].

2.7 Building Information Collection Application for Building Residents (BICA)

The BICA smartphone application provides the means for the collection of building related data from residents, for improved renovation design and planning before any actual renovation works start. Through BICA, building residents can explore through intuitive visualization their apartment’s BIM model that includes rooms, ambient conditions, and registered equipment. They can contribute to the enhancement of the current BIM model by providing through BICA complementary information about their apartments and the installed components, such as manufacturer, type, model etc. Additionally, residents can highlight building weaknesses to facilitate the renovation design, by reporting through BICA any issues and faults related to their building, apartment, or specific equipment/components. Supplementary to the above and towards more personalized renovation design, the BICA application enables end-users to provide feedback on their actual comfort status against the current ambient conditions and projected comfort status, through a five-level scale. Finally, residents can declare their preferred room usage to allow better planning of the renovation works scheduling [9].

2.8 Renovation Decision Support System (RenoDSS)

RenoDSS provides a novel BIM-based renovation configurator that allows the user to explore alternative renovation interventions. For each renovation scenario, RenoDSS calculates economic, sustainability, energy, and comfort KPIs. The KPIs are calculated by BIM-based calculation engines and the state-of-the-art simulation engine EnergyPlus. The main advantage of the BIM-based approach is the efficient and fast generation of potential renovation scenarios, providing KPIs and IFC representation for each scenario, enabling the user to identify the most promising renovation scenarios, and fine-tune them in their favorite BIM software by building on the provided renovation scenario IFC files [10].

2.9 BIMERR Process & Workflow Modelling And Automation (PWMA)

The Process & Workflow Modelling and Automation (PWMA) toolkit allows to graphically model renovation processes and enables their simulation for optimization across project phases to identify and leverage opportunities for fine-tuning process steps and their attributes. It aims to eliminate undesired documentation for project delivery and to exploit on-site tools for on-the-fly progress reporting and guidance of workers via innovative AR-enabled smart glasses for improved productivity and re-work elimination. The PWMA toolkit facilitates the construction phase of the renovation project and is mostly targeted to renovation planners, project managers and construction contractors/workers. It includes a back-end application (for the modelling and adaptive monitoring of the entire renovation process) as well as dedicated applications targeted to stakeholders in the renovation site (contractors/workers & building residents). The modelling environment allows to create a renovation process starting from an existing template and, through a refinement process supported by the simulation toolkit, generates a workflow that the PWMA execution engine can run to track and guide the workers on the process activities. This approach is supported by two apps, one for the smart glasses for workers showing and monitoring the workflow activities, and one specifically designed for the residents to notify them of potentially critical activities they should be aware and collect their feedbacks. PWMA aims to deliver all the benefits of process and workflow management to the energy efficient building renovation, with special emphasis on modelling, communication, risk management, process optimization through simulation and continuous improvement. It allows the renovation designer/planner to define different workflows for different types of jobs or processes for the design, construction and delivery of the works (i.e., automated transmission of designs for approval by the building owner, routing of appropriate information to the various tools of the BIMERR system, job planning and scheduling on the construction site accounting for dependencies between them). The workflow automation tool also enables interactive adaptation based on information from other tools [11].

3. KRIPIS Smart Home Pre-Validation Activities

The pre-validation phase took place in actual buildings, which however were not renovated. During the process, we experimented fully with the as-is digital building model creation tools and with the renovation-support tools. By comparing the results and evaluating them, we assessed the applicability to real-life situations, the usability of the tools and provided feedback for improvements.

3.1 Building Description

In this subsection general information about the first pre-validation building of BIMERR is provided, such as the architecture, the construction materials, its opaque and glazing elements, as well as details about the installed HVAC system and its MEP components.

3.1.1 Overall Architecture

KRIPIS[1] SmartHome is located in Thessaloniki, Greece (latitude and longitude 40.566493 and 22.998849 respectively) and owned by CERTH. It is a duplex apartment, representative of a single-family residential building, built in 2016, and is already equipped with many IoT, Smart Home solutions that provide a lot of information about its operational characteristics. Its orientation is 42° angle to the true North. People can enter the building both by the ground floor and the first floor (by using an external winding staircase). The two stories are connected internally by a staircase, while also by an additional elevator, and the height of each floor is 3.3 meters. In addition, acoustic

[1] https://smarthome.iti.gr/

ceilings have been placed in construction at an elevation of 2.6 meters above the floor level. Therefore, the building contains not only occupied spaces but also plenums[2].

Figure 1. KRIPIS SmartHome

The building has a total surface of 391 m^2; the 192.6 m^2 belong to the ground floor and the 198.4 m^2 to the first floor. More specifically, the ground floor covers an area of 182.7 m^2 and the engine room 9.9 m^2 while the first floor covers an area of 135 m^2 and its

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[2] A plenum is an unconditioned area above a conditioned space that holds ductwork returning air from the space to the coil.

balconies are 47.8 m^2, 5.7 m^2 and 9.9 m^2 respectively. As it will be further analyzed in next section, most of the building spaces are heated and cooled by a Variable Refrigerant Flow (VRF). Here it is only worth mentioning that the conditioned area of the ground floor and first floor is 173.7 m^2 and 126 m^2 respectively; hence the total conditioned area of the building is almost 300 m^2. The house has no residents, since it functions as an office during the usual office hours. However, except for the specific rooms that are officially used as offices (Control Rooms) the building has also common residential rooms such as a living room, bedrooms etc. equipped with IoT devices.

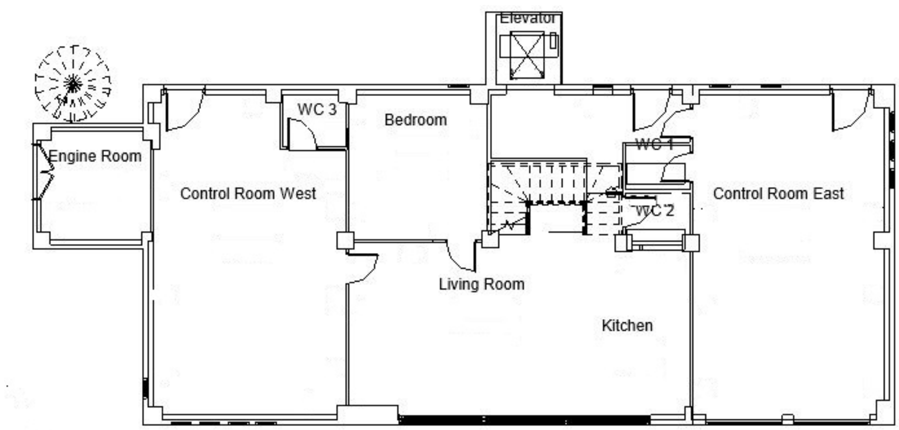


Figure 2. Floor Plan: Ground Floor of KRIPIS building.

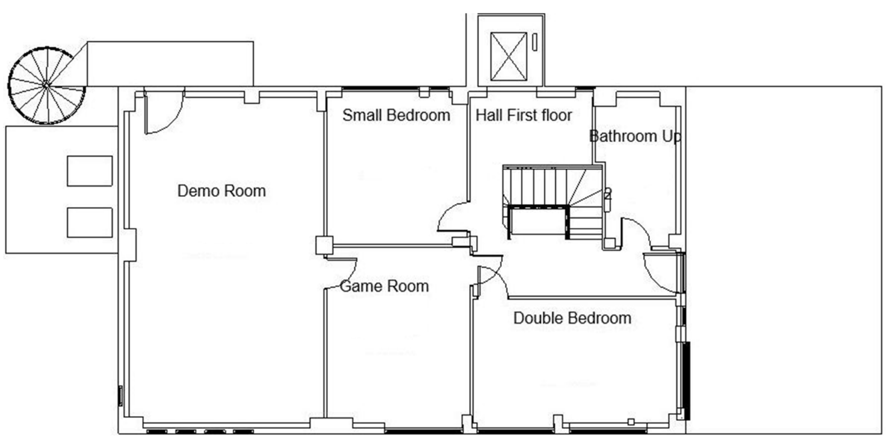


Figure 3. Floor Plan: First Floor of KRIPIS building.

3.1.2 Construction Materials and Fenestration

Opaque elements

Regarding the structural construction of the building, it is a mixed steel-concrete structure with steel (columns-beams) and concrete (slabs-walls) elements. Reinforced concrete is used for the slabs. In the exterior walls, lightweight concrete (perlite) is placed, while also the interior walls are constructed with gypsum wallboard (by Fibran). For damp proofing, asphalt bitumen membrane layers have been placed in the lower and upper slab. Additionally, other common but necessary materials such as mortars, finishes and tiles are also used in the construction.

Due to lack of information about the materials that were finally used in the construction, assumptions and estimations were made. The relevant necessary information and values (i.e. thermal conductivity) required for adding Thermal Properties at the opaque materials, were derived from the Greek Regulation for the Energy Efficiency of Buildings (KENAK) as well as from Revit Material Libraries. The thermal conductivity value, and the thickness of the opaque elements of the layers of the walls and of the slabs is presented in Table 1 and Table 2 respectively.

Wall	Material name	Material thickness (cm)	Thermal Conductivity (W/m·K)	Total Thickness (cm)
External	plaster	1	0.87	28
	plaster	1	0.87	
	Insulation	16	0.0352	
	Lightweight perlite	9	0.23	
	Plaster	1	0.87	
Internal	Paint	0.1	0.87	8.2
	Gypsum Wallboard	1.5	0.25	
	Insulation	5	0.033	
	Gypsum Wallboard	1.5	0.25	
	Paint	0.1	0.87	

Table 1. Wall material layering in KRIPIS building.

Slab	Material name	Material thickness (cm)	Thermal Conductivity (W/m·K)	Total Thickness (cm)
Ceramic Tiles	Ceramic tiles	0.5	1.84	30.7
	Cement mortar	5	0.87	
	Reinforced concrete (2% reinforcement)	15	2.5	
	Damp-proofing	0.1	1.15	
	Insulation	5	0.033	
	Damp-proofing	0.1	1.15	
	Insulation	5	0.033	
First Floor	Ceramic tiles	0.5	1.84	20.5
	Cement mortar	5	0.87	
	Reinforced concrete (2% reinforcement)	15	2.5	
First Floor Balconies	Ceramic tiles	0.5	1.84	31.5
	Cement mortar	5	0.87	
	Reinforced concrete (2% reinforcement)	15	2.5	
	Air	1	0.025	
	Insulation	10	0.033	
Roof	Asphalt waterproofing membrane (SBS)	0.1	0.19	30.1
	Unreinforced concrete (gross beton)	5	1.512	
	Insulation	10	0.0345	
	Reinforced concrete (2% reinforcement)	15	2.5	

Table 2. Slab material layering in KRIPIS building.

Insulation

At this point, our research mainly focused on the insulation materials of the building, given that this factor is more effective and of high impact for energy analysis. In KRIPIS' case the insulation materials were produced by Fibran. More specifically, as an external insulation, rockwool was placed (FIBRAN GEO BP Etics), as well as for interior walls (FIBRAN GEO B-570). In addition, expanded polystyrene was used for the slabs' insulation (FIBRAN xps 300L for the roof and FIBRAN xps seismic 400 for the ground floor slab). It is worth mentioning that for the slab of the first floor no insulation was placed, except for the balcony area (FIBRAN GEO B-570). Table 3 presents the used insulation Fibran products as well as their crucial thermal conductivity (λ value).

Product Name	Product Type	Thermal Conductivity (λ value) (W/(m·K))	Structural Element
FIBRAN xps seismic 400	Expanded Polystyrene	0.0330	Ground Floor Slab
FIBRAN xps 300L	Expanded Polystyrene	0.0345	Roof Slab
FIBRAN GEO B-570	Rockwool	0.0330	First Floor Balcony Slab, Interior Walls
FIBRAN GEO BP Etics	Rockwool	0.0352	Exterior Walls

Table 3. Information for insulation products used in KRIPIS building.

Glazing elements

Regarding the fenestration, specific factors (such as Thermal conductance (U-value), Solar Heat Gain Coefficient (SHGC) and Visual Light Transmittance (VT)) of each element) must be defined. However, in KRIPIS' case assumptions were also made at this step due to lack of information. More specifically, the windows and glass doors of the building were designed by Alumil but only the product model and the dimensions were already known; hence the Analytical Properties for these were specified through an online calculator of U_w on the manufacturer's website[3]. The calculator takes into account information about

[3] https://www.alumil.com/international/specifiers/service-support/services-tools/uw-calculator

the glazing material as well as the specific Alumil model and the results can be extracted in a pdf file.

Regarding the glazing, two different types were used in our case: double-glazing in the Control Rooms, and triple glazing in the "residential" areas of the building. The double-glazing is constructed of Planitherm XN (4mm)/ Argon 90% (14mm)/ Clear (4mm) while the triple glazing is constructed of Planitherm XN (4mm)/ Argon 90% (16mm)/ Clear (4mm)/ Argon 90% (16mm)/ Planitherm XN (4mm). The selected values for the $U_{glazing}$, Light Transmittance and the Solar Heat Gain Coefficient of the double and triple glazing were specified based on the Declaration of Performance (DOP). As it was already mentioned, estimations were made; due to discrepancies between the existing and default glazing, these values were selected approximately and are presented in Table 4.

Glazing	**Composition (mm)**	**Gass Filling**	**$U_{glazing}$ (W/(m²·K))**	**Light Transmittance**	**Solar Heat Gain Coefficient**
Double	4*/14/4	Argon > 90%	1.1	0.82	0.65
Triple	4*/16/4/16/4	Argon > 90%	0.6	0.74	0.54

Table 4. Glazing elements of KRIPIS building - values used for the Uw calculation.

These aforementioned values were subsequently used for the calculation of these factors for the windows. The relevant window/ door models and their final U values are presented in Table 5.

Alumil model	**Glazing**	**Dimensions (Width*Height) (m*m)**	**Heat Transfer Coefficient (U_{window}) (W/(m²·K))**	**Visual Light Transmittanc e**	**Solar Heat Gain Coefficient**
S700 Triple sliding door	triple	6.9*2.2	1.37	0.74	0.39
S77 Glass door	triple	1.1*2.2	1.38	0.74	0.31

M11000 window	double	2.1*2.2	1.41	0.82	0.43
S77 window (with shutter)	triple	2.1*2.2	1.00	0	0
S77 window	triple	2.1*2.2	1.04	0.74	0.4
S77 window	double	0.55*1.9	1.88	0.82	0.33
S77 window	triple	0.55*1.9	1.64	0.74	0.27
S77 window	triple	0.55*0.55	1.94	0.74	0.19
S77 window	double	2.1*0.55	1.88	0.82	0.33
S77 window	triple	2.1*0.55	1.63	0.74	0.27
S77 window	triple	0.55*2.2	1.63	0.74	0.28

Table 5. Analytical Properties values for fenestration of KRIPIS building.

Moreover, for the exterior armored doors, the exterior door of the engine room as well as the interior doors of the house, the above factors were approximately defined, due to lack of information about the specific placed products; for each product, the construction materials were defined and consequently the relevant values were specified using default values extracted from the Revit 2021 Library, based on the material of the product (the process will be analyzed in the subsection 3.3.1). The relevant models and their Analytic Construction value as described above are presented in Table 6.

Model	**Analytic Construction**	**Heat Transfer Coefficient (U_{door}) (W/(m²·K))**	**Visual Light Transmittance**	**Solar Heat Gain Coefficient**
Exterior Armored Door	Wood panel, metal storm	2.3279	0	0
Exterior Metal Door	Metal	3.7021	0	0
Interior Door	Wooden	2.1944	0	0

Table 6. Values of the relevant factors for the opaque doors of the building.

Environmental impact of products

At this step, it was also important to collect information regarding the Environmental Product Declaration (EPD). An Environmental Product Declaration (EPD) is a transparent, objective report that communicates what a product is made of and how it impacts the environment across its entire life cycle.

The environmental performance indicators are shown in the following tables for the declared unit of $1m^2$ at 30 mm thickness (0.030 m^3). For stages A1-A3 the results are aggregated.

ENVIRONMENTAL IMPACTS PER 1 m^2 of FIBRANgeo

ENVIRONMENTAL IMPACTS	Unit	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	D
GWP-total	kg CO2 eq	4,28E+00	2,58E-01	1,66E-02	0,00E+00	0,00E+00	2,47E-02	0,00E+00	2,58E-01	0,00E+00
GWP-fossil	kg CO2 eq	4,27E+00	2,58E-01	1,66E-02	0,00E+00	0,00E+00	2,47E-02	0,00E+00	2,58E-01	0,00E+00
GWP-biogenic	kg CO2 eq	8,59E-03	8,69E-05	1,29E-05	0,00E+00	0,00E+00	8,32E-06	0,00E+00	8,69E-05	0,00E+00
GWP-luluc	kg CO2 eq	3,37E-03	8,75E-05	8,11E-06	0,00E+00	0,00E+00	8,38E-06	0,00E+00	8,75E-05	0,00E+00
GWP-GHG[1]	kg CO2 eq	4,27E+00	2,58E-01	1,66E-02	0,00E+00	0,00E+00	2,47E-02	0,00E+00	2,58E-01	0,00E+00
ODP	kg CFC-11 eq	4,16E-07	5,90E-08	2,16E-09	0,00E+00	0,00E+00	5,65E-09	0,00E+00	5,90E-08	0,00E+00
AP	mol H+ eq	2,13E-02	1,29E-03	6,07E-05	0,00E+00	0,00E+00	1,24E-04	0,00E+00	1,29E-03	0,00E+00
EP-freshwater	kg $PO4^{-3}$ eq	1,59E-02	5,35E-05	5,66E-06	0,00E+00	0,00E+00	5,13E-06	0,00E+00	5,35E-05	0,00E+00
EP-freshwater[2]	kg P eq	5,18E-03	1,75E-05	1,85E-06	0,00E+00	0,00E+00	1,67E-06	0,00E+00	1,75E-05	0,00E+00
EP-marine	kg N eq	3,64E-03	4,51E-04	2,29E-05	0,00E+00	0,00E+00	4,32E-05	0,00E+00	4,51E-04	0,00E+00
EP-terrestrial	mol N eq	2,87E-02	4,92E-03	2,12E-04	0,00E+00	0,00E+00	4,71E-04	0,00E+00	4,92E-03	0,00E+00
POCP	kg NMVOC eq	9,46E-03	1,40E-03	6,39E-05	0,00E+00	0,00E+00	1,34E-04	0,00E+00	1,40E-03	0,00E+00
ADPe	kg Sb eq	7,34E-05	7,18E-06	3,18E-07	0,00E+00	0,00E+00	6,87E-07	0,00E+00	7,18E-06	0,00E+00
ADPf	MJ	7,98E+01	3,94E+00	2,08E-01	0,00E+00	0,00E+00	3,78E-01	0,00E+00	3,94E+00	0,00E+00
WDP	m^3 eq	4,71E-01	5,82E-03	9,29E-04	0,00E+00	0,00E+00	5,58E-04	0,00E+00	5,82E-03	0,00E+00

Figure 4. Environmental impacts of Fibran geo insulation material.

Hence, relevant information about the Life Cycle Assessment[4] (LCA) and Life Cycle Cost[5] (LCC) of the products used within BIMERR was collected. This kind of information

[4] LCA is a method to assess the potential environmental impact of a product or service throughout its entire life cycle. That is, from the supply of raw materials and production, to use, disposal or end-of life waste management (cradle-to-grave) [16].

[5] LCC is generally defined as an assessment of all costs which are related to a certain product, directly covered by one or several actors in the life cycle of the product [16].

considers to be necessary for the next stage of the BIMMER, the creation of the related renovation scenarios. Based on the products that have been used in the building (i.e. Fibran geo, Alumil S77 window etc.) we searched for the relevant Tables and data corresponding to these factors and values (Figure 4). This information was then stored in the building material and component database and exploited at the KPI's calculation stage by the RenoDSS tool.

3.1.3 HVAC System and MEP Components

Rooms and spaces

For the spatial discretization of the building, we assumed that each room represents a different space. Specific properties for each space should be defined (such as the Condition and Space Type) to perform a more accurate energy analysis. The selection of these properties depends on the use of each space of the building (i.e. a bedroom should be defined as a Dormitory) and its HVAC system (i.e. Heated, Heated and cooled etc.).

In our case, a Variable Refrigerant Flow (VRF) fan powered HVAC System is installed; consequently, many of the existing spaces are served by terminal Air Condition units, considered to be "Heated and cooled". On the contrary, plenums should be handled as "Plenums" (non occupiable) while the Engine Room as a "non Occupiable" space too. Spaces which miss an AC (mostly WCs) should be considered as "Naturally vented only" or as "Unconditioned", depending on having windows or not respectively.

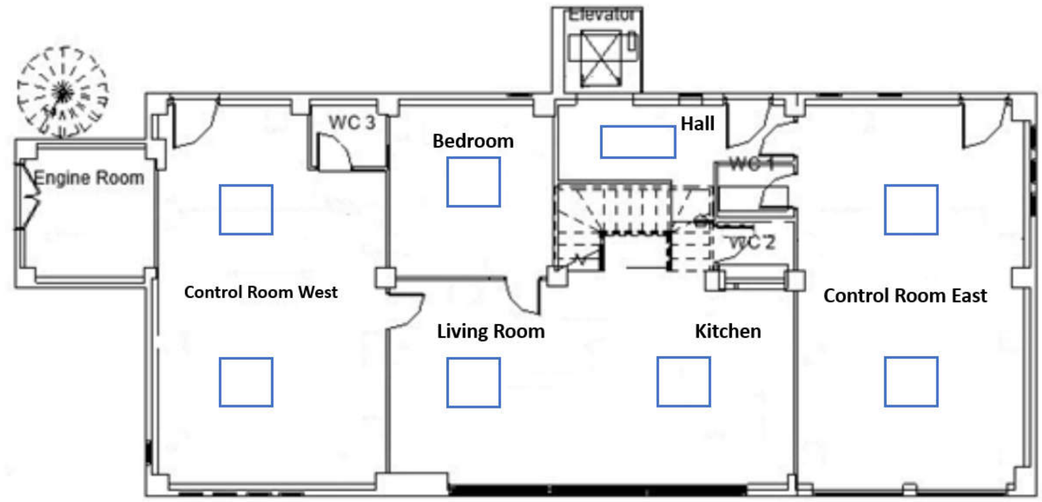


Figure 5. Floor Plan: Ground floor AC indoor units.

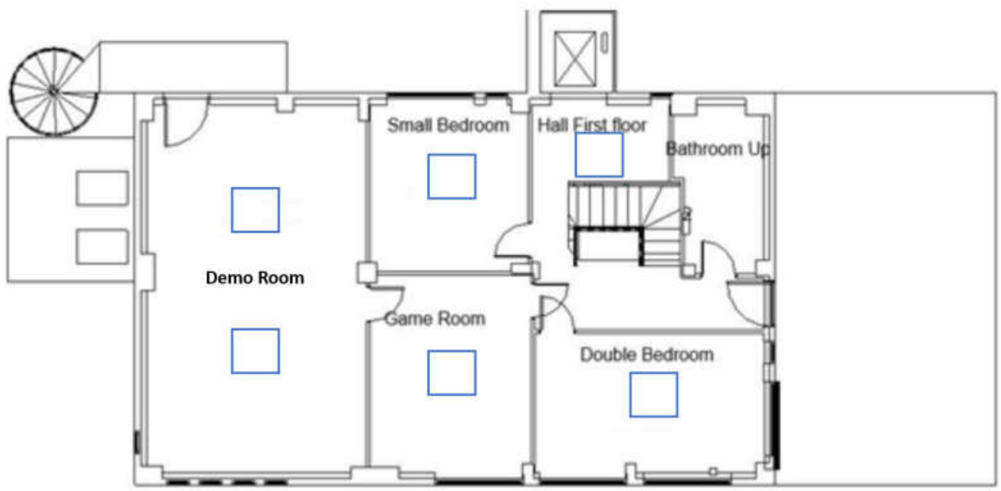


Figure 6. Floor Plan: First floor AC indoor units.

Air Condition System

Regarding the HVAC System, as mentioned above, in KRIPIS building, a VRF air conditioning system is installed and used for both heating and cooling of the occupied spaces.

An individual outdoor unit, known as the "supply side" of the system, serves each story. A variety of different models of ceiling mounted air conditions (4-Way or 1-Way cassettes) that constitute the "demand side" are placed at the different spaces of the building. Most of the models differentiate simply in the cooling and heating capacity values while the geometry remains unchanged.

More specifically the two installed outdoor units are from the manufacturer LG, model ARUN (Heat Pump), Multi V IV, Inverter type and Heat Pump, with Power Supply characteristics: 3Φ, 380-415 V, 50 Hz. In the table below additional information for each outdoor unit is presented.

LG Model	Serving Floor	Total Cooling Capacity (HP)
ARUN100LTE4	Ground floor	10
ARUN080LTE4	First floor	8

Table 7. The LG Outdoor Units of KRIPIS building.

In Table 8 specifications of each AC outdoor unit are presented.

Properties / LG Model	ARUN100LTE4	ARUN080LTE4
ConsumptionHeatingCapacity (W)	5490	4580
ConsumptionCoolingCapacity (W)	5380	4380
EfficiencyHeatingCapacity (W)	31500	25200
EfficiencyCoolingCapacity (W)	28000	22400
EER	5.2	5.11
COP	5.74	5.5
MaxOutdoorTemperatureCooling (ºC)	43	43
MinOutdoorTemperatureCooling (ºC)	-10	-10
MaxOutdoorTemperatureHeating (ºC)	18	18

MinOutdoorTemperatureHeating (ºC)	-25	-25

Table 8. Specifications of the outdoor units of KRIPIS building.

Regarding the indoor units, 4-Way and 1-Way LG cassettes were placed inside the rooms. All the demand units families are both ceiling hosted and their specifications are shown in Table 9.

Properties /LG Model	**ARNU07GTRC4**	**ARNU12GTRC4**	**ARNU15GTQC4**	**ARNU18GTQC4**	**ARNU09GTUC4**
n-Way	4-Way	4-Way	4-Way	4-Way	1-Way
HeatingCapacity (W)	2500	4000	5000	6300	3200
CoolingCapacity (W)	2200	3600	4500	5600	2800

Table 9. Specifications of indoor units of KRIPIS building.

Figure 7. left) The outdoor units placed in KRIPIS building, right) 4-Way Cassette indoor unit placed in KRIPIS building.

The next Table present the LG products placed inside KRIPIS building organized per floor.

Ground floor indoor unit LG model (served by the ARUN100LTE4)	**Served Room**	**First floor indoor unit LG model (served by ARUN080LTE4)**	**Served Room**

ARNU07GTRC4	Guest Room	ARNU07GTRC4	Back Corridor
ARNU09GTUC4	Entrance Hall	ARNU07GTRC4	Single Bedroom
ARNU18GTQC4	Living Room	ARNU09GTUC4	Demo Room Front
ARNU18GTQC4	Kitchen	ARNU12GTRC4	Demo Room Back
2x ARNU12GTRC4	Control Room West	ARNU12GTRC4	Office
2x ARNU15GTRC4	Control Room East	ARNU18GTQC4	Double Bedroom

Table 10. Demand sides and spaces of the ground and first floor.

Thermostats

In order to regulate the temperature of the spaces of the building, thermostats were placed. The product used was the PREMTB001 (LG manufacturer). It is worth mentioning that in our case, one thermostat controls each indoor unit. Based on the relevant WG3v3 confluence page, three basic properties were needed for each thermostat, to differentiate it from the others while controlling each air condition unit independently.

Figure 8. Thermostats installed in KRIPIS building.

Electric radiator

Regarding the heating system, in KRIPIS building only one wall mounted electric radiator exists in the bathroom of the first floor (Figure 9).

Electric equipment

Finally, information about the electrical outlets as well as the manual switches has been also collected. Two different types of outlets have been placed in KRIPIS: the standard and the weatherproof, however both are type F (Schuko) and comply with the default value for the residential voltage of Greece. As for the manual switches, in the building exist single pole and three-way switches (Figure 9).

Figure 9. left) The electric radiator, right) the outlet installed in KRIPIS building.

Ventilation system

As already mentioned, fenestration does not exist in two of the restrooms of the ground floor; hence, a ventilation system has been installed for the sufficient air circulation. However, we did not take into account this factor and we assumed that these spaces are unconditioned.

Solar water heater

On the roof of the building a solar water heater has been placed to exploit the solar energy for having domestic hot water. The product is a triple energy "Sonnentech S200" (Figure 10).

The tank is manufactured in accordance with European specifications EN 12976 and it contains insulation from self-extinguishing environmentally friendly polyurethane 48 kg/m^3 with thickness of 50 mm. Its working pressure is 10 bars and its material thickness 2.5 mm. Its external surface is metal, covered by color coating, and it is also anticorrosion protected while also contains magnesium anode. Finally, its capacity is 150L. The solar collector panel is 2.5 m^2 (2.0 m x1.25 m) covered by Tinox and 8.5 mm aluminum anode. It also contains rockwool 50 kg/ m^3 with thickness of 20 mm.

Photovoltaics

On the roof of the KRIPIS SmartHome, solar panels have been installed, to exploit the solar energy for different operations of the building. The module is the product "Solar Frontier 165W". Given the surface restrictions, 58 thin film CIS (Copper Indium Selenide) PV panels have been installed, providing anominal power of 9.57 kWp. The orientation of the panels is 228° to the South-West with an inclination of 18°. The panels are separated into nine strings; 4 and 5 strings, each one consisted of 7 and 6 panels respectively. Finally they are led into the two MPPT trackers of a DC/AC inverter. The inverter is the Symo product (10kWp Power) made by Fronius. In Figure 10 left and in Figure 10 right, the solar water heater and the installed photovoltaic system are presented respectively.

Figure 10. left) The solar water heater, right) The photovoltaics installed on the roof of KRIPIS building.

3.1.4 Energy Footprint

KRIPIS building considers to be a near-Zero (NZEB) Energy Smart Home of CERTH/ITI and has very high energy performance. A NZEB is defined as "a building with very high energy performance", where "the nearly zero or very low amount of energy required should be extensively covered by renewable sources produced on-site or nearby" [12]. KRIPIS is the first house in Greece that combines enhanced construction materials and intelligent ICT solutions creating a future-proof, sustainable and active testing, validating and evaluating environment.

In Table 11 the annual energy consumption data of the building is presented. As already mentioned thoroughly in the 3.1.1 subsection, the total surface area and the conditioned area of the building is 391 m^2 and 300 m^2 respectively.

Year	Energy Consumption (kWh)	Energy Consumption per total area (kWh/ m^2)	Energy Consumption per conditioned area (kWh/ m^2)
2017	11749	30	39.2
2018	20842	53.3	69.5
2019	22980	58.8	76.6
2020	26046	66.6	86.82

Table 11. Annual energy consumption of KRIPIS building.

3.2 BUILDING MONITORING AND EVALUATION

In recent construction industry, the implementation of an effective monitoring and evaluation (M&E) system considers a necessary effective tool for project performance and optimization of a project's contribution to society and the environment, by ensuring that construction projects meet approved quality, cost, time and social sustainability objectives. With the emergence of technology, stakeholders on a project are able to ensure that the right things are done and are also able to access any relevant information required for the purpose of evaluation and decision making even if they work remotely. Technologies such as sensors, drones or unmanned aerial vehicles (UAVs), Geographic Information Systems (GIS) and Building Information Modelling (BIM) facilitate Monitoring and Evaluation in complex project environments.

3.2.1 Wireless Sensor Network Installation

A Wireless Sensor Networks (WSN) monitors physical or environmental conditions, such as temperature, sound and pressure. The KRIPIS SmartHome is a modern bi-directional network which can both collect data and enable control of sensor activity. It is a rapid prototyping and novel technologies demonstration infrastructure resembling a real domestic building where occupants can experience actual living scenarios while exploring various innovating smart IoT-based technologies with provided Energy, Health, Big Data, Robotics and Artificial Intelligence (AI) services.

A WSN is built of nodes, where each node is connected to other sensors. Moreover, it communicates with a Local Area Network or Wide Area Network through a gateway. The gateway acts as a bridge between the WSN and the other network. This enables data to be stored and processed by devices with more resources. Figure 11 illustrates the Wireless Sensor Network of KRIPIS. However, in CERTH's organizational level, the Smart-Home network map considered confidential document and for this reason, only a limited part of it is provided.

Regarding the sensors a huge variety is installed in KRIPIS; CO_2, temperature, humidity, luminance etc. Moreover, several smart applications such as Smart Parking, Smart Agriculture, Smart Relay and Smart Water are implemented. Finally, several smart electric appliances such as (smart fridge, smart dishwasher etc.) are also used. The types of the IoT-based technologies placed in the building are presented in Figure 12.

Three servers are used in KRIPIS' WSN; a Central, a Local and an OPC BACnet. Several gateways connect their nodes with the Servers through different protocols and standards such as Raspberry Pi, EnOcean, ZigBee, Televes, LoRa and Infrared.

Describing briefly the Sensor Network of KRIPIS, the A/C units are connected to the Central SmartHome Server through an OPC BACnet Server while the smart electric appliances are connected to the Central SmartHome Server through the Local Server. Furthermore, the sensors are connected to the Central Server through the gateways immediately or through the Local Server. All the above details are depicted in Figure 11.

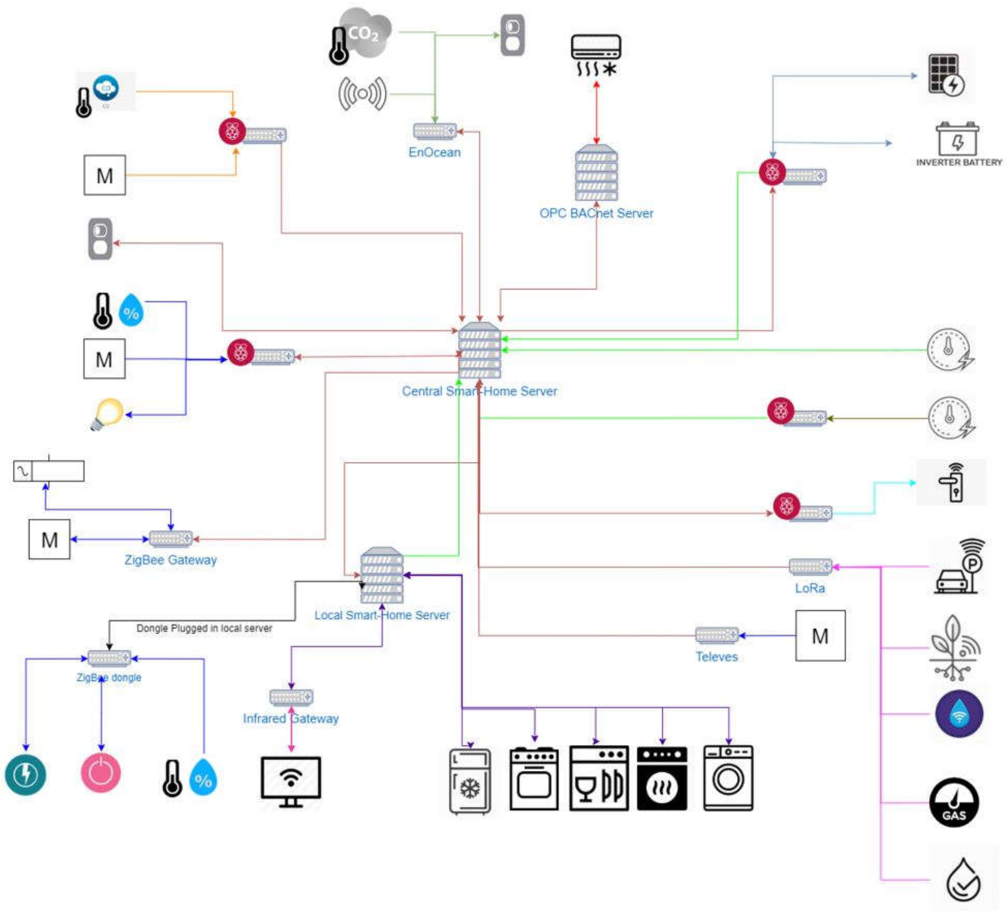


Figure 11. Wireless Sensor Network of KRIPIS building.

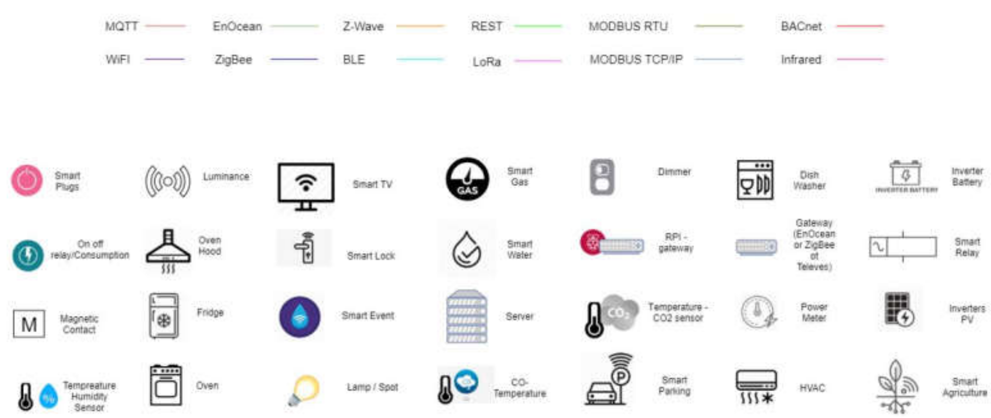


Figure 12. Definition of the symbols of the WSN of KRIPIS building.

3.2.2 *Middleware Deployment and Testing*

As described in the previous sections, the KRIPIS pre-validation site consists of an existing system for data management of the WSNs. This system incorporates various components for local data collection and secure storage on the cloud. The BIMERR middleware, being a set of building blocks to expose the WSN data in a standardized form, interfaced with the existing KRIPIS provided two main functionalities: device metadata and sensor data modeling and secure hosting (see Figure 13).

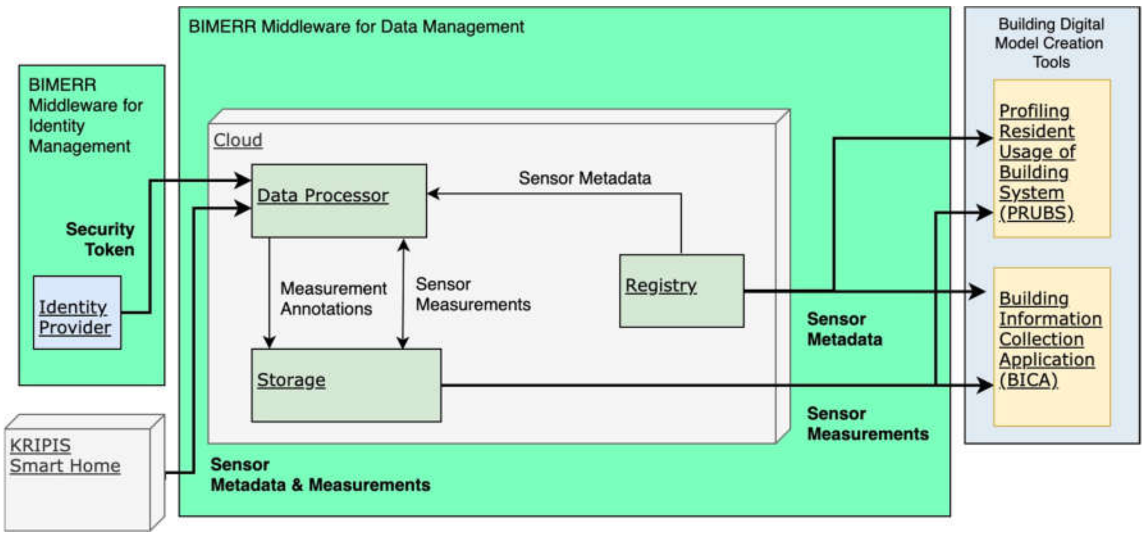


Figure 13. Middleware deployment for KRIPIS site.

The KRIPIS device metadata are available via extensive networking APIs. Interested consumers can query this information to know the specification of various devices, the payload formats, and various details of the deployments. The operations and the information exposed by these APIs follow proprietary formats which had been chosen beyond the scope of BIMERR based on the requirements of this site. On the other hand, the BIMERR project has chosen to a selection of standards which satisfy generic requirements of WSNs and allow extensions for specific domain requirements. The role of the middleware was to deploy necessary connectors to convert the existing metadata to the selected standard in BIMERR that is the W3C Web of Things (WoT) Thing

Descriptions[6]. This standard was already proven to be representative of heterogeneous devices and this was validated again when describing KRIPIS devices.

Similar to device metadata, the sensor data of KRIPIS is available via a simple and pragmatic API, which is custom and tailored to the requirements of this specific site. The middleware provided the necessary connectors to convert and store the data from certain sensors for a predefined period. The chosen BIMERR format for sensor data was the RFC8428 Sensor Measurement Lists[7] (SenML) standard which is very concise and extensible. The middleware uses a central configuration file to select specific sensors and migrate the necessary data into BIMERR cloud locations.

Overall, the KRIPIS pre-validation provided a valuable opportunity to develop the middleware using already available data in the early phases of the project, offering the project an extended amount of time to develop while other BIMERR pilot WSNs were being designed and deployed. In particular, the pre-validation using KRIPIS led to the initial development of middleware Data Processor and Registry as well as the extensions to the Storage components. These components were consecutively used by other BIMERR components such as PRUBS to drive the early interface development and validation. The details of the implementation are available in D8.2 - BIMERR Middleware prototype [1].

3.3 IFC CREATION

A crucial step within the BIMERR workflow is the creation of the IFC file in an appropriate way, in order to include all the necessary information. If a point cloud is available, the designer can use the Scan-to-BIM tool to generate the original IFC file. Otherwise, if floor plans, sections, and side views of the building are available, a BIM modeler can create the

[6] https://www.w3.org/TR/wot-thing-description

[7] https://datatracker.ietf.org/doc/html/rfc8428

BIM model in widely used professional BIM authoring tools (i.e. Revit, ArchiCAD etc.). In the next subsections these two processes are described.

3.3.1 BIM Authoring Tools

As it was mentioned above, the designer can exploit the floor plans, sections etc. of a building, to create the IFC file using a professional BIM authoring tool. For the KRIPIS pre-validation site, these elements (2D floor plans and sections) were available; therefore, it was decided to generate an IFC file by exploiting Autodesk Revit 2021 while this version it is up to date and has some great advantages.

For the appropriate IFC generation, the relevant general guidelines from the Deliverable 5.2 were followed, to meet the building's static data requirements of BIMERR [6]. These guidelines describe the first steps within Revit to create a generic BIM model, ensuring that all the necessary thermal properties of each material are included.

A 3D view and a section view of the building designed in Revit 2021 is illustrated in Figure 14 and Figure 15 respectively.

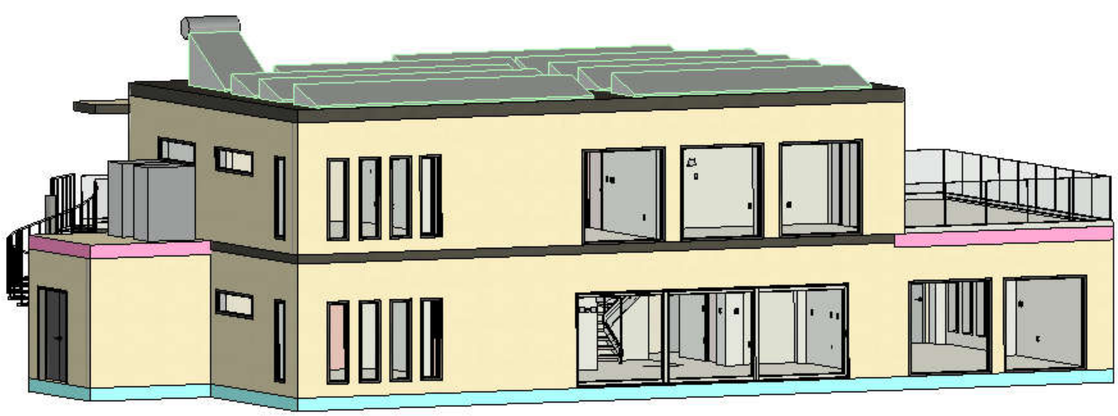


Figure 14. 3D View of KRIPIS building.

Figure 15. Section View of KRIPIS building.

Acoustic ceiling and plenums

The acoustic ceiling of the building was an issue that needed to be handled when comparing the two different methods of creating an IFC file. By using a laser scanner to generate an IFC, the acoustic ceiling would operate as the upper limit of the room, ignoring the fact that a plenum exists over it. Hence, in the Scan-to-BIM approach, the acoustic ceiling, the plenum are triggered as a single construction element consisting of three layers. In contrast, the BIM model designed in Revit was decided to contain all these details related to the acoustic ceiling and plenums and handle plenums as separate spaces for an accurate energy simulation.

Spaces and zones

As it was mentioned in subsection 3.1.3, a VRF fan powered air conditioning system operates in KRIPIS; hence, to regulate the temperature of the spaces of the building, thermostats have been installed. In our case, one thermostat controls each indoor unit. To meet the BIMERR energy requirements, only one thermostat must exist per space, while each thermostat should control only one space. However, in some rooms (and consequently spaces) (i.e. Control Room West) two rooftop units exist. Therefore, the initial space had to be divided virtually using the space separator tool in Revit (i.e. Control Room West A', Control Room West B'); in this way, each thermostat is connected to a single space.

Within BIMERR, the consortium has agreed that the space grouping into zones should be performed according to the building apartments; each zone should indicate one apartment. For KRIPIS, we assumed that each floor constitutes an apartment; hence, two different zones were defined.

Heating and cooling load analysis

After the space placement in the BIM model, the designer defined specific properties for each space of KRIPIS (such as the Condition and Space Type), depending on the use of each space of the building (i.e. a bedroom, kitchen etc.) and its HVAC system (i.e. Heated, Heated and cooled etc.). As it was aforementioned, due to the Variable Refrigerant Flow (VRF) HVAC System of the building, many of the existing spaces are served by air condition units and were defined as "Heated and cooled", plenums and the Engine Room were defined as "Plenums" and "non Occupiable" space respectively, while the spaces which miss an AC were defined as "Naturally vented only" or as "Unconditioned", depending on having windows or not respectively.

Custom Revit families

Some of the MEP components of the building did not exist in the online BIM libraries (i.e. BIMobject, BIMsmith etc.) or visualization issues were arisen when the exported IFC was imported to relevant IFC viewers (i.e. Solibri). Therefore, it was decided to create custom Revit families for the desired MEP objects from scratch, to deal with the aforementioned limitations.

This basic created family contained only a solid geometry but of course, further geometric details can be further added in the future. However, in our case we assumed that the specific MEP components would be visualized approximately as simple boxes/ shapes with the real dimensions of the objects though. The same process was repeated for all the MEP components of KRIPIS; brand new families were created for the air condition units of the building and their thermostats, for the electric radiator, as well as for the solar collector and the photovoltaics. Each MEP component placed in the project must contain specific properties depending on its use to meet the BIMERR Energy Systems requirements. Therefore, specific Parameters were added and defined in Revit appropriately, depending on the referred MEP component. Apparently, many options exist, and the user should choose the best option every time. In addition, the created families can be editable for the user; in this way the designer would be able to modify the geometry of a type of the family within the project and specify different dimensions for different types of the family. However, this step is considered optional while the created families could have fixed dimensions according to the specifications of each product.

Connection of supply and demand side of the A/C units

Normally, a standard way to connect two objects in Revit is by creating systems and exploiting the use of pipes and connectors. However, this way was considered quite time-consuming and complicated. For the connection of the supply and demand side of the HVAC system instance parameters were leveraged; the instance parameter must be defined for each instance element in the project independently. More specifically, the supply side family in Revit contained an instance[8] parameter "Name" and the demand side family an instance parameter "SupplySideSystemName" (Figure 16). By giving the same string value in these two parameters (i.e. OUTDOOR_GROUND_FLOOR) we managed to associate the two components without any physical representation (i.e. pipes).

[8] The Instance option enables the user to modify the parameter value separately for every instance while the Type option enables the user to modify the parameter value, which applies to all elements of the family type.

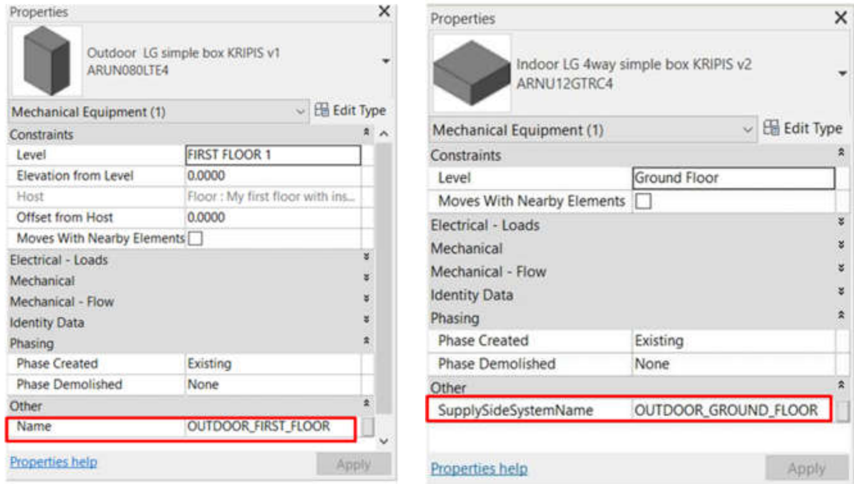


Figure 16. Instance parameters visible in Properties palette: left) the Supply side and right) the Demand side of the HVAC System.

IFC exportation – project parameters

In addition, an important point at the BIM process is to export an IFC file, which contains all the necessary classes and types of the placed elements and has assigned each class and type correctly to them. Not only is necessary the placement of a component in Revit, but also the definition of its Class and Type to be exported. For example, in KRIPIS pre-validation site, the HVAC system of the building needed to be exported as IfcUnitaryEquipment Class while the Type was differentiated according to the unit; more specifically the outdoor unit is an AIRCONDITIONINGUNIT Type, instead of the indoor unit which is a ROOFTOPUNIT Type (the classes and types' enumeration are defined from IFC4 Documentation[9]).

Due to these restrictions the conventional way of exportation of Revit categories could not respond effectively to our requirements, because different elements must be

[9] https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML//

exported in the same Class but in different Types and so far the conventional way does not support this requirement. Therefore, it was decided to follow the "Project Parameters" approach, since it was considered a more effective and stable way to export different families in different IFC Classes and Types. Two project parameters (IFCExportAs, IFCExportType) were created once in the Revit project and every element of this project had the two above parameters as two additional properties in its Type Properties window. The designer was then able to define the desired Class and Type of each type of a family to be exported in the IFC in accordance with the BIMERR Requirements properties for each component category (i.e. The supply side of the VRF system was exported as IfcUnitaryEquipment, AIRCONDITIONINGUNIT) as shown in Figure below.

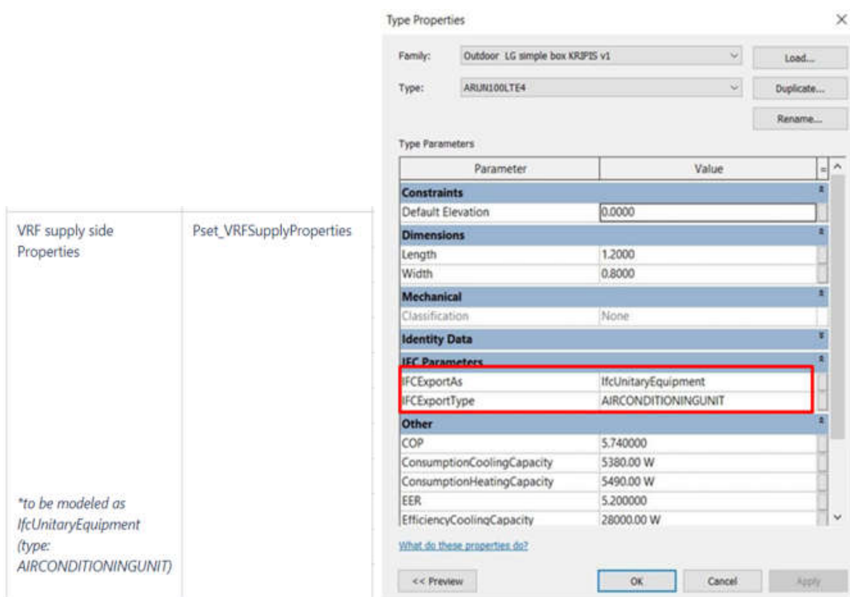


Figure 17. Exportation per object in Revit: left) BIMERR Requirements; right) IFCExportAs, IFCExportType definitions for each type of a family.

It is also worth mentioning that the designer should choose if the relevant parameters in a MEP family would be set as instance or as type; this would depend on the concept in which each parameter would be used and should be left in the designer's judgement. By following these steps, the exported IFC file was checked in relevant IFC viewers to ensure that it finally contained all the necessary HVAC information that BIMERR Solution requires in the appropriate way as shown in Figure 18.

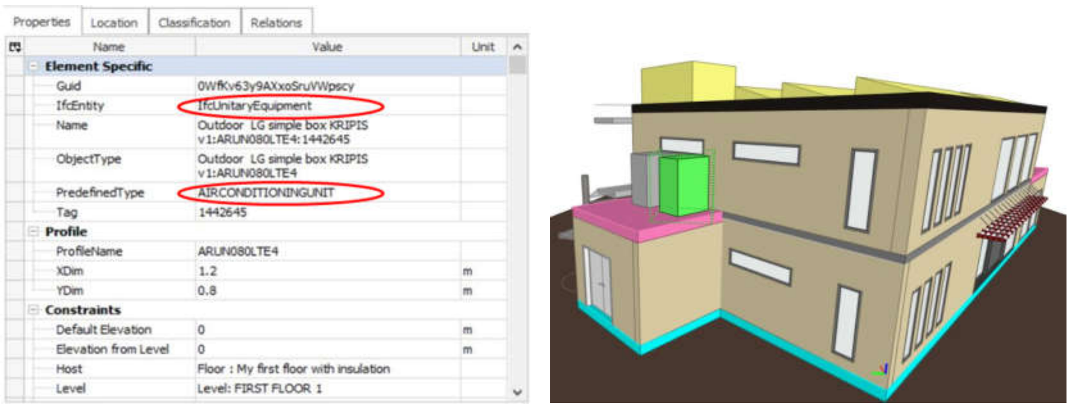


Figure 18. Checking of the Class and Type of an element in the exported IFC file.

By using these two Project Parameters, we managed to export two different mechanical equipment families in two different Types. However, attention must be paid to avoid typos. Finally, the total MEP categories exported from Revit to IFC file by using the exportation approach as described above are presented in Table 12.

MEP Object	IFC Class	IFC Type
AC supply side	IfcUnitaryEquipment	AIRCONDITIONINGUNIT
AC demand side	IfcUnitaryEquipment	ROOFTOPUNIT
Thermostat	IfcUnitaryControlElement	THERMOSTAT
Radiator	IfcSpaceHeater	RADIATOR
Outlet	IfcOutlet	POWEROUTLET
Light switch	IfcSwitchingDevice	CONTACTOR
Light fixture	IfcLightFixture	POINTSOURCE
Photovoltaic	IfcSolarDevice	SOLARPANEL
Solar collector	IfcSolarDevice	SOLARCOLLECTOR
Water heater storage	IfcTank	STORAGE

Table 12. Exported IFC Classes and Types of MEP objects of the building

3.3.2 Scan-to-BIM

The Scan-to-BIM tool has been used for the semi-automatic generation of a BIM model of the KRIPIS Smart Home following the Industry Foundation Classes standard. As mentioned in Section 2.2 the tool encompasses three sub-components, namely *Structural*, *MEP* and *Editor* that are related as shown in Figure 19. As illustrated, the inputs to the process are a point cloud and images of the building.

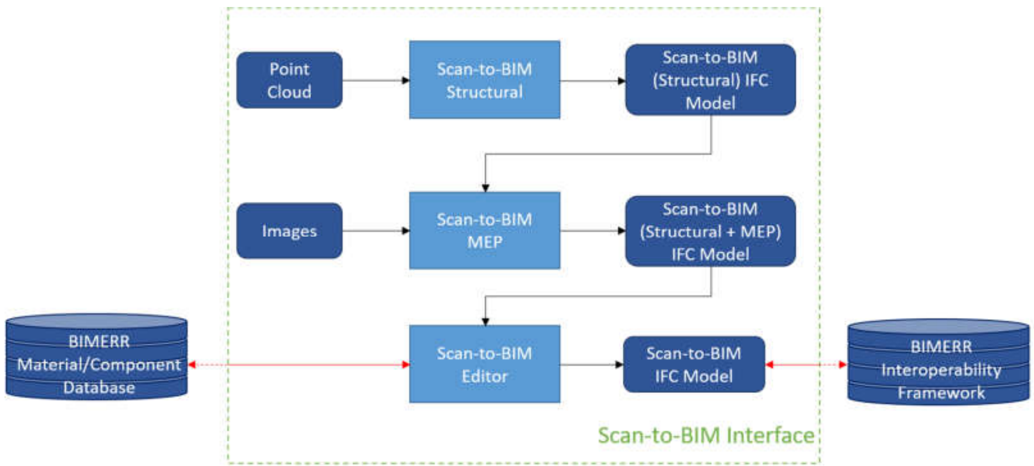


Figure 19. Pipeline of the Scan-to-BIM process

For digitizing the KRIPIS pre-validation site, a Faro Focus 150s laser scanner[10] was used. Regarding the scanning process, 10 scans for the exterior, 31 scans for the ground floor and 28 scans for the first floor were obtained, to generate the point cloud of the building.

Figure 20 illustrates the stages of the Scan-to-BIM *Structural* process for the KRIPIS SmartHome. First, the above-mentioned point cloud, obtained by means of a laser scanner, is pre-processed (registered, cleaned, and subsampled), and next it is segmented in floors (see Figure 20a). Data belonging to ceilings and floors is used to model the slabs

[10] http://geosense.gr/assets/pdf/Faro%20s150%203D.pdf

(Figure 20b). Then, surfaces defining the walls are identified and its connectivity determined to produce the spaces, or first level space boundaries, as illustrated in Figure 20c. Surfaces are subsequently used to model walls (as in Figure 20d) and openings are identified and labelled as doors or windows, as seen in Figure 20e. Finally, second level space boundaries (2LSBs) are calculated, considering all the identified structural elements (see Figure 20f).

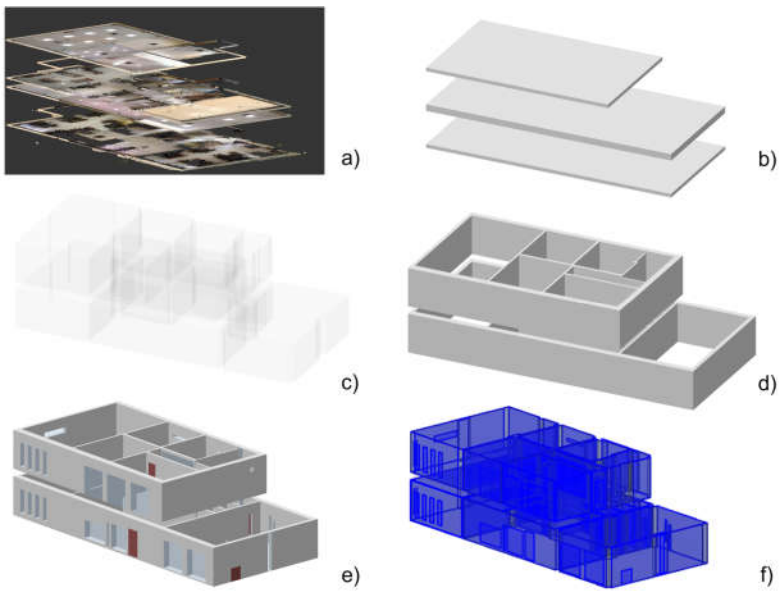


Figure 20. Results of Structural Scan-to-BIM for KRIPIS.

Once the 2LSBs are calculated, a Scan-to-BIM Structural IFC model is produced. This file, together with a number of images of the building, which can be acquired by DSLR cameras or taken/produced by the laser scanner, are the inputs to the Scan-to-BIM *MEP* process. First, by means of photogrammetric techniques, point clouds of the different spaces are produced (Figure 21a illustrates the case of a bedroom on the first floor). The pictures used for the photogrammetric reconstruction are processed with the MEP Object Detector (detailed information is provided in Deliverable 5.4) to detect and classify MEP objects (i.e. radiators and air conditioning units) present in each space. When one of these entities is identified, the image coordinates of the bounding box containing the HVAC unit are re-projected onto the point cloud where world (i.e. IFC model) coordinates are calculated. Finally, these 3D points are utilized to define the geometry of the object in the IFC model and its label (e.g. Air Conditioning unit) to establish the nature of the entity.

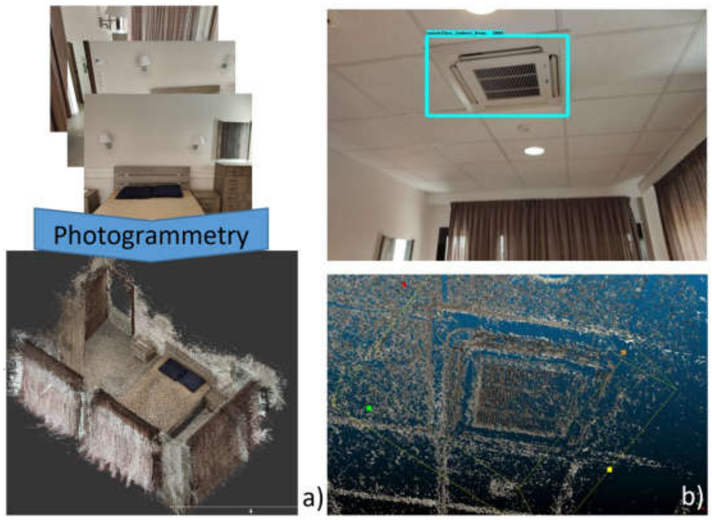


Figure 21. MEP Scan-to-BIM process applied to KRIPIS.

The Scan-to-BIM (Structural + MEP) model produced after these two stages is finally modified with the Scan-to-BIM *Editor*, where features and properties that cannot be retrieved by means of computer vision techniques are manually added with a GUI (main window shown in Figure 22a). These include: material information of structural components (as illustrated in Figure 22b), specifications of MEP objects, and classification of spaces into zones (i.e. apartments) as seen in Figure 22c. Figure 22d shows in detail a region of the produced KRIPIS Smart Home IFC file, loaded into Solibri Anywhere. In the image, a wall linked to *storey1* is highlighted and material information in shown in the panel on the left-hand bottom side. The details of the implementation are available in D5.4: Innovative Scan-to-BIM tools for Automated BIM generation 2 [2].

The produced IFC file, including both structural and MEP entities is subsequently checked by the BIM Manager Platform, as detailed in Section 3.4, and modified accordingly by means of BIM authoring tools (e.g. ArchiCAD, Revit).

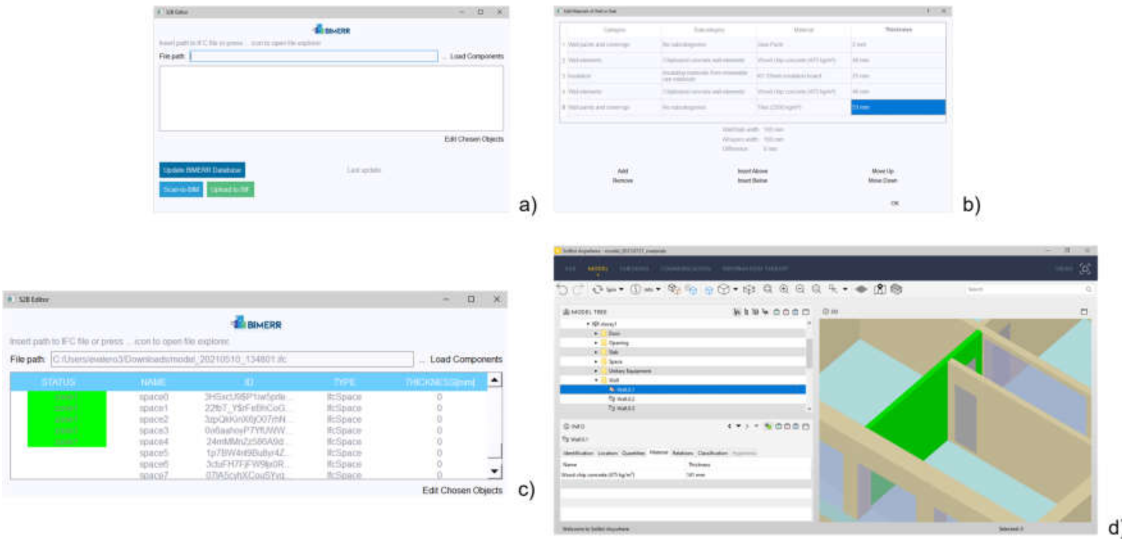


Figure 22. Scan-to-BIM Editor process.

3.4 IFC CHECK AND ENRICHMENT

In this subsection the tests that took place in the KRIPIS pre-validation site, regarding the BIM-MP BIMERR tool are presented.

3.4.1 B-rep Generation

The B-rep generation module of BIM Management was used to extract the boundary representations of all architectural elements of interest of KRIPIS building. The execution of the B-reps module of BIM-MP is displayed in Figure 23.

The extracted B-reps of KRIPIS pre-validation site are presented in Table 13.

Site	1
Spaces	29
Walls	36
Wall openings	53
Windows	34
Doors	18
Slabs	8

Slab openings	1
Coverings	17
Columns	43

Table 13. Extracted B-reps of KRIPIS pre-validation site.

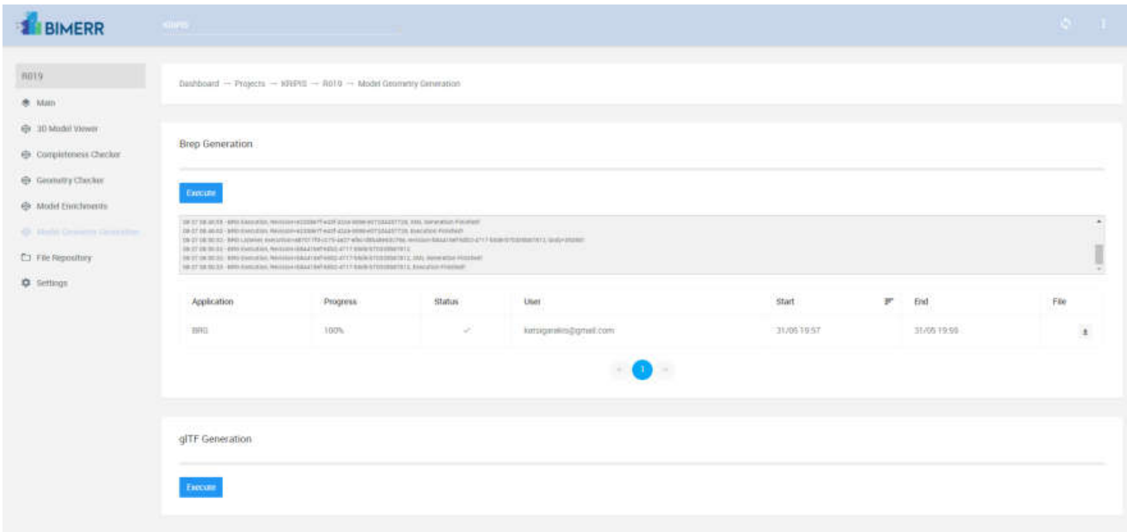


Figure 23. B-rep generation execution page.

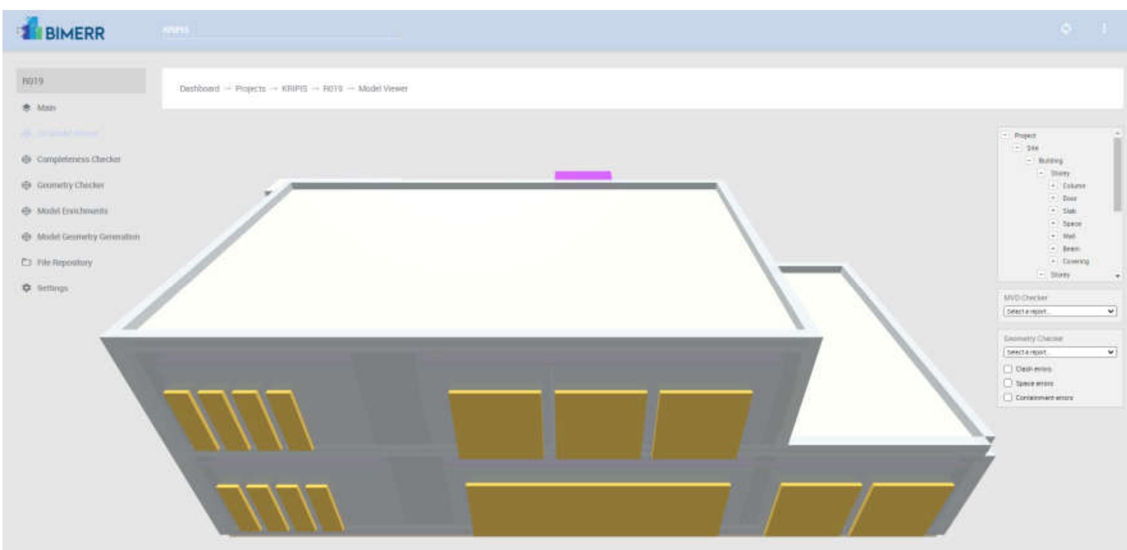


Figure 24. 3D model viewer page.

The overall building model and its respective building tree is displayed using BIM-MP's viewer in Figure 24. By clicking on the expansion buttons on the building tree (right part of Figure 24), the user can also hide or display sets of building components (walls, doors, etc.) grouped by their respective story.

3.4.2 Geometry Error Detection

To ensure a geometric error-free model for BEPS model generation purposes, BIM-MP's Geometric Error Detection (GED) tool was executed as displayed in Figure 25. GED tool reports also the statistics of the detected error types as indicated in the pie chart at the bottom of Figure 25.

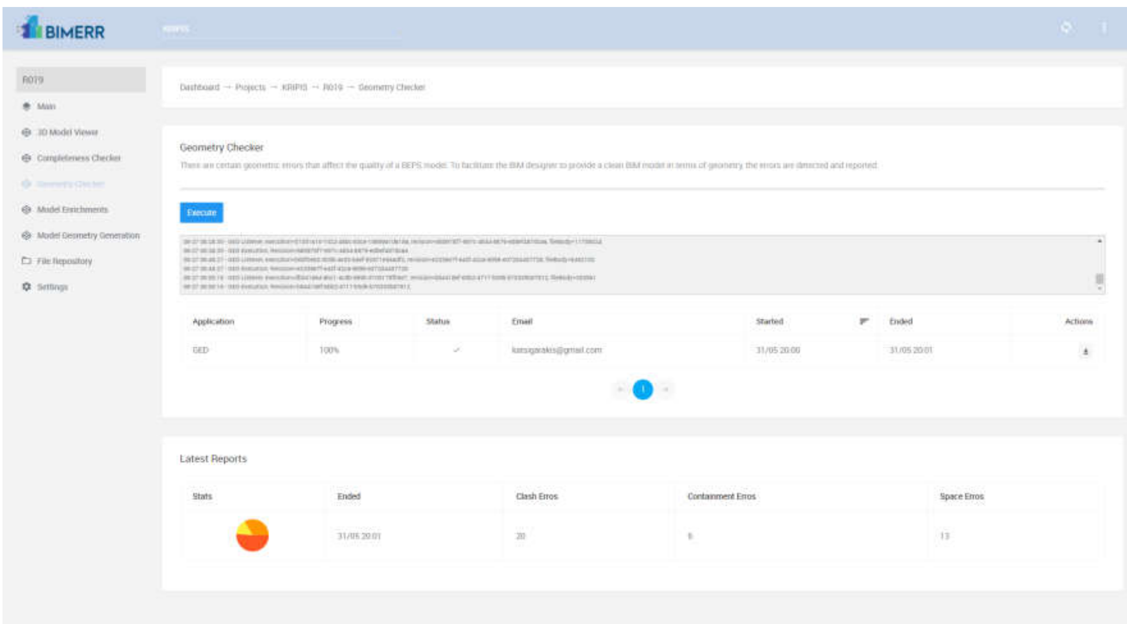


Figure 25. GED tool's execution page.

The detected geometric errors of KRIPIS model are displayed to the user of BIM-MP using GED tool's viewer as illustrated in Figure 26. Two error types are reported: clash errors (including containment errors where one entity is contained inside another entity) and space errors where a space volume is not attached to any other building entity. As displayed in the same Figure 26, the error surfaces are displayed in red color. By clicking on the error surfaces the user can view also the involved entity pair if the error is a clash or the involved space volume if the error is a space error.

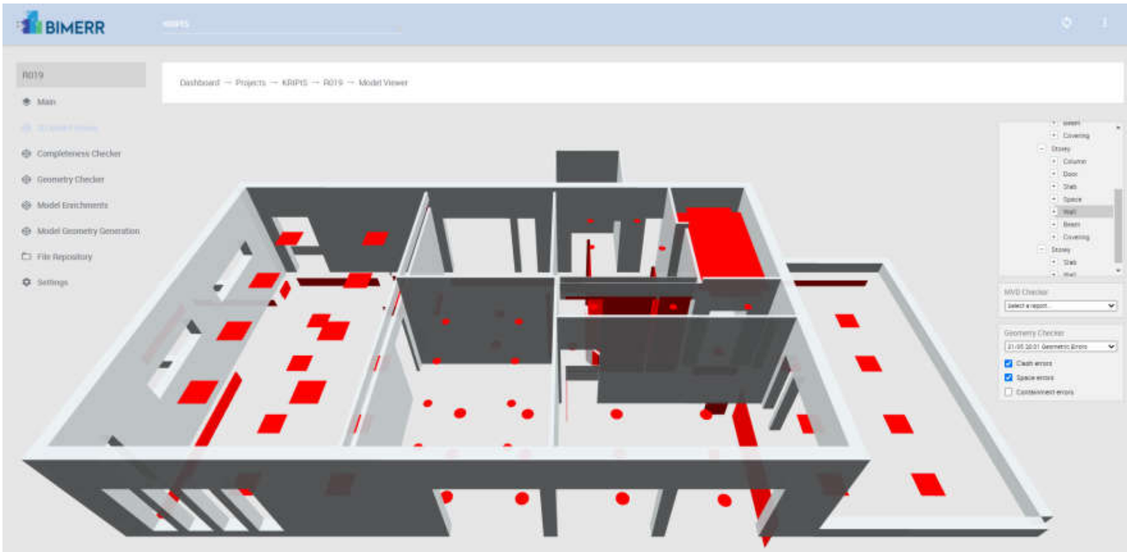


Figure 26. Detected geometric errors of KRIPIS building model by GED tool.

Figure 27. Geometric error-free building model of KRIPIS building.

After working iteratively in two steps: (a) with the GED tool for error detection and (b) with a BIM authoring tool for manual correction (Revit) the designer produced an error-free model of KRIPIS building as displayed in Figure 27.

3.4.3 MVD Checking for Thermal Properties and Schedules

When the geometric error-free model is produced, the IFC file of the KRIPIS building is checked for completeness regarding the thermal properties of materials and schedules. The completeness checking for thermal properties of the KRIPIS building is performed using BIM-MP's MVD service. To trigger the MVD checking for Thermal Properties, the user should select one of the original IFC file on the first drop-down menu, choose the Thermal Properties option on the second menu and press the Execute button of the MVD completeness checker page.

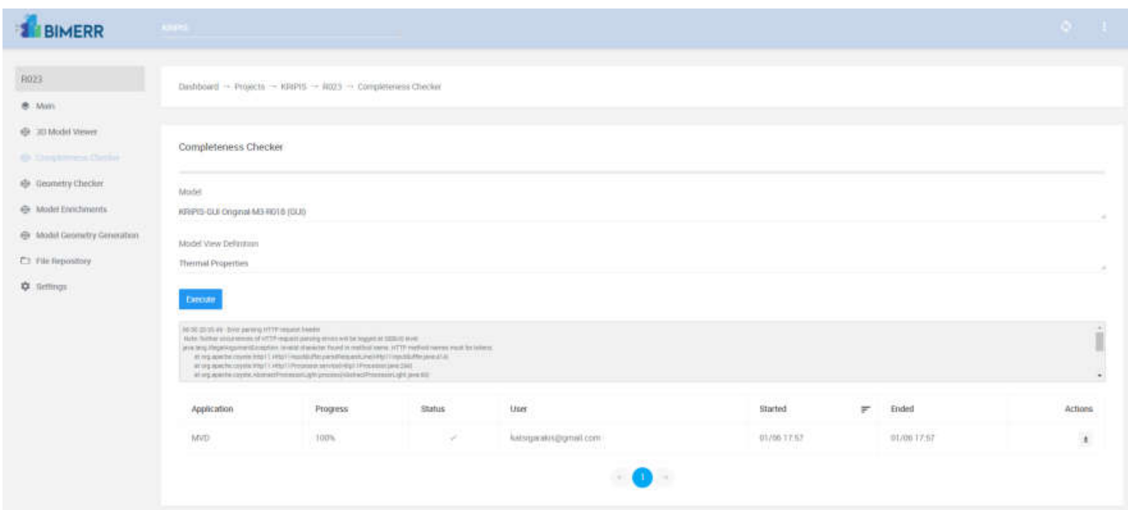


Figure 28. Thermal properties checking of KRIPIS building.

When the execution is completed, the error report of the KRIPIS building is available in three ways: a) Through the 3D model viewer as shown in Figure 29, b) In textual format as shown in Figure 30 and c) Through BIM-MP's file repository in JSON format as shown in Figure 31.

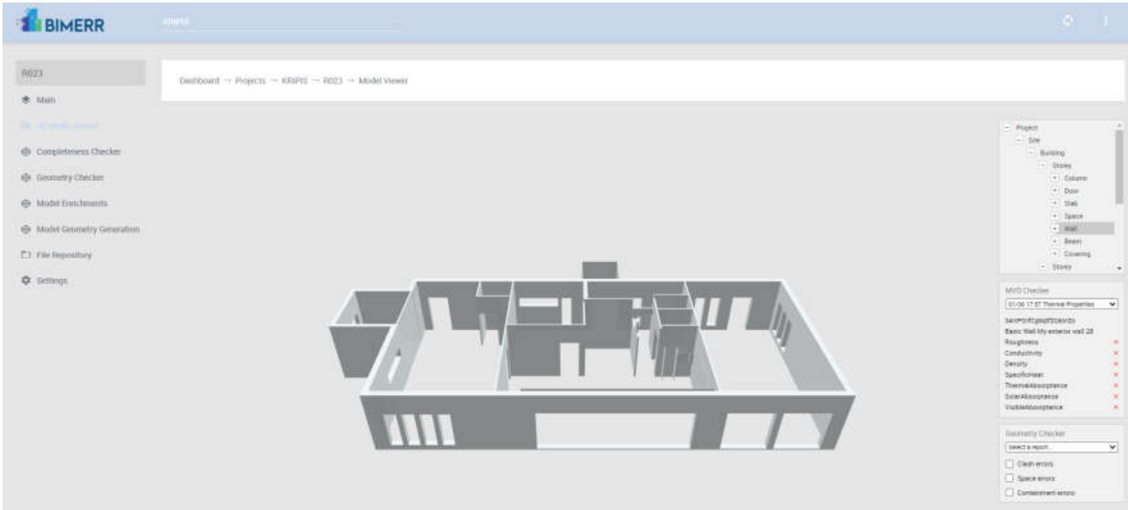


Figure 29. Thermal properties visual report of KRIPIS building.

Opaque_Materials_Thermal_Properties [BuildingElement_MaterialUsage_MaterialLayerSet_Properties] [IfcBuildingElement]

ExpressId	GlobalId	Name	Result	
#15130	2eiQE7k8vC0PCxoOmPaMUL	Basic Wall:My exterior wall 280mm:341795	×	
#15536	2eiQE7k8vC0PCxoOyPaMUL	Basic Wall:My exterior wall 280mm:341795	×	
#15638	2eiQE7k8vC0PCxoOmPaMUI	Basic Wall:My exterior wall 280mm:341796	×	
#15709	2eiQE7k8vC0PCxoOyPaMUI	Basic Wall:My exterior wall 280mm:341796	×	
#15797	2eiQE7k8vC0PCxoOmPaMUJ	Basic Wall:My exterior wall 280mm:341797	×	
#15868	2eiQE7k8vC0PCxoOyPaMUJ	Basic Wall:My exterior wall 280mm:341797	×	
#15956	2eiQE7k8vC0PCxoOmPaMUG	Basic Wall:My exterior wall 280mm:341798	×	
#16027	2eiQE7k8vC0PCxoOyPaMUG	Basic Wall:My exterior wall 280mm:341798	×	
#16130	2eiQE7k8vC0PCxmOqPaMSe	Basic Wall:My interior wall 80mm:341918	×	
#16328	2eiQE7k8vC0PCxmOqPaMX6	Basic Wall:My interior wall 80mm:342256	×	
#16410	2eiQE7k8vC0PCxmOqPaMcN	Basic Wall:My interior wall 80mm:342305	×	
#16515	2eiQE7k8vC0PCxmOqPaMde	Basic Wall:My interior wall 80mm:342366	×	
#16597	2eiQE7k8vC0PCxmOqPaMa7	Basic Wall:My interior wall 80mm:342449	×	
#16679	2eiQE7k8vC0PCxmOqPaMhb	Basic Wall:My interior wall 80mm:342611	×	
#16761	2eiQE7k8vC0PCxmOqPaMxH	Basic Wall:My interior wall 80mm:343655	×	
#16843	2eiQE7k8vC0PCxmOqPaM_h	Basic Wall:My interior wall 80mm:343837	×	

Figure 30. Thermal properties textual report of KRIPIS building.

```
[
    {
        "entities": [
            {
                "valid": false,
                "name": "Puerta_interior_de_1_hoja_abatible_ciega_Single_flush_door_14664:800 x 2100 mm:366478",
                "global": "2$38tkpE98ye0jZw7Tm5LA",
                "express": 22898,
                "rules": [
                    {
                        "valid": false,
                        "description": "Visual Light Transmittance",
                        "parameters": [
                            {
                                "valid": false,
                                "name": "PropertyName",
                                "value": "Visual Light Transmittance"
                            }
                        ]
                    },
                    {
                        "valid": false,
                        "description": "Heat Transfer Coefficient",
                        "parameters": [
                            {
                                "valid": false,
                                "name": "PropertyName",
                                "value": "Heat Transfer Coefficient (U)"
                            }
                        ]
                    },
                    {
                        "valid": false,
                        "description": "Solar Heat Gain Coefficient",
                        "parameters": [
                            {
                                "valid": false,
                                "name": "PropertyName",
                                "value": "Solar Heat Gain Coefficient"
                            }
                        ]
                    }
                ]
            },
            {
                "valid": false,
                "name": "Puerta_interior_de_1_hoja_abatible_ciega_Single_flush_door_14664:800 x 2100 mm:366887",
                "global": "2$38tkpE98ye0jZw7Tm51Z",
                "express": 22977,
                "rules": [
                    {
                        "valid": false,
                        "description": "Visual Light Transmittance",
                        "parameters": [
                            {
                                "valid": false,
                                "name": "PropertyName",
                                "value": "Visual Light Transmittance"
                            }
```


Figure 31. Thermal properties JSON report of KRIPIS building.

3.4.4 CBIP – Second Level Space Boundaries

To produce a Building Energy Performance Simulation (BEPS)-ready IFC model in terms of geometry, an enrichment of the IFC model with the building's second-level space boundary topology must take place. This enrichment in the case of KRIPIS building is performed using BIM-MP's CBIP service. The resulted enriched IFC model contained the necessary second-level space boundary surfaces as displayed for one building space in Figure 32 using Solibri Model Checker.

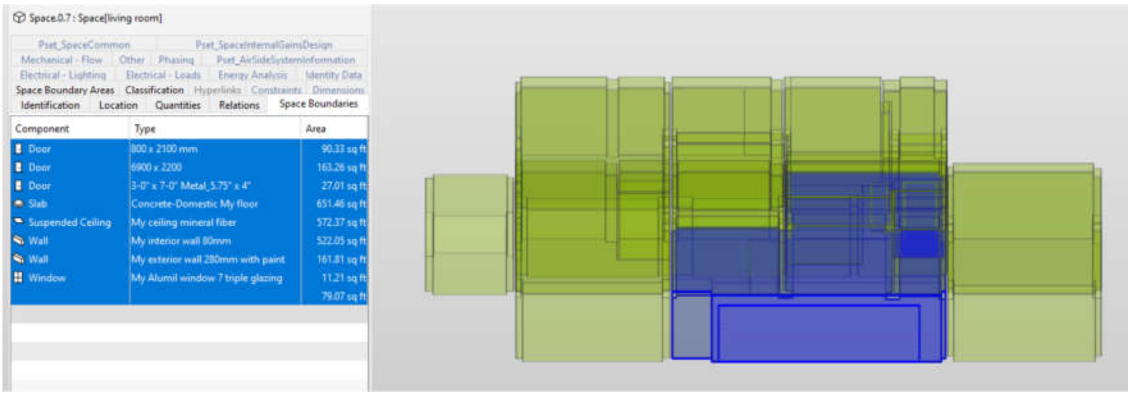


Figure 32. Example of second-level space boundary surfaces used to enrich KRIPIS IFC model (Solibri screenshot).

3.4.5 MVD Checking for Semantic Enrichment

When the IFC enrichment of the KRIPIS model is completed, the IFC is checked against a set of rules which validate the existence and the semantics of the 2nd-level space boundaries instances. The semantic checking is performed using BIM-MP's MVD checking service. To trigger the MVD checking of the 2nd-level space boundaries, the user should select the enhanced IFC on the first drop-down menu, choose the Space Boundaries option on the second menu and press the Execute button of the Completeness Checker page.

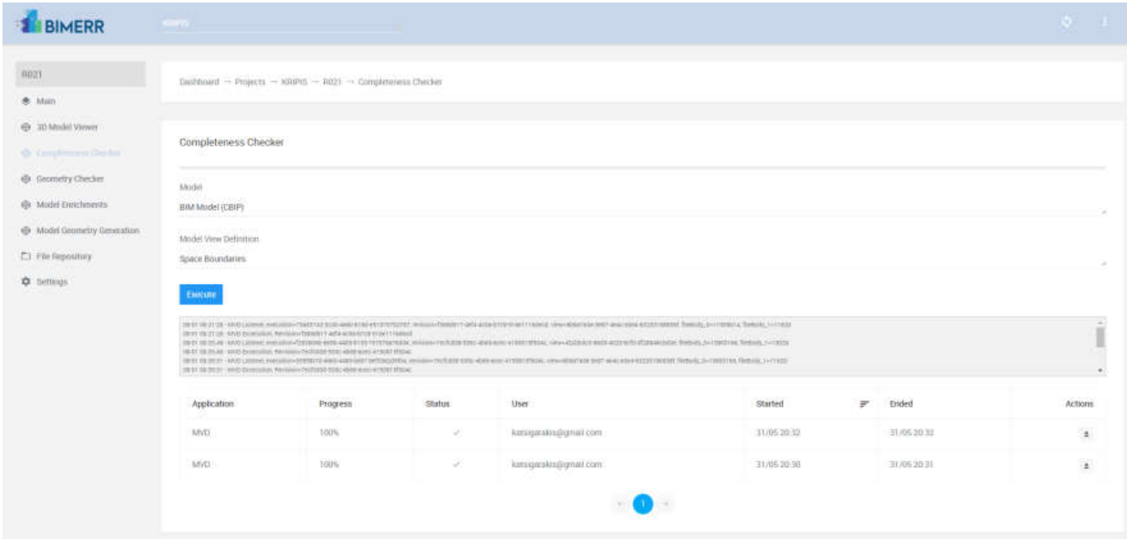
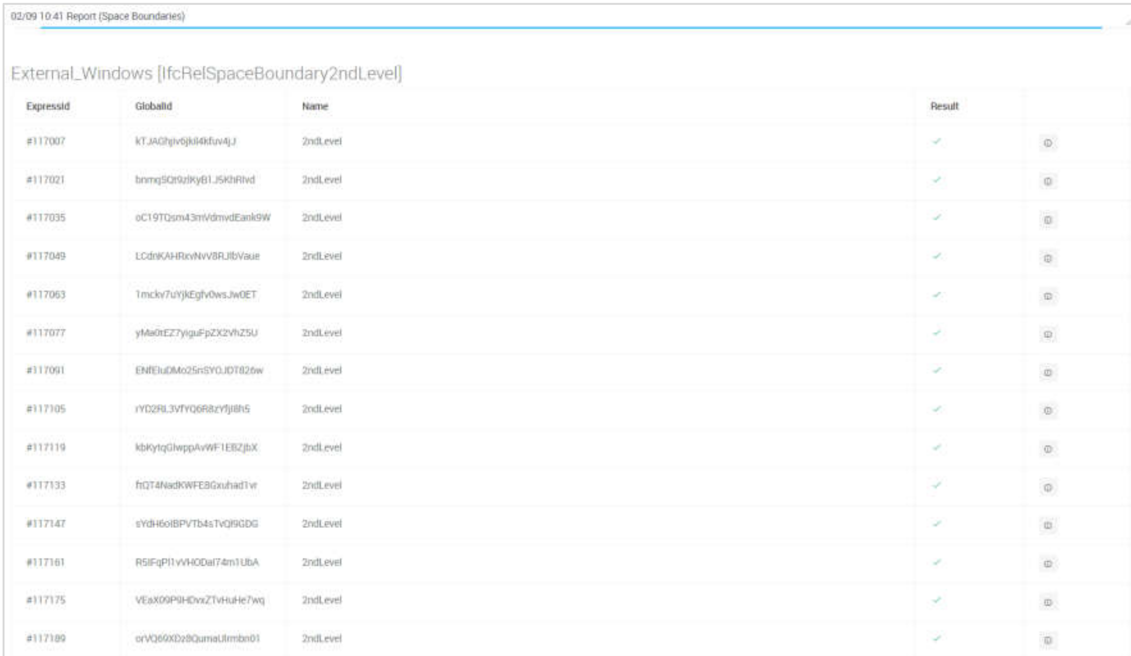


Figure 33. 2nd-level space boundaries checking of KRIPIS building.

When the MVD checking is completed, the error report of the KRIPIS building is available in three ways: a) Through BIM-MP's file repository page in JSON format as shown in Figure 34 and b) In textual format as shown in Figure 35.


```
[
    {
        "entities": [
            {
                "valid": true,
                "name": "2ndLevel",
                "global": "kTJAGhjiv6jkil4kfuv4jJ",
                "express": 117007,
                "rules": [
                    {
                        "valid": true,
                        "description": "Parent space boundary is required for external windows"
                    }
                ]
            },
            {
                "valid": true,
                "name": "2ndLevel",
                "global": "bnmqSQt9zlKyBlJ5KhRlvd",
                "express": 117021,
                "rules": [
                    {
                        "valid": true,
                        "description": "Parent space boundary is required for external windows"
                    }
                ]
            },
```


Figure 34. 2nd-level space boundaries JSON report of KRIPIS building.



02/09 10:41 Report (Space Boundaries)

External_Windows [IfcRelSpaceBoundary2ndLevel]

Expressid	Globalld	Name	Result	
#117007	kTJAGhjiv6jkll4kfuv4jJ	2ndLevel	✓	
#117021	bnmqSQt9zlKyB1J5KhRlvd	2ndLevel	✓	
#117035	oC19TQsm43mVdmvdEank9W	2ndLevel	✓	
#117049	LCdnKAHRxvNvV8RJlbVaue	2ndLevel	✓	
#117063	1mckv7uYjkEgfv0wsJw0ET	2ndLevel	✓	
#117077	yMa0tEZ7yiguFpZX2VhZ5U	2ndLevel	✓	
#117091	ENfEluDMo25nSYOJDT826w	2ndLevel	✓	
#117105	rYD2RL3VfYQ6R8zYfjI8h5	2ndLevel	✓	
#117119	kbKytqGlwppAvWF1EBZjbX	2ndLevel	✓	
#117133	ftQT4NadKWFEBGxuhad1vr	2ndLevel	✓	
#117147	sYdH6oIBPVTb4sTvQl9GDG	2ndLevel	✓	
#117161	R5IFqPl1vVHODal74m1UbA	2ndLevel	✓	
#117175	VEaX09P9HDvxZTvHuHe7wq	2ndLevel	✓	
#117189	orVQ69XDz8QumaUlmbn01	2ndLevel	✓	

Figure 35. 2nd-level space boundaries textual report of KRIPIS building.

More details for the BIM-MP implementation are available in D5.2: Prototype of Enhanced BIM Platform 2 [6].

3.4.6 Interacting with BIF

When the IFC file of the KRIPIS building is ready, it is forwarded to BIM-MP through BIF to perform quality checking and enriching operations. Within BIF, the creation of a data collection job is required to upload IFC files. On the other hand, the initialization of a query is required to download the previously uploaded IFC.

The IFC Upload data collection job contains the following steps: a) The configuration of the Harvester as shown in Figure 36, b) The configuration of the Mapping as shown in Figure 37 and c) The configuration of the Dataset as shown in Figure 38.

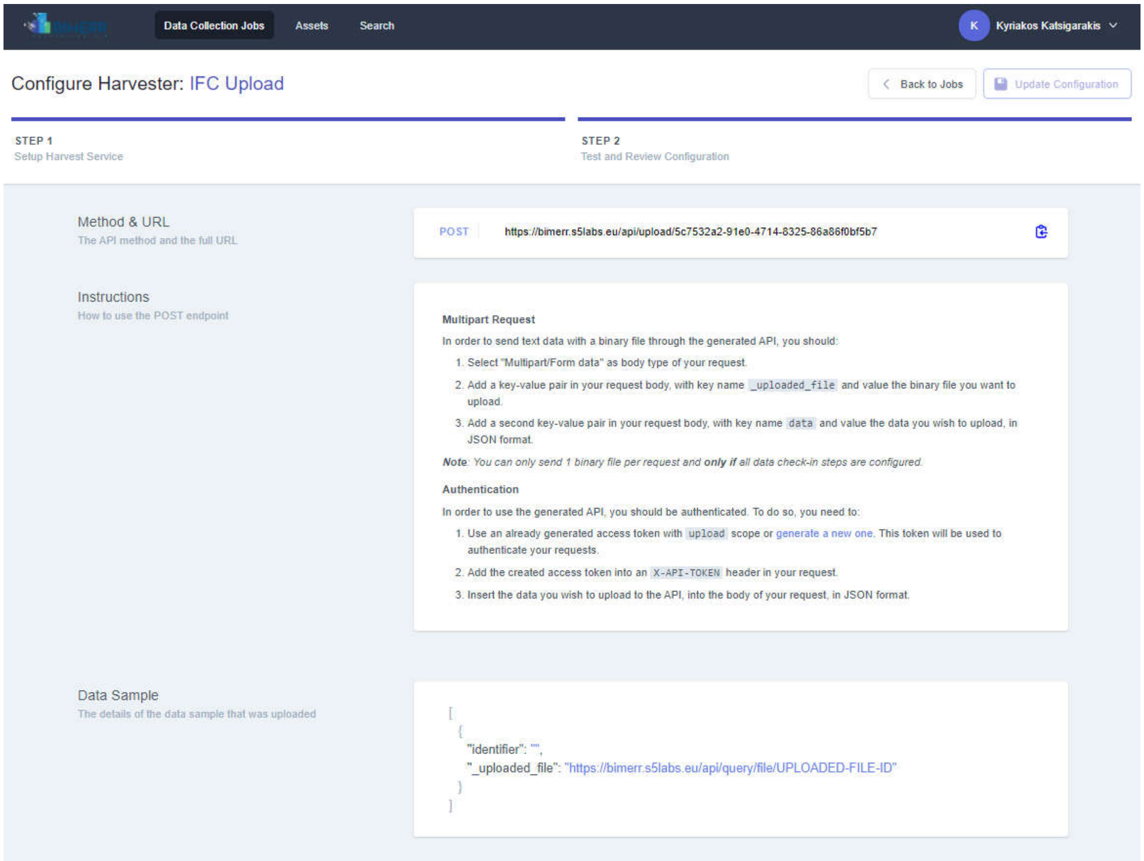


Figure 36. Harvester Configuration for the IFC Upload data collection job.

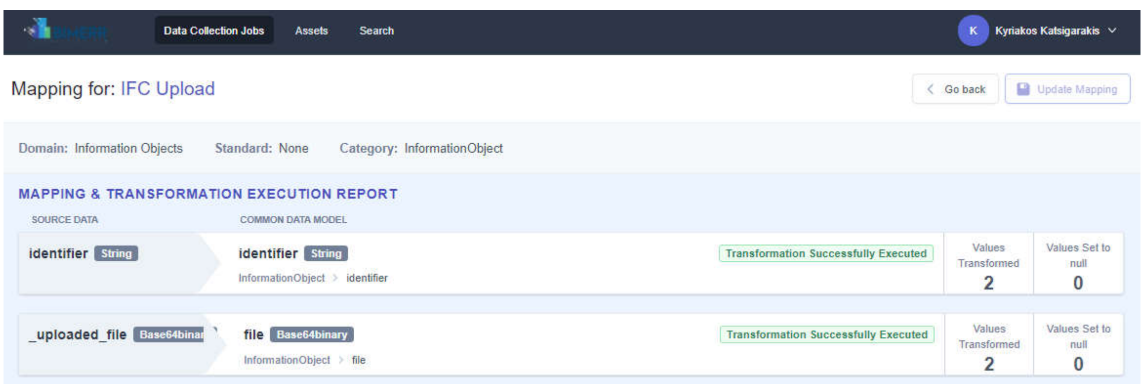


Figure 37. Mapping configuration for the IFC upload data collection job.

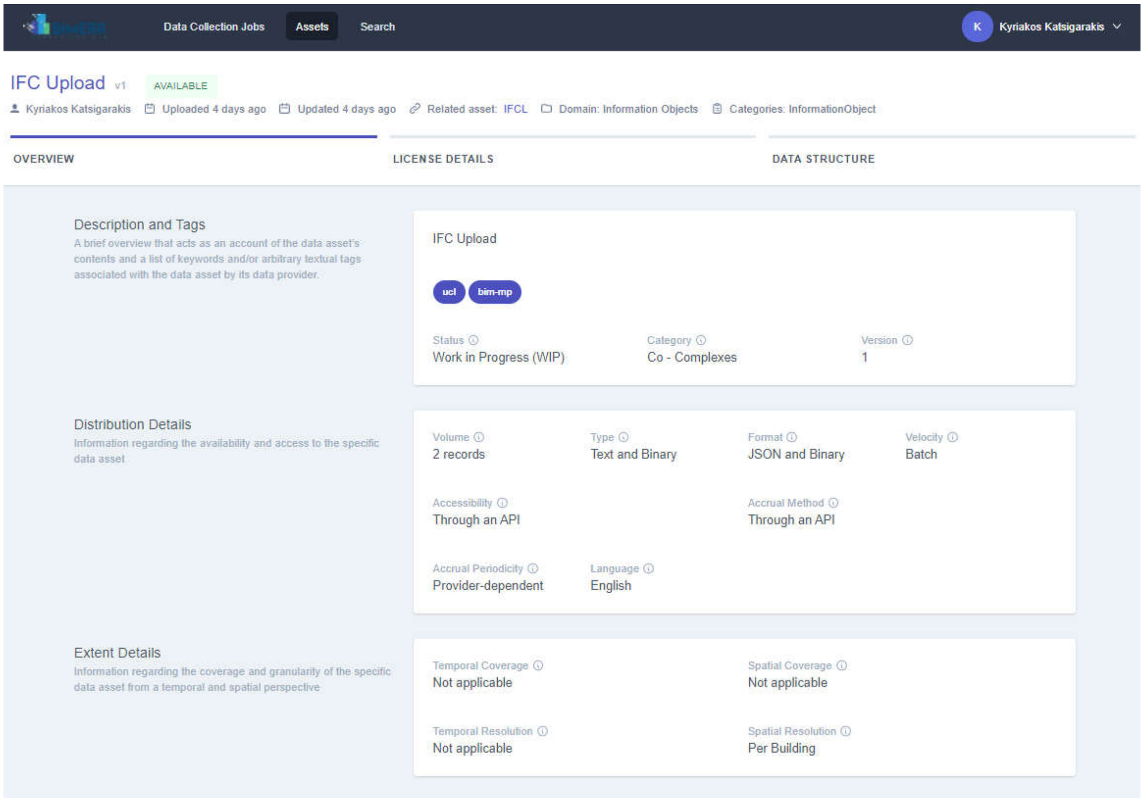


Figure 38. Dataset configuration for the IFC Upload data collection job.

The initialization of the query to retrieve the IFC of the KRIPIS building contains the following steps: a) The selection of applicable dataset, b) The selection of the result fields and the query parameters as shown in Figure 39, and c) The initialization of the POST and GET endpoints.

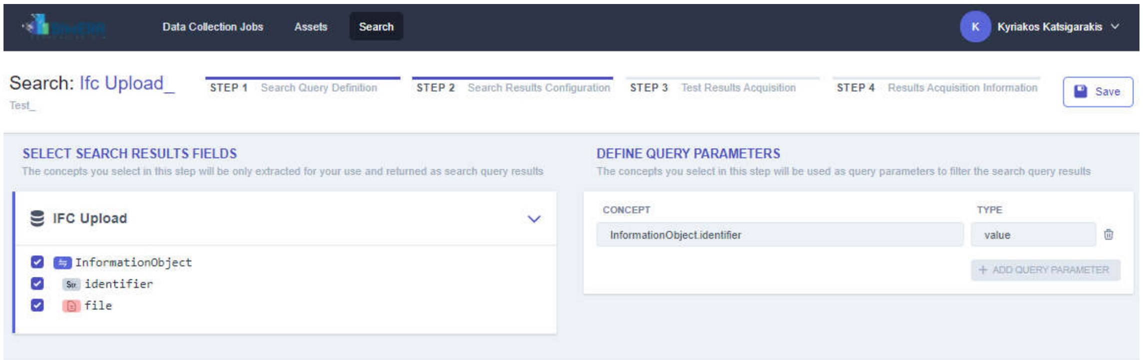


Figure 39. Query configuration for the IFC Upload dataset.

On the BIM-MP's KRIPIS project main page the user has the option to retrieve the IFC directly from the BIF by clicking the BIF Synchronizer button as shown in Figure 40.

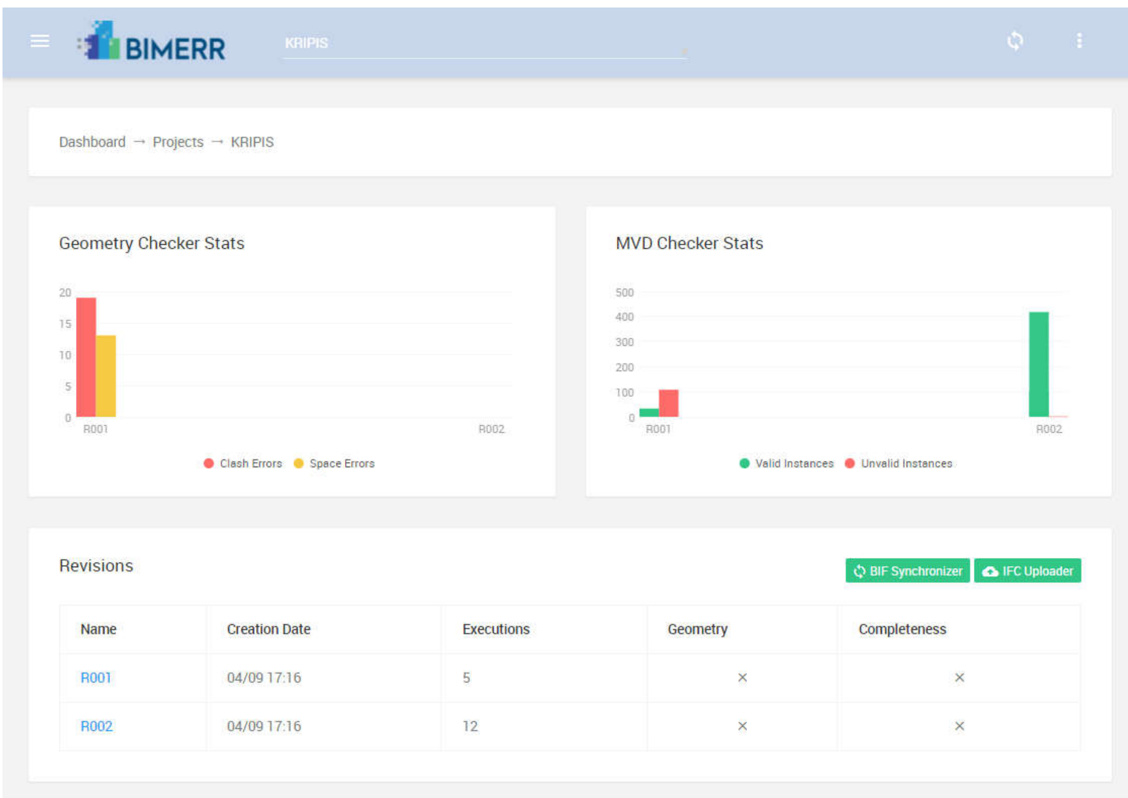


Figure 40. BIM-MP's KRIPIS project page.

After the KRIPIS IFC file has passed the data quality control checking stages and has been successfully enriched, can be forwarded to BIF, along with the derived data files. A new data collection job is required for uploading the enriched IFC with the corresponding Building Data Model JSON file. The mapping configuration of the new data collection job is shown in Figure 41.

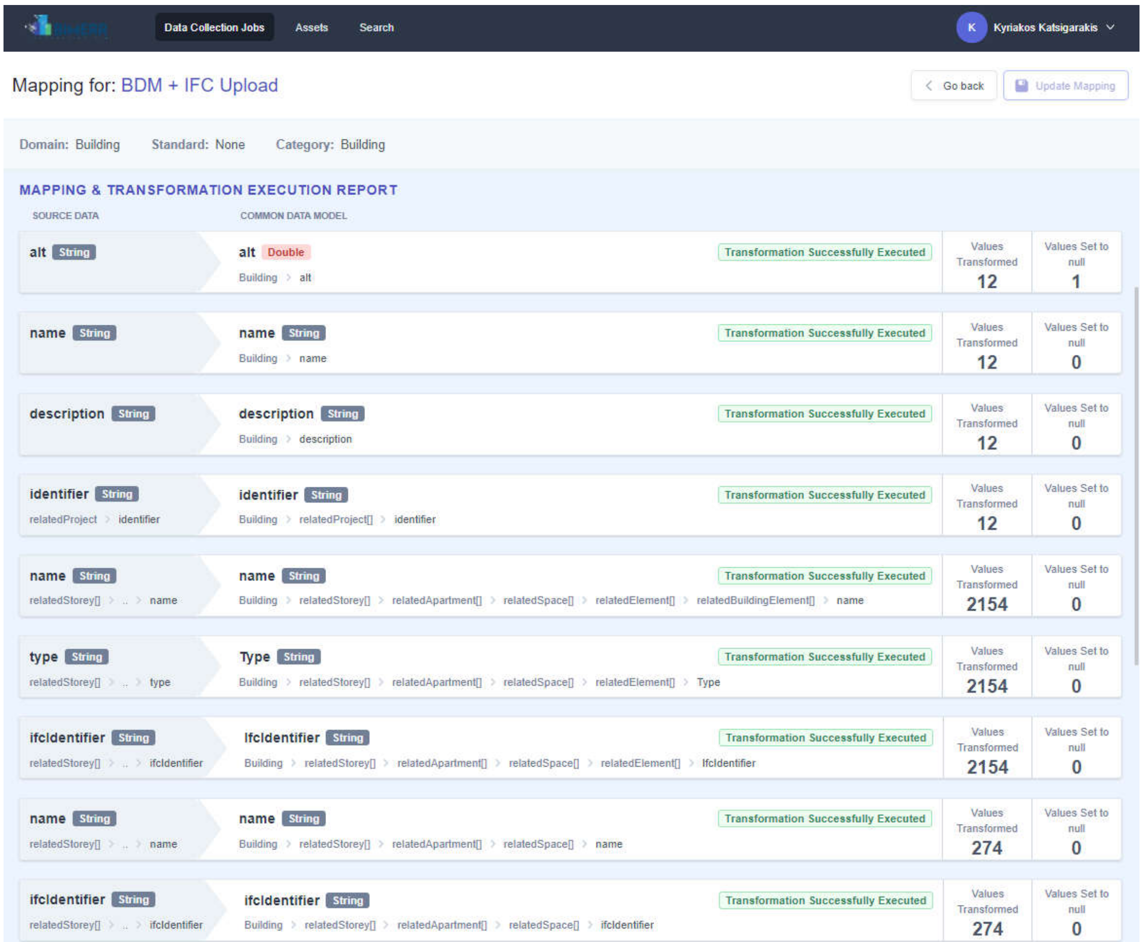


Figure 41. Mapping configuration of the BDM & IFC Upload collection job.

On the BIM-MP's KRIPIS project File Repository page the user has the option to upload the IFC and the corresponding JSON file to BIF by clicking the BIF Synchronizer button as shown in Figure 42.

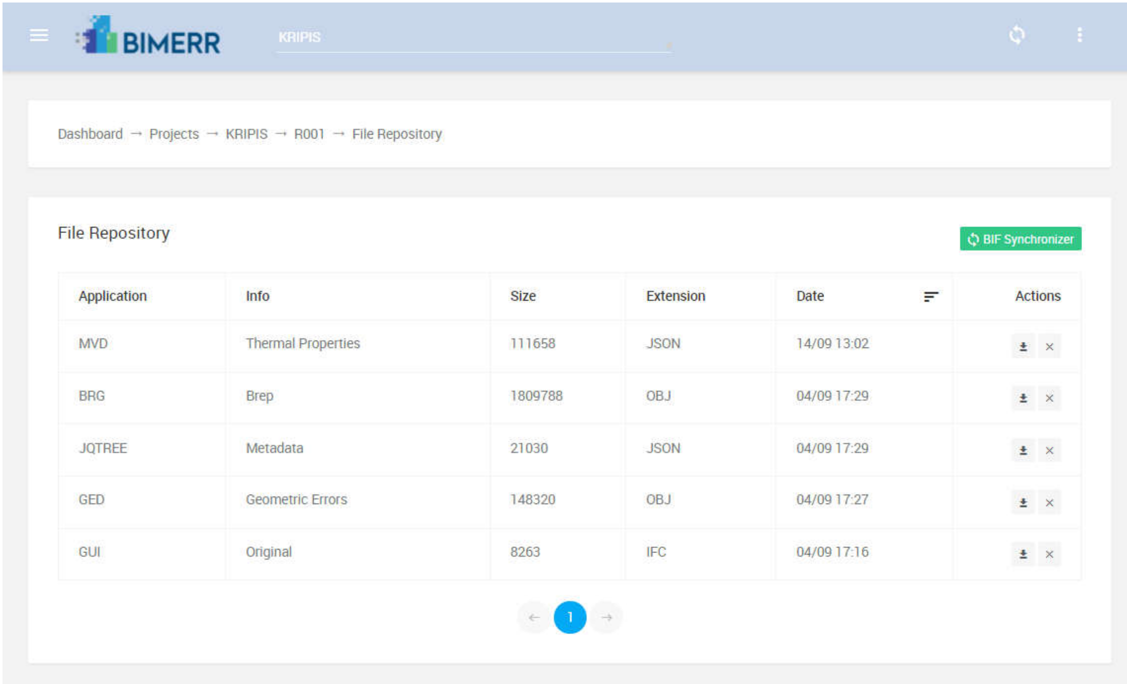


Figure 42. BIM-MP's KRIPIS project File Repository page.

3.5 On Site Visualization And Annotations

The functionalities of the application were thoroughly tested and evaluated on the KRIPIS SmartHome during the pre-validation phase. In this subsection, the evaluation of the various functionalities of the ARIBFA tool on the KRIPIS building will be discussed. More details for the implementation of the ARIBFA tool are available in D5.10: AI-enabled tools (hardware & software) for in-situ digital building model annotation via smart- glasses 2 [7].

3.5.1 Visualization and Registration

A key functionality of the ARIBFA tool is the real-time visualization of the 3D BIM model on the AR HMD, i.e., the Hololens.

Evaluation of the 3D BIM model visualization. The IFC file of the building (as described in Section 2.5), along with the corresponding OBJ file, were the input to the ARIBFA tool.

The goal of the BIM 3D Model Visualisation submodule of the ARIBFA tool is to successfully utilize Unity game engine as a BIM viewer. The functionality was validated since the 3D BIM model of the KRIPIS SmartHome was successfully viewed and edited using Unity, as can be seen in Figure 43.

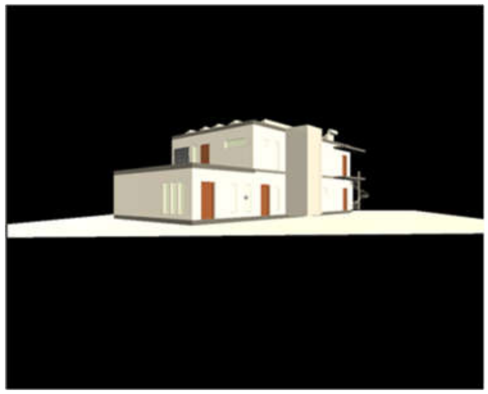


Figure 43. The 3D BIM model of KRIPIS SmartHome as visualized in the Unity game engine.

Evaluation of the 3D BIM model registration. The BIM 3D Model Registration and Tracking submodule of the ARIBFA tool implements the real-time visualization of the 3D BIM model on the AR HMD, i.e., the Hololens. To validate the registration, i.e., the alignment of the 3D BIM model to the actual building, the registration procedure was performed on site by wearing the AR HMD. Since the registration procedure of the ARIBFA tool relies on image targets, the optimal position for placing the image target on the KRIPIS building was the first decision to be made. After a visual inspection of the building, it was decided to place the image target in the living room on the top corner of a door frame. The exact position of the image target in the actual building and in the 3D BIM model in Unity are displayed in Figure 44.

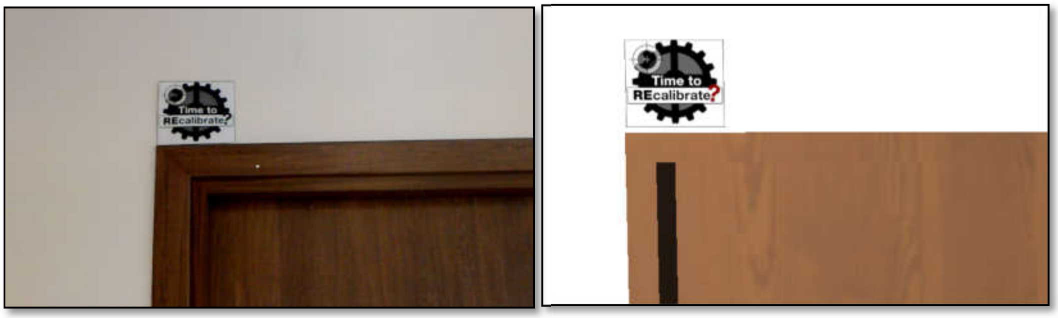


Figure 44. left) A print of the image target was placed in the living room of the KRIPIS SmartHome, right) the image target was placed in the same position in the 3D BIM model of the KRIPIS SmartHome in the Unity game engine.

The accuracy of the registration was evaluated based on the proximity that the 3D BIM model overlayed the actual building. The closest the match between the position of the image target in the actual building to the position of the image target in the 3D BIM model in Unity, the more accurate the alignment of the model to the real world. To maximize the registration accuracy, the position of the image target on the 3D BIM model in Unity was manually finetuned on a local machine (laptop) on the KRIPIS building. By finetuning the position of the image target in the 3D BIM model and subsequently, deploying the ARIBFA application on the Hololens and inspecting the registration, the optimal position (i.e., closest to the actual position) was selected for the image target in the 3D BIM model. The achieved registration accuracy is displayed in Figure 45.

Figure 45. The position of the image target was finetuned to optimize the registration accuracy. The depicted registration accuracy was considered successful.

Evaluation of the localization functionality. An important feature of the ARIBFA tool is to accurately determine the user's position and orientation within the building. The efficiency of this feature was evaluated on the KRIPIS building, where a user wore the AR HMD and opened the ARIBFA application. As a prerequisite, the registration process should already have been performed. To start receiving localization information, the user used the speech command "Show Location". The command was validated since the application started displaying information regarding the user's position, i.e., the IfcSpace they are currently located in, as can be seen in Figure 46. By walking around the KRIPIS building, the IfcSpaces that were depicted via the ARIBFA tool corresponded to the actual spaces that the user was located.

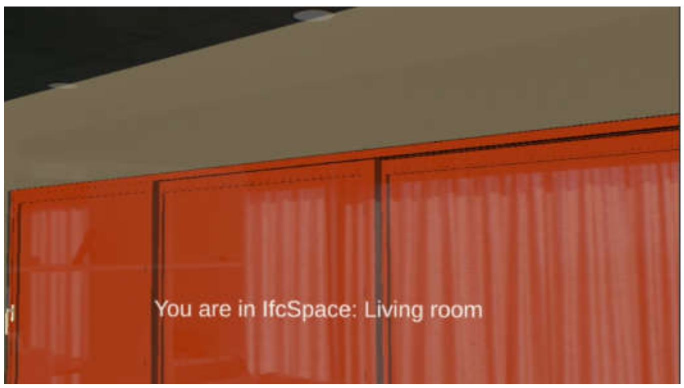


Figure 46. The localization functionality of the ARIBFA tool was evaluated on the KRIPIS SmartHome.

3.5.2 Add Annotations

A key functionality of the ARIBFA tool is to allow users to look at and select building components of interest. To this end, the ARIBFA tool provides an interactive menu that displays the IFC properties of the selected building component. The ARIBFA tool also provides the ability to the user to add annotations on components of interest. These functionalities were thoroughly tested on the KRIPIS SmartHome.

Evaluation of the IFC properties visualization menus. To validate this functionality, the KRIPIS SmartHome was visited and the ARIBFA application was started on the AR HMD (i.e., the Hololens). After successful registration of the 3D BIM model, the air tap gesture (i.e., selection gesture on Hololens) was performed on several 3D building components. The expected behavior of the air tap gesture on a 3D building component for the application is to open a menu in front of the user that displays information regarding the IFC properties of the selected building component. The functionality was validated since the depicted IFC properties were the actual IFC properties of the building component that were successfully parsed and displayed by the application. An example of this menu is depicted in Figure 47.

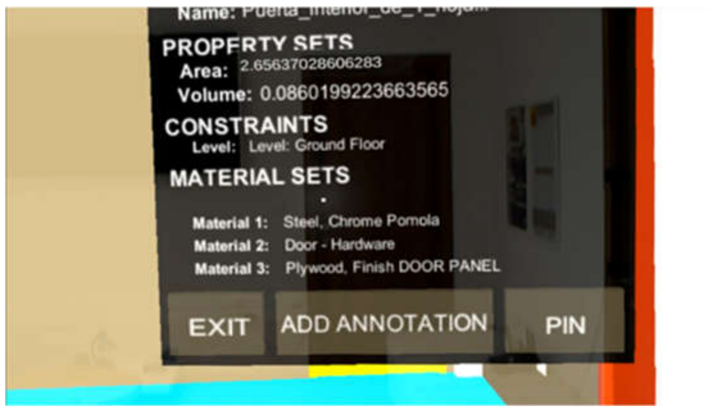


Figure 47. IFC properties visualization menu which was visualized after performing the air tap gesture on a static building component (door) in the KRIPIS building.

To exit the IFC properties visualization menus, the user should tap on the "Exit" button (depicted in Figure 47). The functionality of the "Exit" button was validated on the KRIPIS building since the menus were successfully closed by air tapping on the "Exit" button. Moreover, the speech command "Exit Menu" that provides an alternative way to close the displayed menu was successfully tested. The "Pin" button, which is used to pin the displayed menu in its current location in the 3D space, was also successfully tested, since after performing the air tap gesture on the "Pin" button, the menu was pinned on its current location. If not pinned, the displayed menu follows the user's movement so that is always properly displayed in front of the user.

Evaluation of the add annotation functionality. This functionality was tested on the KRIPIS building by selecting the "Add annotation" button (depicted in Figure 47 of the IFC properties visualization menus. By performing the air tap gesture on this button, the menu in Figure 48 appeared, as expected. The speech command “Add annotation” was also tested and successfully opened the menu in Figure 48. All input fields (such as the “Title” input field where the user enters text using the Hololens’ keyboard) and all drop-down lists (such as the drop-down list for the “Type” of the annotation) were tested.

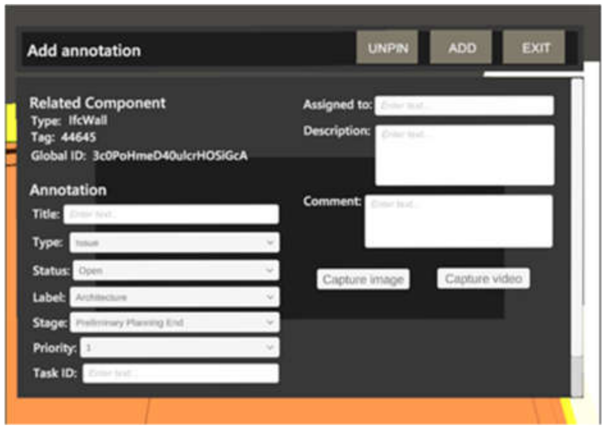


Figure 48. The input fields and the drop-down lists of the Add Annotation Menu were tested on the KRIPIS building.

To finalize the adding of the annotation to the building component, the user selected the “Add” button (displayed on the top right corner of the menu, as can be seen in Figure 48). This functionality was validated in the KRIPIS SmartHome since the annotation mark was successfully placed near the annotated building component, as can be seen in Figure 49. Along with the placement of the annotation in the 3D space, the input of the user to the annotation fields was successfully exported via the application in a .JSON file that holds all the annotation properties. A sample of the annotation .JSON file is depicted in Figure 50. The correct completion of this .JSON file was tested for sample annotations added in the KRIPIS building. Finally, the air tap gesture was performed on the annotation mark and successfully opened the View Annotation menu, which displayed the user add annotation properties, as expected.

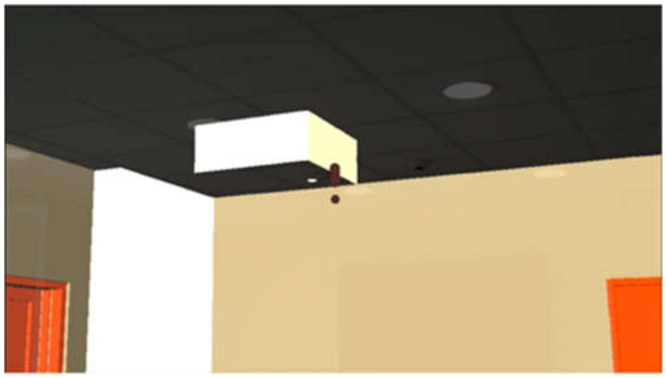


Figure 49. The placement of an annotation mark near the annotated building component was validated in the KRIPIS building.


```json
{
    "identifier": "3_GOL1J6n3NO89Dz8W9VFa",
    "hasTopic": {
        "identifier": "f1252d35-d860-4572-b995-2979600b79fa",
        "topicType": "Comment",
        "topicStatus": "Open",
        "title": "",
        "label": "Architecture",
        "creationDate": "19-52-2021",
        "creationAuthor": "aribfa_user",
        "assignedTo": "worker3",
        "description": "",
        "stage": "Preliminary Planning End",
        "taskId": "",
        "priority": "1",
        "relatedImageFile": {
            "location": ""
        },
        "relatedVideoFile": {
            "location": ""
        },
        "relatedAudioFile": {
            "location": ""
        },
        "relatedComponent": {
            "ifcIdentifier": "1jjiFjndDDzf_MiC181K1k"
        },
        "relatedSpace": {
            "ifcIdentifier": ""
        },
        "relatedIFCFile": {
            "location": ""
        },
        "hasComment": {
            "identifier": "",
            "creationDate": "",
            "creationAuthor": "",
            "comment": ""
        }
    }
}
```


Figure 50. The file in JSON format that holds the inserted annotation properties was successfully created.

3.5.3 Task Visualization

The task visualization functionality of the ARIBFA tool was validated on the KRIPIS SmartHome during the pre-validation phase. A dummy workorder was received from the

PWMA toolkit and the application was tested on this workorder. After wearing the Hololens and initiating the ARIBFA application, the indicator button was visualized when the user entered the living room of the KRIPIS building. Since the dummy workorder included assigned tasks for the Living Room IfcSpace of the IFC file of the KRIPIS building, the task notification functionality was validated. By performing the air tap gesture on the indicator button, the menu in Figure 51 displays information regarding the workorder. Finally, the air tap gesture was applied to building components with assigned tasks to verify if the task details were properly displayed.

Figure 51. The dummy workorder was successfully visualized in the ARIBFA tool after selecting the tasks indicator button in the KRIPIS building.

3.5.4 IFC Editing

The IFC editing capability provided in three ways in the ARIBFA tool. Firstly, the application provides the capability to the user to edit the IFC properties of the selected building component by using the interactive AR menus that display the IFC properties of the building component. Secondly, after receiving the IFC error report described in Section 2.5, the ARIBFA tool notifies the user for the building components with missing IFC properties and provides menus so that the user can add the missing IFC properties to the IFC file. Thirdly, the IFC file is edited in the ARIBFA tool after the detection of missing MEP components and their addition to the IFC file.

3.5.4.1 EDITING PROPERTIES

Evaluation of the IFC editing using IFC properties visualization menus. To test the IFC editing functionality on the KRIPIS building, the user started the application in the KRIPIS building, selected a 3D building component (using the air tap gesture) and tapped on the value of an IFC property to change it. As can be seen in Figure 52 the user could successfully edit the IFC property and insert a new value by either using dictation or the keyboard. The dictation functionality was tested for inserting numbers and sentences. It should be noted that the speech recognition capability was also tested on noisy conditions (with other people having conversations) and the recognition of speech from the user wearing the Hololens was still satisfactory and sufficient.

Figure 52. The editing of an IFC property using the appropriate menu was tested in the KRIPIS building.

Evaluation of the IFC editing based on the IFC error report. The notification of the user for the missing IFC properties was tested by using as input a sample error report provided by BIM-MP. Since the building components with missing IFC properties were visualized in red color, which is the intended behavior from the application, the functionality was validated. In Figure 53 an HVAC component in the KRIPIS Smart Home with missing IFC properties was displayed in red to notify the user. By clicking on it, the depicted menu appeared that guided the user to add the missing IFC properties to the IFC file.

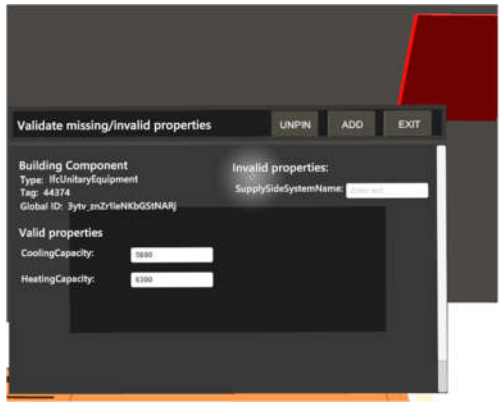


Figure 53. In the KRIPIS building, the building components with missing IFC properties were visualized in red to notify the user, who was prompted to add the missing IFC properties to the IFC file.

3.5.4.2 Adding Missing MEP Components

The detection of missing MEP components was tested on the KRIPIS SmartHome. This functionality relies on the communication of the Hololens device with a local machine (laptop) to perform MEP component detection. The DesktopARIBFA application, which is a desktop application developed to accompany the ARIBFA application and facilitate the communication between the Hololens and a local computer, was installed on the laptop.

The laptop and the Hololens were connected to the same WiFi network. The IPs of both the Hololens and the laptop were obtained since they were needed to complete the procedure. Firstly, the ARIBFA application was opened, and the anchored 3D BIM model was loaded. The IP of the laptop to be connected to the Hololens was inserted in the corresponding field in the menu depicted in Figure 54 (left). Subsequently, the user initiated the object detection using the speech command "Detect". Then, the DesktopARIBFA application was opened on the laptop and the Hololens' IP was inserted in the corresponding field depicted in Figure 54 (right). This enables the laptop to receive the Hololens camera stream and perform object detection on each frame.

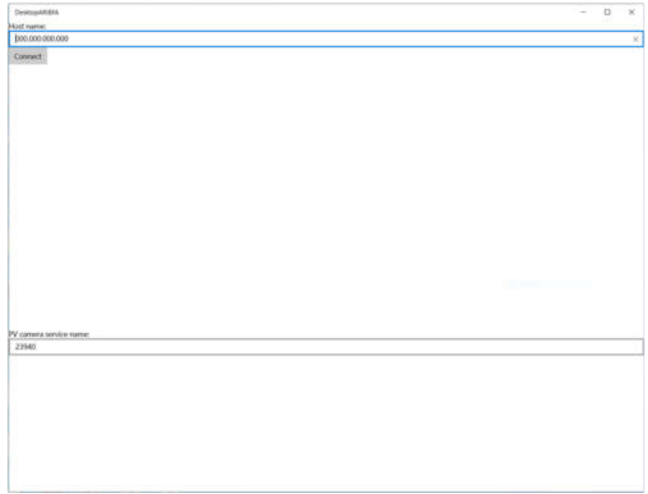


Figure 54. left) The IP of the laptop to be paired with Hololens was inserted in the corresponding field of the menu, right) The IP of the Hololens was inserted in the corresponding field of the DesktopARIBFA application running on the laptop to be paired with Hololens.

Evaluation of the trained MEP component detection algorithm. Initially, the detection was tested for only two classes (switches and outlets) to receive feedback regarding the finetuning of the detection algorithm. To perform a first quick check of this functionality, a more basic approach was followed for the detection and the detected objects were visualized with 2D bounding boxes surrounded by the class label and the class probability, as depicted in Figure 55. The white color of the plugs and switches on the KRIPIS SmartHome in combination with the white color of the walls proved to be a challenge for the object detection algorithm. It was concluded that firstly, more training images were needed to enhance the finetuning of the algorithm to perform sufficiently for those two classes and secondly, the user should approach very close (less than a meter) to the plugs and switches to be detected. The required distance may be smaller in buildings where there is greater contrast between the color of the plugs/switches and the color of the walls. In addition, to avoid visualizing false positives, the detection threshold was finetuned based on the object detection performance on the KRIPIS building. A very small threshold would lead to the visualization of many false positive detections, while a very large threshold would lead to many objects being undetected.

Figure 55. First check of the object detection was performed for two classes (switches and outlets) and was displayed with 2D bounding boxes.

The feedback that was received from this first quick evaluation of the functionality on the KRIPIS building led to more informed decisions regarding the size of the training dataset that was required to achieve satisfactory results in object detection for the remaining classes. After training the object detection algorithm on the remaining classes (various types of indoor and outdoor HVAC components), the detection accuracy was tested again on the KRIPIS building. Since there is only one outdoor HVAC unit in the KRIPIS building and the indoor HVAC units are of specific types (ceiling cassettes and a ceiling suspended unit), not all classes could be tested on the KRIPIS building. To this end, this functionality of the ARIBFA tool was also tested on other buildings such as the office premises of CERTH. Finally, the final object detection pipeline in the ARIBFA tool where the detected MEP component is visualized using 3D bounding boxes with handlers that can be adjusted by the user was also tested on the KRIPIS SmartHome.

Dealing with latency. During the first tests of the functionality on the KRIPIS building, a latency was observed when displaying the bounding boxes on the Hololens. This is attributed to the fact that the detection is performed on the laptop on a frame-by-frame level and the detection coordinates of each frame are converted to Hololens screen coordinates to be visualized to the exact same position by the person wearing the device. It was observed that if the person wearing the Hololens moved quickly in the meantime, the bounding box was displayed in the wrong position. To address this, we reduced the time (in 10^{-2} seconds) that the laptop sends new bounding boxes to the Hololens to be displayed. If this time was reduced too much, the displayed bounding boxes would be refreshed rapidly and fatigue the user. An efficient compromise was reached by testing different values for this time. Of course, in either case the person wearing the Hololens is expected to make smooth and slight movements while performing the object detection functionality of the ARIBFA tool.

Evaluation of the addition of the detected MEP components to the IFC. After the detection of a MEP component in the ARIBFA tool, the component can be added to the IFC file using appropriate menus, as the one depicted in Figure 56. This procedure was validated for the IFC of the KRIPIS building since the modified IFC file (that was created by the ARIBFA application on the Hololens) included the detected objects and their IFC properties.

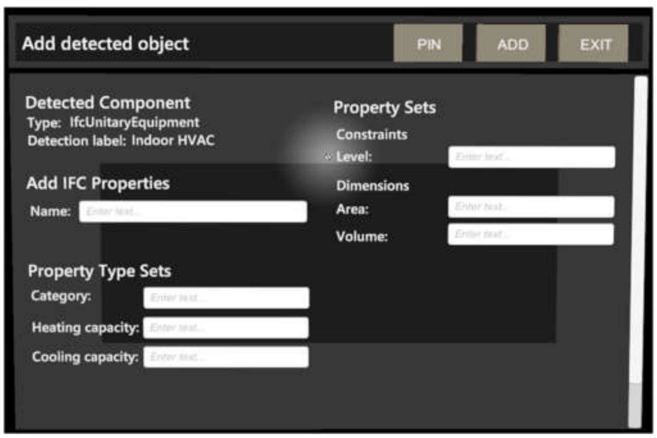


Figure 56. The functionality of the menu to add IFC properties to the detected object was also tested on the KRIPIS SmartHome.

3.5.5 Interacting with BIF

The connectivity to the BIF was also tested on the KRIPIS SmartHome during the pre-validation activities. To establish a connection to the BIF, the appropriate data collection jobs are setup and their endpoints become available for requests from external tools through the info provided from the BIF's interface.

Mapping the annotation to the annotation data model in BIF. When the user of the ARIBFA tool adds an annotation to a building component (using the menu depicted in Figure 57 the annotation properties are stored in a .JSON file, which is depicted in Figure

50. This .JSON file is uploaded to the BIF using the BIF's API. The fields of the .JSON file are mapped to the annotation data model, as implemented in BIF. The mapping of the annotation properties included to the .JSON file to the properties of the annotation data model was successful as can be seen in Figure 57, since the mapping was validated in the BIF. The mapping of a very important annotation property, i.e., the ifcIdentifier of the annotated building component, is depicted in Figure 58.

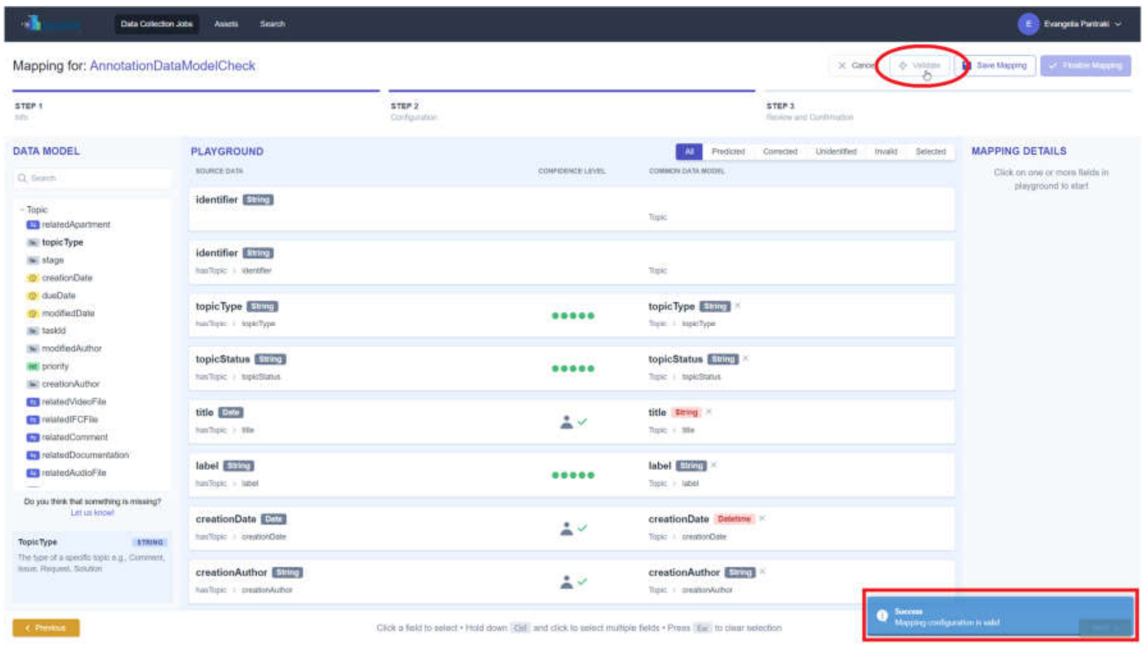


Figure 57. The mapping of the properties of the annotation file (in JSON format) to the annotation data model in BIF was validated.

Figure 58. Mapping of the ifcIdentifier property of the annotated building component to the annotation data model in BIF.

Tests to upload data to the BIF. Once the appropriate data collections were setup, tests have been executed through Postman's interface to upload relevant data to the previously set up data collections. Authentication credentials were used in the request's header as the data collection setup page instructs. The "X-API-TOKEN" can be found in the user's profile page.

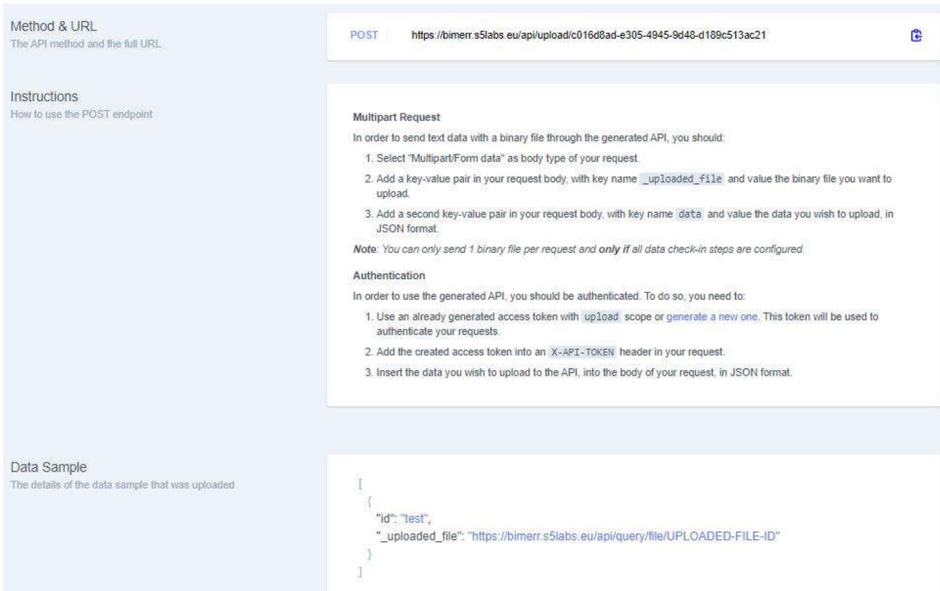


Figure 59. Data Collection for IFC files example setup.

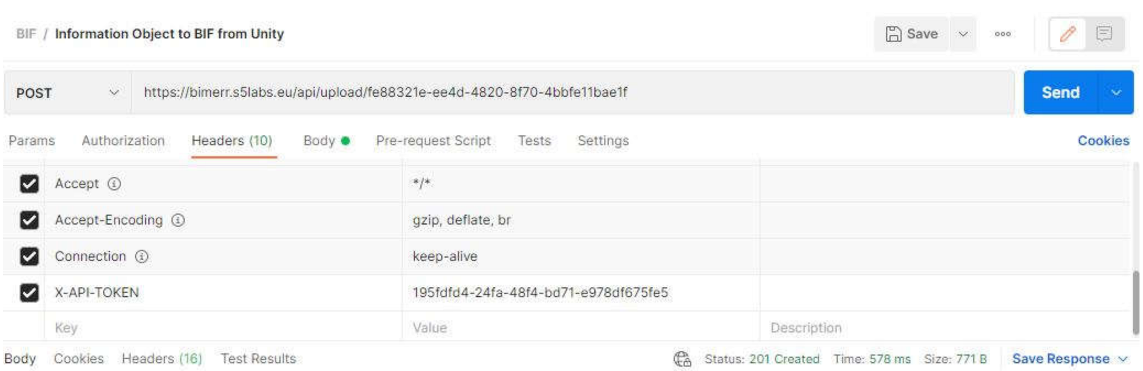


Figure 60. Postman Request Header Authentication.

Furthermore, the key-value pairs that comprise the Multipart/form data fields are created and filled appropriately in accordance with the data collection's instruction page. The aforementioned data create the body of the request that will be sent to the BIF's internals.

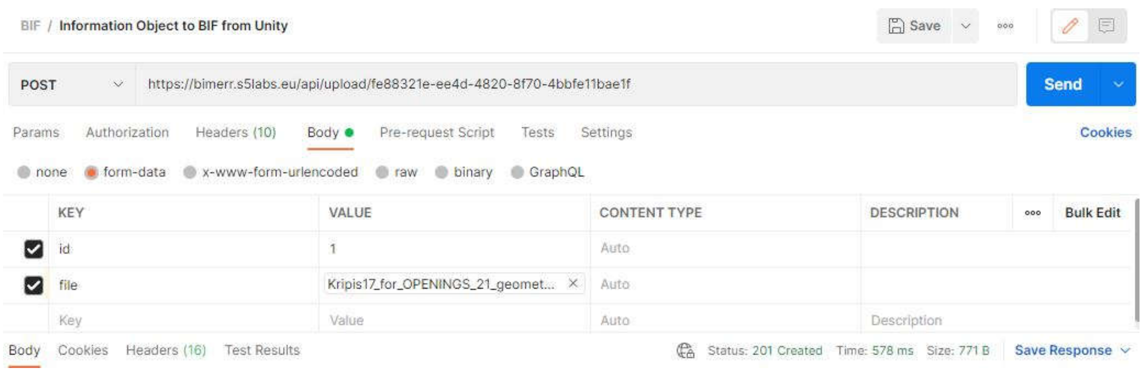


Figure 61. Example of an IFC file post request to BIF.

Tests to retrieve data from the BIF. Next the data collection's sample list can be retrieved by performing a GET request using the endpoint provided from the Search Query creator on the BIF. A test query run can be performed through the BIF's web interface, as displayed in Figure 62. The same procedure can be executed through external tools like Postman, using the previously token from the user's profile in the header, as displayed in Figure 63.

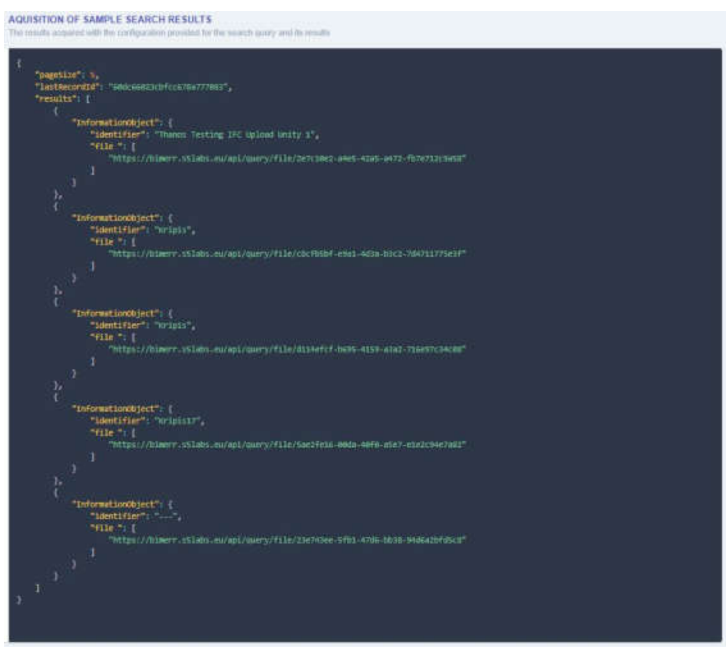


Figure 62. BIF's integrated test query runner.

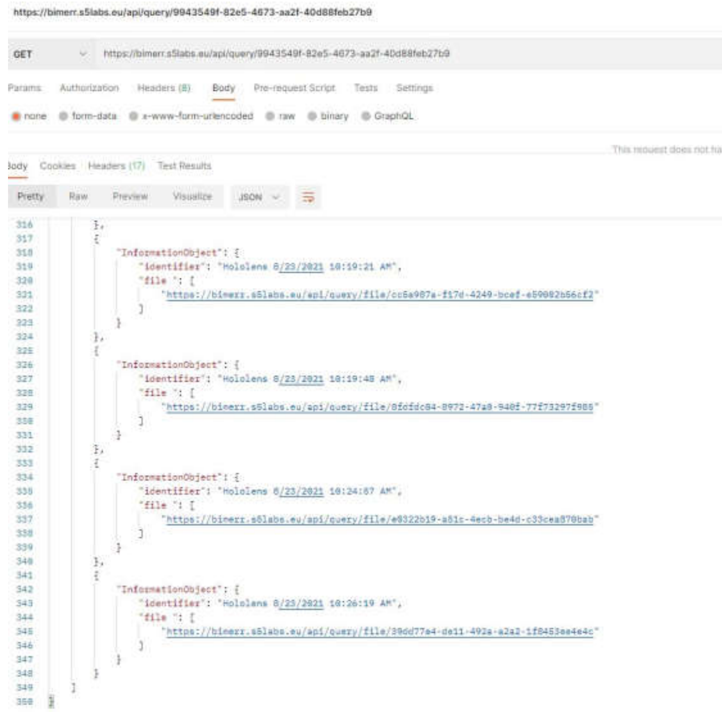


Figure 63. Postman BIF data collection samples retrieval.

Finally, by performing a GET request on the url provided by the **file:** field in each retrieved data collection entry, the actual binary file uploaded can be retrieved.

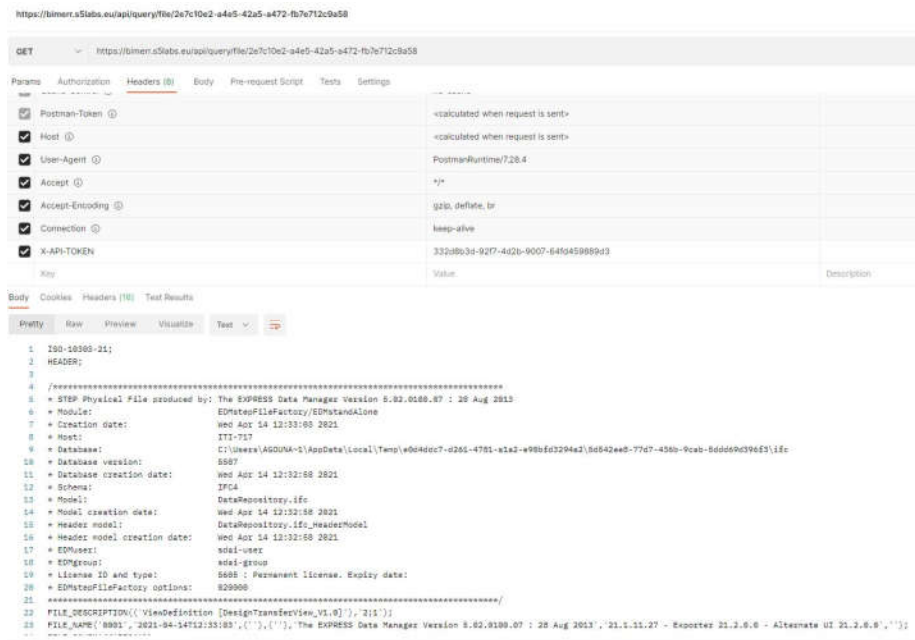


Figure 64. Binary file retrieval from Data Collection sample url.

The main functionality of the ARIBFA tool is to facilitate the surveying process by providing AR-powered capabilities, such as detection and annotation of building components, as well as issue reporting on objects of interest (MEP plans, building zones) during the planning and renovation stages of construction. The functionalities of the application were thoroughly tested and evaluated on the KRIPIS SmartHome during the pre-validation phase. In this section, the evaluation of the various functionalities of the ARIBFA tool on the KRIPIS building will be discussed.

3.6 Renovation Scenarios And KPIs Calculation

The IFC file of the KRIPIS building (as described in Section 3.4) was used as input for RenoDSS to (i) extract building material and component information, (ii) enrich this information with missing material information from the BIMERR Material and Component Database, (iii) calculate the baseline KPIs of the building, (iv) generate potential renovation scenarios, (v) calculate renovation scenario KPIs, and (vi) provide the user with tools to compare renovation scenarios by its KPIs.

Figure 65 shows the RenoDSS base data view of the KRIPIS building. Material and component properties which are relevant for the energy performance and LCA/LCC analysis were extracted from the IFC file. Missing property values are added by the user manually or by mapping existing materials from the BIMERR Material and Component Database.

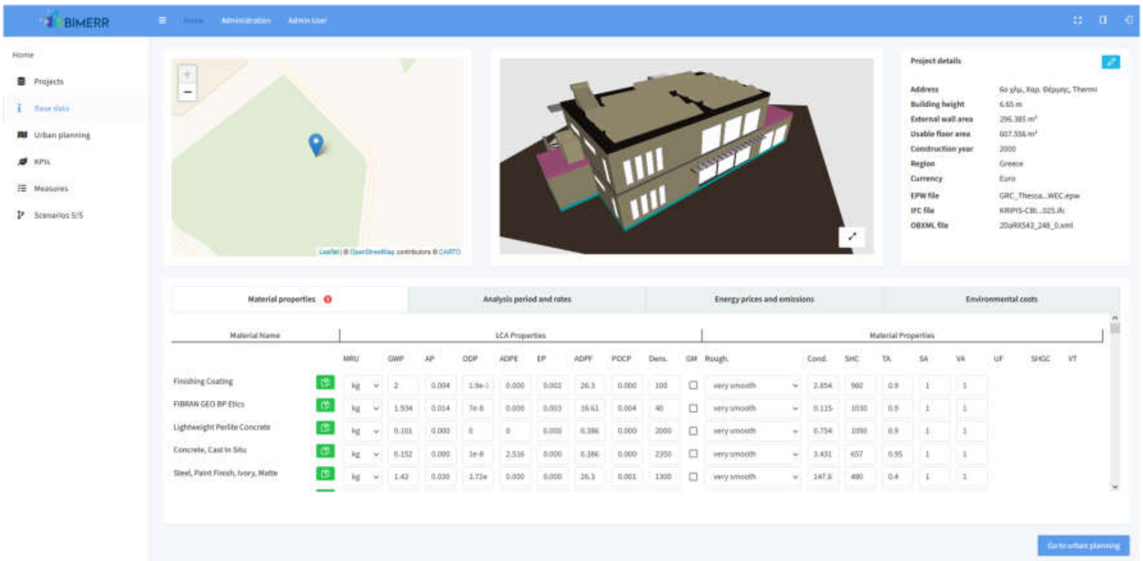


Figure 65. KRIPIS base data view.

Once the necessary information regarding geometrical features of the KRIPIS building, materials, heating/cooling system and other relevant energy loads is gathered, the RenoDSS BEP module was employed to calculate the energy-related KPIs. Initially, the IDF Generator module was invoked to generate the BEP simulation Input Data File (IDF), i.e. the main input of EnergyPlus. For the sake of completeness, in Figure 66 a SketchUp representation of the KRIPIS building is depicted, as this results from the given IFC file, executing the automated IFC-to-IDF mapping process of the IDF Generator. Figure 67 illustrates a segment of the IDF file, demonstrating the capability of the IDF Generator on populating information regarding the variable refrigerant flow (VRF) system for the ground floor of the KRIPIS building.

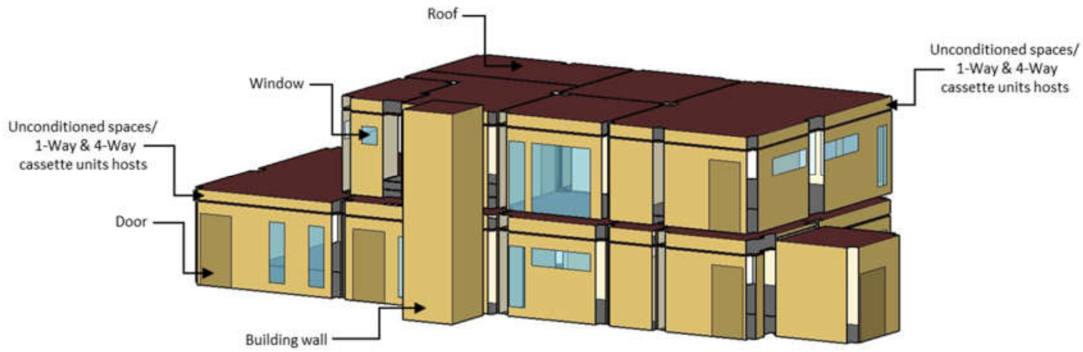


Figure 66. SketchUp representation of the KRIPIS building with indications of the various building components. View as seen from the Northwest.

```
HVACTEMPLATE:SYSTEM:VRF,
    OUTDOOR_GROUND_FLOOR,       !- Name
    ,                           !- System Availability Schedule Name
    autosize,                   !- Gross Rated Total Cooling Capacity
    5.2,                        !- Gross Rated Cooling COP
    -10,                        !- Minimum Outdoor Temperature in Cooling Mode
    43,                         !- Maximum Outdoor Temperature in Cooling Mode
    autosize,                   !- Gross Rated Heating Capacity
    1,                          !- Rated Heating Capacity Sizing Ratio
    5.74,                       !- Gross Rated Heating COP
    -25,                        !- Minimum Outdoor Temperature in Heating Mode
    18,                         !- Maximum Outdoor Temperature in Heating Mode
    0.15,                       !- Minimum Heat Pump PartLoad Ratio
    ,                           !- Zone Name for Master Thermostat Location
    LoadPriority,               !- Master Thermostat Priority Control Type
    ,                           !- Thermostat Priority Schedule Name
    No,                         !- Heat Pump Waste Heat Recovery
    30,                         !- Equivalent Piping Length used for Piping Correction Factor in Cooling Mode
    10,                         !- Vertical Height used for Piping Correction Factor
    30,                         !- Equivalent Piping Length used for Piping Correction Factor in Heating Mode
    33,                         !- Crankcase Heater Power per Compressor
    2,                          !- Number of Compressors
    0.5,                        !- Ratio of Compressor Size to Total Compressor Capacity
    5,                          !- Maximum Outdoor Drybulb Temperature for Crankcase Heater
    Resistive,                  !- Defrost Strategy
    Timed,                      !- Defrost Control
    0.058333,                   !- Defrost Time Period Fraction
    autosize,                   !- Resistive Defrost Heater Capacity
    5,                          !- Maximum Outdoor Drybulb Temperature for Defrost Operation
    AirCooled,                  !- Condenser Type
    autosize,                   !- Water Condenser Volume Flow Rate
    0.9,                        !- Evaporative Condenser Effectiveness
    autosize,                   !- Evaporative Condenser Air Flow Rate
    0,                          !- Evaporative Condenser Pump Rated Power Consumption
    0,                          !- Basin Heater Capacity
    2,                          !- Basin Heater Setpoint Temperature
    ,                           !- Basin Heater Operating Schedule Name
    Electricity,                !- Fuel Type
    -15,                        !- Minimum Outdoor Temperature in Heat Recovery Mode
    45;                         !- Maximum Outdoor Temperature in Heat Recovery Mode
```

Figure 67. KRIPIS building IDF – Mapping of the variable refrigerant flow (VRF) system information for the ground floor, as derived from the IFC data.

Figure 68 shows the energy performance and LCA/LCC KPIs of the current KRIPIS building configuration. The KPIs are calculated by the RenoDSS BEP and LCA/LCC module based on the IFC file and the provided material and component properties.

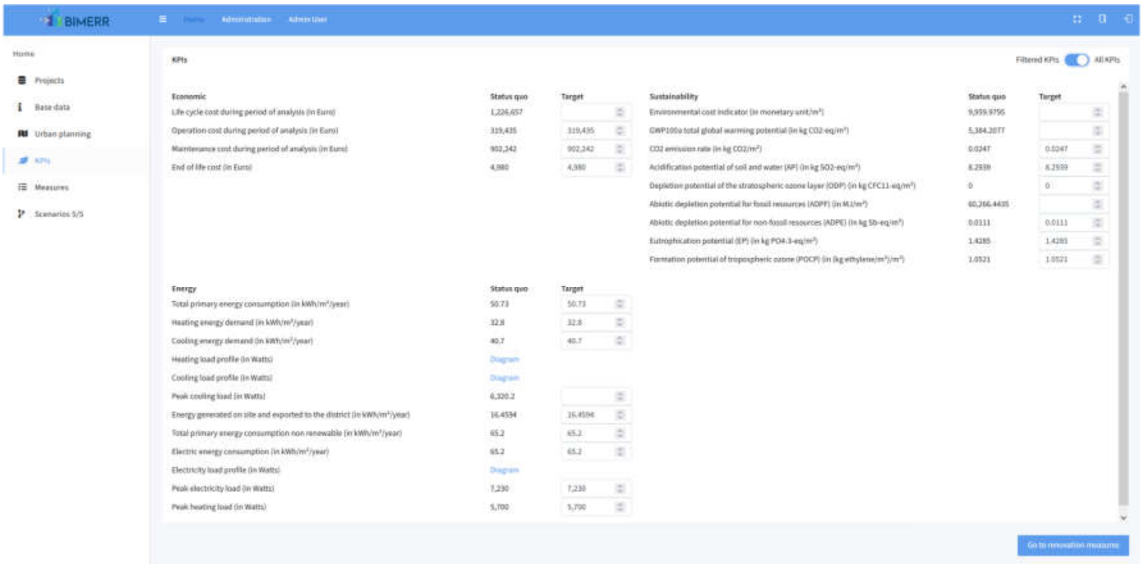


Figure 68. KRIPIS KPI view.

Figure 69 shows the renovation measures view, in which potential renovation measures were configured for the KRIPIS building. For pre-validation purposes we selected renovation measures from each renovation measure category (wall, roof, solar system, etc.).

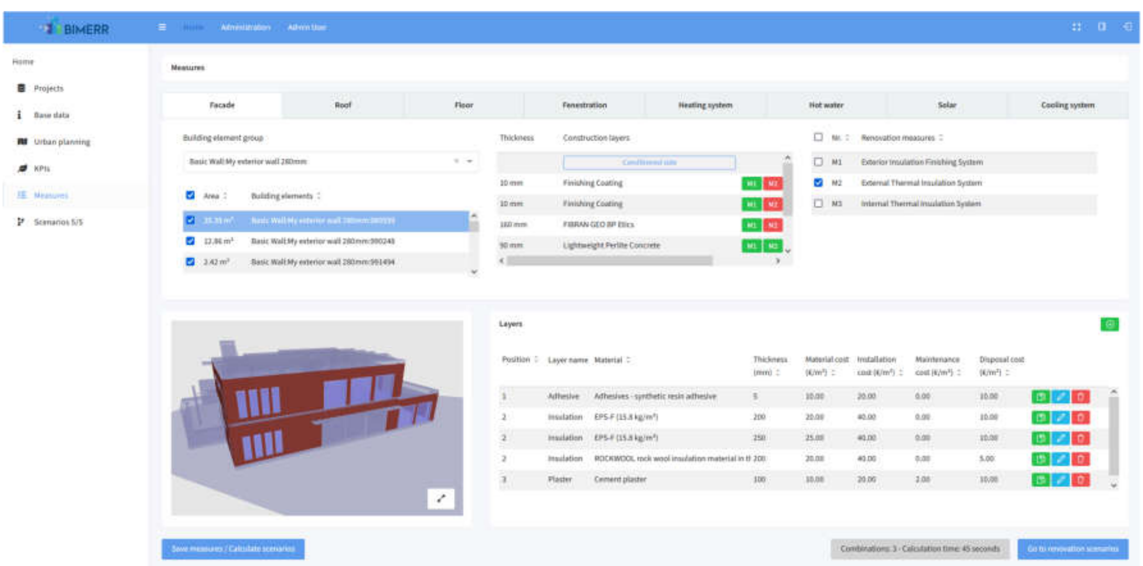


Figure 69. KRIPIS renovation measures view.

Based on the selected renovation measures. Figure 70 shows the generated renovation scenarios and their KPIs. The KPIs were calculated by the RenoDSS BEP and LCA/LCC module based on the building and component properties configured in the RenoDSS renovation measures view or retrieved from the BIMERR Material and Component Database.

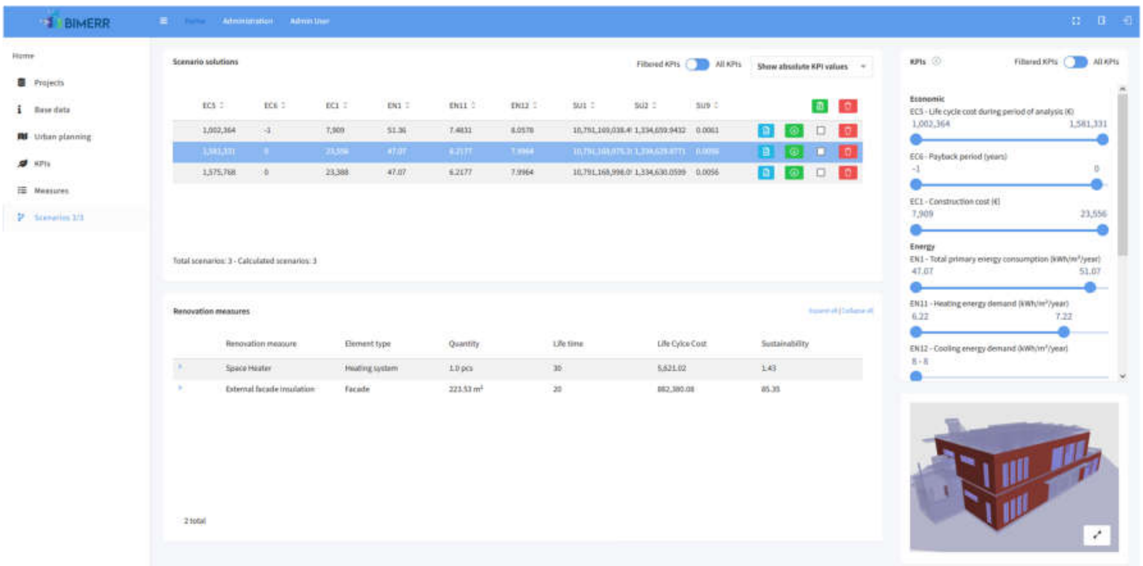


Figure 70. KRIPIS renovation scenario view.

More details regarding the RenoDSS BIMERR tool are available in D7.10: Integrated BIMERR Renovation Decision Support System 2 [10].

3.7 Renovation Process Modelling, Progress Monitoring And Alerting

This subsection presents the tests that took place in the KRIPIS pre-validation site regarding the generation of the Renovation Process workflow, based on the scenario derived from the RenoDSS tool. Furthermore, the tests conducted by the PWMA tool-kit applications (for project managers, construction contractors/workers and residents) are also described for the same pre-validation site.

3.7.1 Renovation Process Generation

For the pre-validation of the PWMA modelling and simulation toolkit in the KRIPIS SmartHome a demonstrative renovation process model has been created following the process template for the renovation of the outside façade of a building. The process involves the installation of a ventilated façade for the specific project of KRIPIS, identified in BIMERR with id 249 (Figure 71).

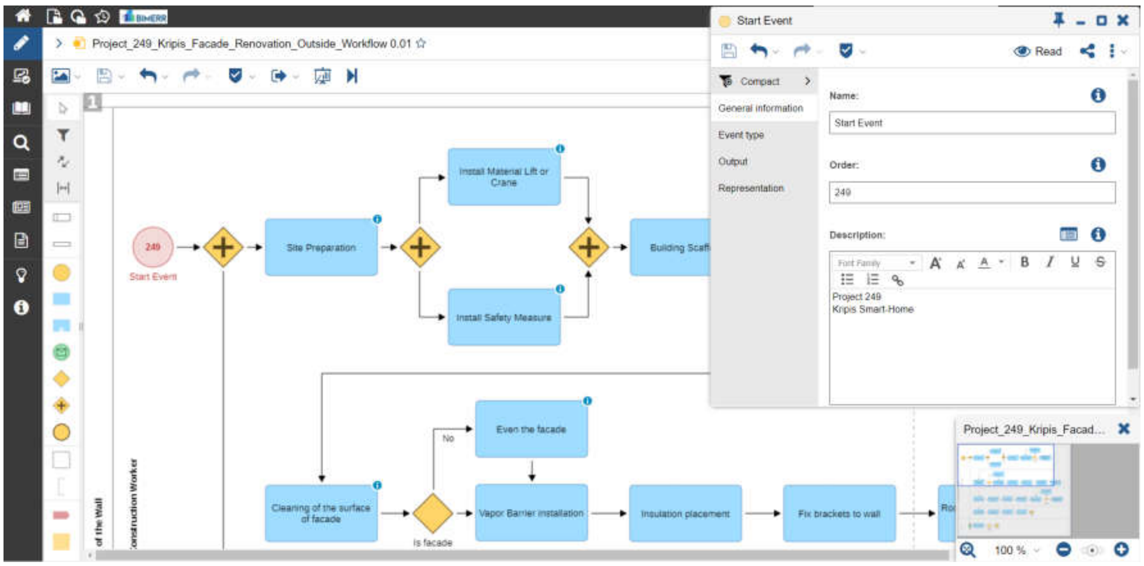


Figure 71. KRIPIS Renovation Process.

Three simulation scenarios have been created for the KRIPIS renovation process with risk factors details for an optimistic, moderate, and pessimistic case. The renovation process simulation has been successfully validated over the three scenarios.

In addition to the process model, a specific model for the KPIs related to the KRIPIS renovation process has been created and connected with (a) the RenoDSS to retrieve the area of the façade to renovate and (b) the PWMA execution engine to retrieve the actual status of the renovation process. This information will be used in the KPI model as metrics for the calculation of a specific and demonstrative KPI, related to the renting cost of the needed scaffold. The integration with the RenoDSS and PWMA execution engine has been verified in the KRIPIS scenario, correctly retrieving the façade area dimension of the building and the current execution time of the process, using them in the KPI calculation of the scaffolding cost (Figure 72).

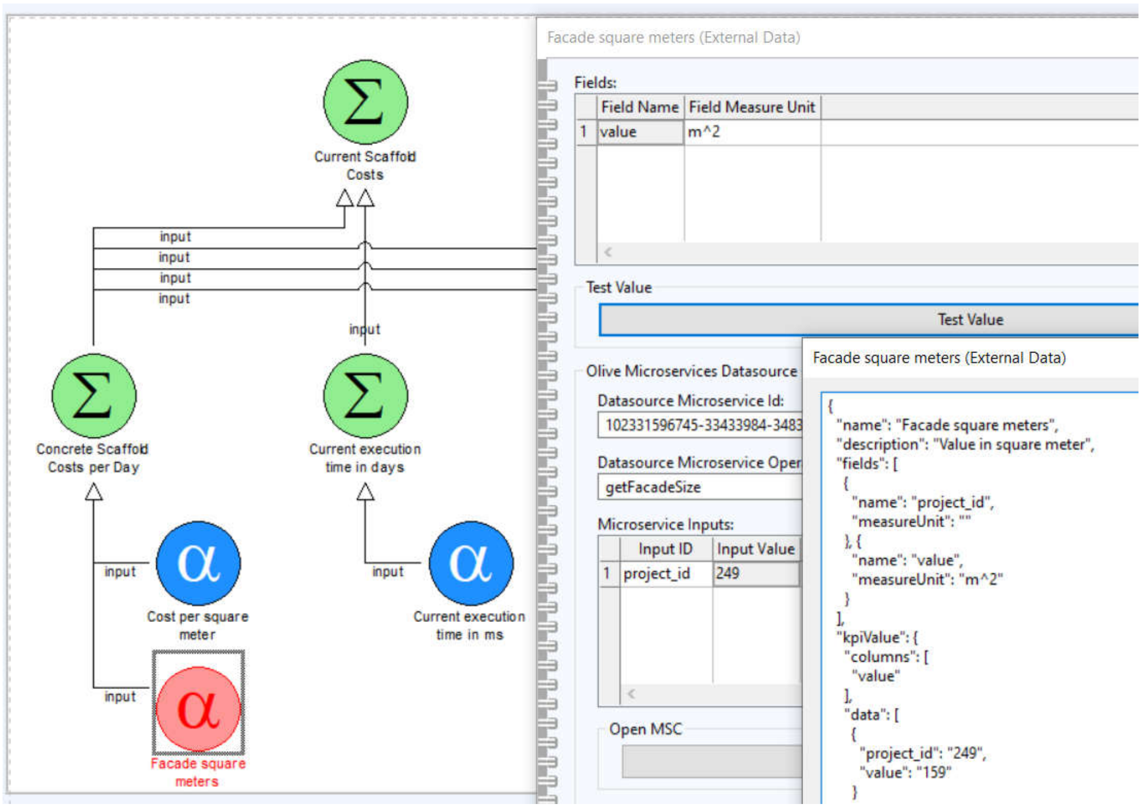


Figure 72. KRIPIS KPIs model.

The KPI model, as well as the simulation results, have been used as foundation for the definition of a specific dashboard for the KRIPIS scenario, where the KPI values are calculated, relying on the information contained in the KPI model and visualized comparing them with the simulated costs and times (Figure 73).

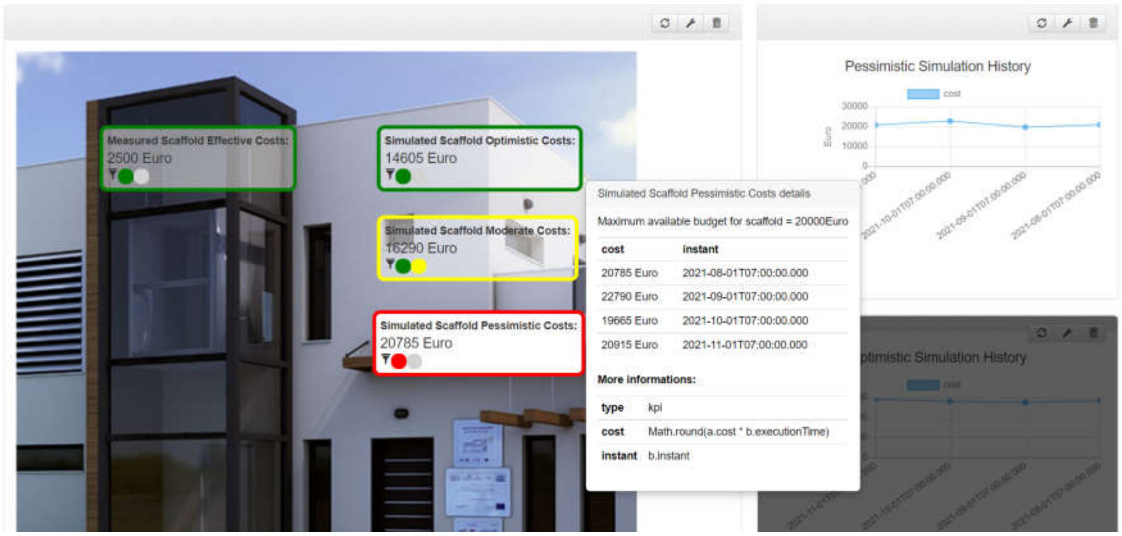


Figure 73. KRIPIS KPIs and simulation dashboard.

Finally, a simple renovation workflow has been created starting from the process model and enriching it with more tasks details and has been sent to the PWMA execution engine validating the integration between the two components.

3.7.2 PWMA For Managers

The PWMA consists of two main components; PWMA For Managers, and PWMA For Workers (described in subsection3.7.3). PWMA For Managers is addressed to Project Managers or Site Managers, allowing them to create detailed workflows and assign them to workers. These workflows contain information about all the tasks needed to be done, along with the data of the specific building and its components. Within the scope of the PWMA application, they're called workorders.

The KRIPIS SmartHome followed the standard procedure of handling the input data – after PWMA received a workflow from the Renovation Process Generation, the workflow was automatically analyzed and parsed to the databases. The workflow was represented in a JSON format file following BPMN standards. It contained all tasks, their respective information, connections between them, and other essential details. After transforming and loading the relevant data, the system enables specific managers to see the received workflow and use it as a base for workorders (Figure 74).

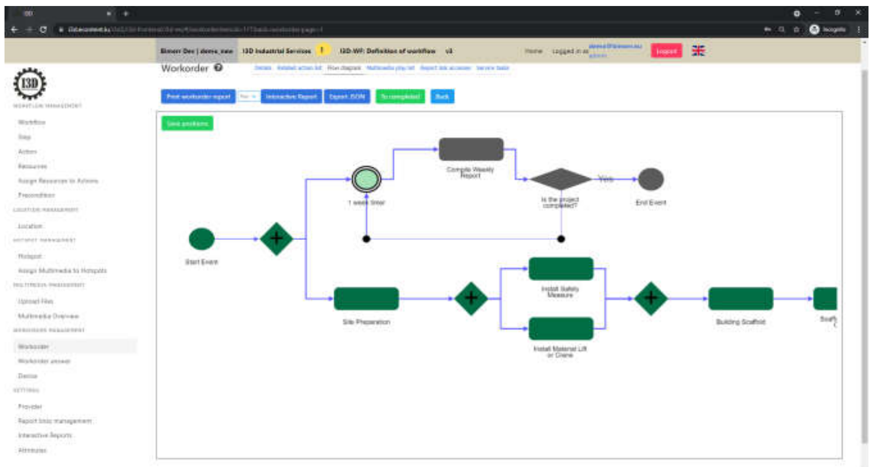


Figure 74. Workflow diagram inside the PWMA for Managers application.

During the initialization phase, a workorder needs to be assigned at a specific owner. This owner is typically the main person from the group of workers responsible for the execution of the workorder along with the results reporting. They may or may not be the ones executing the specific tasks, this depends on the human resources management.

All available workers are automatically loaded from the internal database of the PWMA For Managers. The database itself runs on the server and consists of multiple data used by both main parts of the PWMA. Aside from the workers, it includes all workflows, workorders, multimedia, results, and so forth. After choosing one, the workorder can be specified further by physical space in which the tasks are relevant. The locations are all loaded either from a BIM model or an IFC file received and parsed from the BIF component.

In the case that the original workflow has multiple lanes of tasks, it is possible to assign a specific worker to each of the lanes separately. This again may or may not include the workorder owner. This way, every lane has its own worker or provider, allowing for a seamless execution. In their nature, lanes usually run in parallel order, often depending on each other at specific points. This allows the workers to work separately, and if needed, halt their progress for a while, and wait for the others to finish their part.

Once the manager finishes the initialization and setup of the workorder, it is ready to be started and executed by workers inside the PWMA For Workers.

3.7.3 PWMA For Workers

The second main component of PWMA is PWMA for Workers, also called On-site support App for Workers. Its focus is loading workorders created in PWMA for Managers and allow their execution, all whilst providing various options for better working performance. The workorders shown in the interface were automatically filtered based on the position of the worker. If the worker's present within the relevant building and/or room assigned to the workorder, it is shown and available for running, otherwise it's unavailable for that location. If the workorder doesn't have its location specified, it is considered universally located, and can be therefore chosen from any position.

Once the worker chooses a particular workorder, they see the description, available tasks, state of the work, and other information. After choosing and starting the appropriate workorder, the worker can execute each action in a sequence order.

During the workorder execution, there are multiple options for helping the workers with their work. One of those options is a Remote Assistance service, which allows workers to connect with their supervisor, either workorder owner or site manager, and let them communicate. During the communication, it is possible to share the camera feed of the worker, capture and send pictures and videos, and share documents.

After completing each of the tasks, the worker can report specific results and values gathered during the work, summarizing their progress. The report is then visible in PWMA for Managers for competent users to view. Managers can also see the progress of the workorder and status of each task, and are able to change certain details during the execution.

3.7.4 PWMA For Residents

The PWMA For Residents application was tested and evaluated on the KRIPIS SmartHome during the pre-validation phase to verify its good use and performance. The main functionality of this application is the communication between building managers and residents to enhance the quality of renovation services. In addition it implements the formative evaluation as input in planning renovation processes from the residents of the building.

Residents and building managers can communicate and interact through three different ways:

- Notifications (new tasks, tasks changes, H&S issues) that user receives;
- Issue reporting from the resident to the building manager about issues that the resident encounters in his apartment or in a communal space of the building; and
- Task commenting from the resident to the building manager about H&S issues or changes on the schedule.

For testing the notifications functionality at the pre-validation stage, dummy data were used as input. Specifically, workorder data informing the residents regarding new tasks, upcoming tasks, tasks changes and H&S issue that may affect them, was provided in a JSON format.

```
{
  "id":2,
  "name":"Install Material Lift or Crane",
  "description":"obj.58195| task for Install Material Lift or Crane",
  "execution_time":{
    "planned":{
      "id":1,
      "workorder_result_id":2,
      "logattributes_id":1,
      "value":0,
      "comments":null,
      "start":"2021-06-01 14:13:00",
      "end":"2021-06-05 14:13:00"
    },
    "real":{
      "id":1005,
      "workorder_result_id":null,
      "logattributes_id":1,
      "value":1,
      "comments":"mockup",
      "start":"2021-06-01 14:13:00",
      "end":"2021-06-04 14:13:00"
    }
  },
  "health_safety":{
    "issues":[
      {
        "type":"electrical",
        "notes":"Please be advised that during this task, electricity will be cut in this area"
      },
      {
        "type":"noise",
        "notes":"Please be advised that during this task, noise levels will be higher than normal"
      }
    ]
  },
```


Figure 75. Provided JSON file to check the PWMA For Residents app on the KRIPIS building.

While receiving this JSON file the PWMA For Residents application, the relevant information was displayed on the screen, confirming that all the necessary data were communicated to the involved user Figure 76.

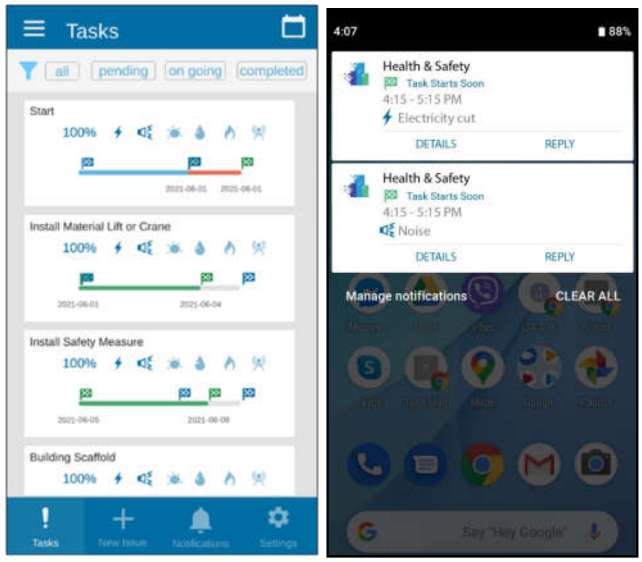


Figure 76. Tasks annotations displayed on the app screen to confirm that all the necessary data was delivered to the user.

Usually each resident has his own apartment. KRIPIS building contains one apartment with two floors; however, for testing purposes we assumed that the first floor is the resident's space and the ground floor is the communal space. This specific hypothesis could help us ensure that the resident of the first floor would receive only the tasks and the Health and Safety (H&S) issues related to his space and not to the communal space. Furthermore, another important test concerned the real time transmission of the data without any delay; eventually the resident received properly the data in time.

Another part needed to be checked during the pre-validation stage was issue reporting and tasks commenting. In KRIPIS' case, a hypothetical scenario of a malfunctioning AC unit of the apartment was elaborated. Therefore, photos captured on site and relevant comments were uploaded to the PWMA For Residents application in order to test these two functionalities and confirm that the data are sent to the BIF completed and in the appropriate way, without any obstacle or missing points.

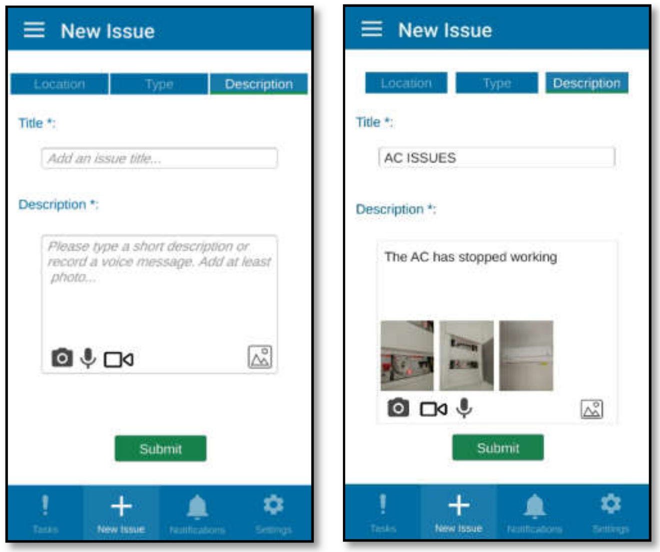


Figure 77. Checking the reporting issues and task commenting function of the app on KRIPIS building.

More details for the implementation of PWMA For Residents are presented in D6.11: Renovation progress monitoring & alerting application for residents 2 [11]. In general, the PWMA For Residents application seemed to function well in the KRIPIS SmartHome pre-validation site.

4. CONKAT Pre-Validation Activities

The pre-validation activities on the CONKAT building took place in an existing apartment that is not planned to be renovated. The purpose of the activities was to test and pre-validate the system under operational conditions. During the actual activities a wireless sensor network was installed on-site, while the apartment was laser-scanned, and its BIM model was created. Thus, the tools for digital model creation were tested, while the renovation support-tools were demonstrated based on the real building characteristics. As it was already mentioned, due to the Covid-19 restrictions, in the CONKAT pre-validation site less checking activities took place and the site was usually exploited to verify the functionality of the BIMERR tools. However, the residential data of the CONKAT apartment was leveraged uniquely for some tools (such as BICA) and the Wireless Sensor Installation process took place only in this site. Therefore, it is normal to have different activities in each site, but the information derived from each site considers to be very useful and important for the BIMERR Solution.

4.1 Building Description

In this subsection, general information about the CONKAT pre-validation building of the BIMERR is provided, such as the architecture, the construction materials used in the building, its opaque and glazing elements, as well as details about the installed HVAC system and its MEP components.

4.1.1 Overall Architecture

The CONKAT building is located at the north-east suburbs of Athens. The elevation of the area above the sea level is 185 m, while the latitude and the longitude are 38.021332 and 23.798630, respectively. The apartment belongs to a three-storey dwelling, built in 2000, with three apartments at each floor, and a basement. The selected apartment has a total surface area of 90 m^2 and is on the second floor facing Southeast. Several views of the building are presented in Figure 78 and Figure 79.

Figure 78. CONKAT pre-validation site – exterior views.

Figure 79. CONKAT pre-validation site – interior views.

In Figure 80, a top-view of the CONKAT pre-validation is presented, along with the labeling for each space of the apartment.

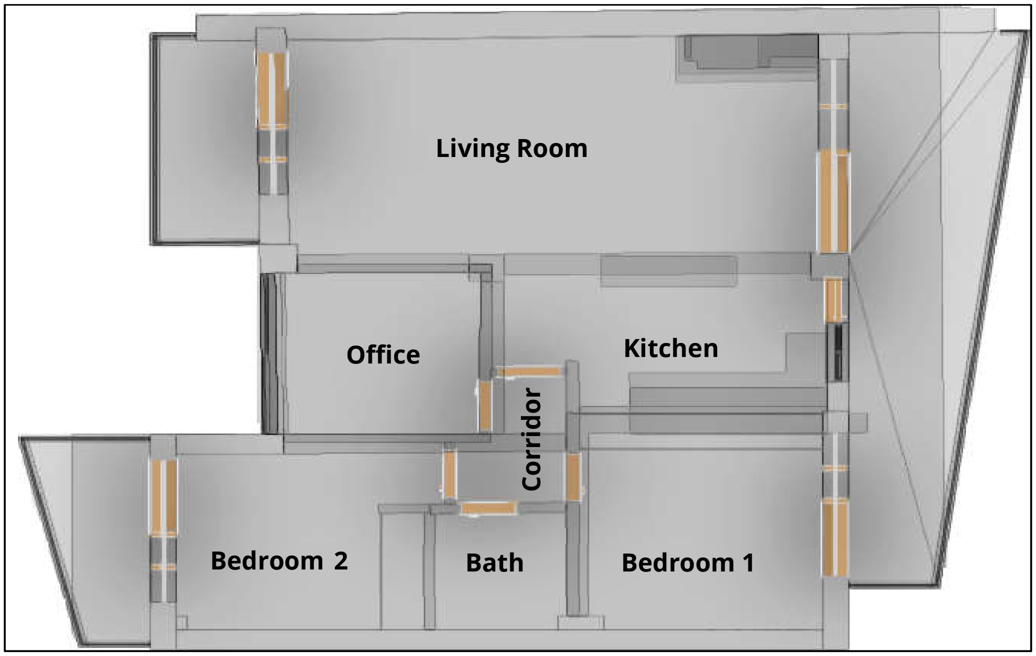


Figure 80. CONKAT pre-validation apartment top view.

4.1.2 Construction Materials and Fenestration

Opaque elements

The building's structural frame (columns, beams) and the building's slabs are made of reinforced concrete. The exterior walls consist of a double layer of brick, insulation and plaster on each side. In total the exterior walls are 30cm thick. For those walls that have sliding balcony doors recessed in the walls, an additional 8cm. opening exist between the two brick layers, for the door to slide in. In that case the walls have a thickness of 38cm. The analytical thickness of each wall layer is presented in the following Table 14.

Regarding the thermal conductivity of the building material, again as in case of KRIPIS, the exact materials that were used during construction was not able to be retrieved. Thus assumptions and estimations were made, with info derived mainly from the Greek

Regulation for the Energy Efficiency of Buildings (KENAK), considering the most commonly used material according to the most common building practices.

External wall	Material name	Material thickness (cm)	Thermal Conductivity (W/mK)	Total Thickness(cm)
Living room, Room 1, Room 2	Plaster	3	0.87	38
	Insulation	5	0.035	
	Brick	9.5	0.4	
	Opening for sliding door	8		
	Brick	9.5	0.4	
	Plaster	3	0.87	
Office	Plaster	3	0.87	30
	Insulation	5	0.035	
	Brick	9.5	0.4	
	Brick	9.5	0.4	
	Plaster	3	0.87	
Kitchen	Plaster	3	0.87	25
	Brick	9.5	0.4	
	Brick	9.5	0.4	
	Plaster	3	0.87	

Table 14. Wall material layering for external walls.

For the internal walls, the layers are presented in the following Table 15.

Internal wall	Material name	Material thickness (cm)	Total Thickness (cm)
All	Plaster	1.5	12
	Brick	9	
	Plaster	1.5	

Table 15. Wall material layering for internal walls.

In addition, for the slabs, the layers are presented in the following Table 16.

Slab	Material name	Material thickness (cm)	Thermal Conductivity (W/mK)	Total Thickness (cm)
Floor	Tiles	1.2	1.84	21.2
	Mortar	5	0.87	
	Reinforced concrete	15	2.5	
Flat roof	Plaster	5	0.87	25.0
	Reinforced concrete	15	2.5	
	Insulation	5	0.035	
Tiled roof	Roof tiles	1	0.40	26.3
	Cement mortar	5	0.87	
	Bitumen membrane	0.3	0.23	
	Insulation	5	0.035	
	Reinforced concrete	15	2.5	

Table 16. Slab material layering in CONKAT pre-validation site.

Glazing elements

Regarding the glazing, all the doors and windows of the apartment are double-glazing with dry air between the two layers of glass. Again, as in KRIPIS case, due to lack of information about the actual materials that were used during the construction of the building in the beginning of 2000, assumptions and estimations were made. Thus, the necessary information and values (i.e. thermal conductivity) required for adding Thermal Properties, were derived again, from the Greek Regulation for the Energy Efficiency of Buildings (KENAK) as well as from Revit Material Libraries.

The windows/doors of the apartment with their thermal properties and characteristics are presented in Table 17.

Door/ Window	Type	Dimensions (Width*Height) (m*m)	Heat Transfer Coefficient (U_{window}) (W/(m²·K))	Visual Light Transmittance	Solar Heat Gain Coefficient
Living room 1	Double glazed sliding pocket door	1.40*2.20	3.1	0.89	0.70

Living room 2	Double glazed sliding pocket door	1.70*2.20	3.2	0.89	0.70
Kitchen (door)	Double glazed door	0.80*2.20	3.9	0.81	0.61
Kitchen (window)	Double glazed sliding overlapping window	1.00*0.90	3.6	0.83	0.67
Office	Double glazed sliding overlapping window	2.80*1.00	3.5	0.83	0.67
Bedroom 1	Double glazed sliding pocket door	1.20*2.20	3.3	0.89	0.70
Bedroom 2	Double glazed sliding pocket door	1.20*2.20	3.3	0.89	0.70

Table 17. Analytical Properties values for fenestration of CONKAT pre-validation site.

4.1.3 HVAC System and MEP Components

Heating system

The heating system of the building is a central system with an oil boiler and hot water radiators at each room. The thermal bodies (radiators) are depicted in the following Figure 81 while their characteristics are presented in the following Table 18.

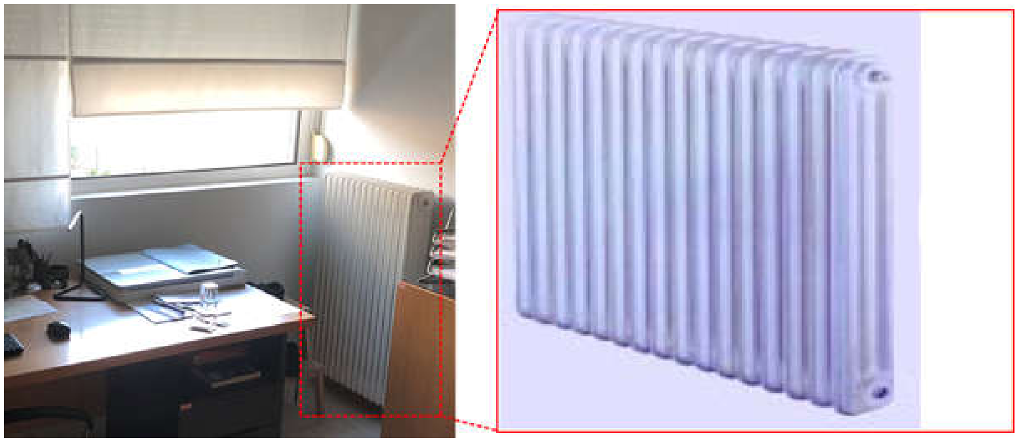


Figure 81. Thermal bodies/Radiators located at each room of the CONKAT pre-validation.

Room/Space	Slices	Length (mm)	Height (mm)	Capacity (kW)
Bedroom 1 >	17	650	1000	2.44
Bedroom 2	17	650	1000	2.44
Office	15	580	1000	2.21
Kitchen	11	420	1000	1.63
Living room	-	700	800	2.55
Living room	-	700	800	2.55

Table 18. Technical characteristics of the thermal bodies.

During winter the central heating system is available all the time, while an apartment thermostat controls its operation. The thermostat controls all the apartment's radiators and is located in the corridor of the apartment. The thermostat is a "Duo plus" constructed by the company "IMIT". The radiators are placed in all the apartment's rooms, so from the central system all the 90 m^2 of the apartment are covered.

Additionally, whenever the occupants do not feel thermally comfortable (e.g. the central heating system is not capable to reach the desired temperature) the occupants may "ideally" turn on the A/C split-type units and electric convectors to heat some rooms (where such systems are placed) independently. More details about the A/C split units are presented in the "Cooling system" subsection.

Cooling System

The cooling of the apartment is available all the time during the summer period. The ideal usage pattern assumes that the occupants turn on the A/C units only when they are present. It is obvious that deviations exist from such "ideal" use cases that are hard to a priori ascertain. Hence, the cooling of the building is exclusively achieved by A/C split units, while supplemental heating is provided by A/C split units and electric convectors.

The A/C split units are controlled by IR controllers for each unit, while the convectors are controlled by a controller placed on the unit. Regarding the area that this equipment covers, the A/C placed in the living room, covers the area of the living room and the kitchen, which is 34 $m^{2.}$ The same area is also covered by the convector placed in the kitchen. The A/C placed in bedroom 1 covers an area of 9 m^2, while the convector placed in bedroom 2 covers an area of 10 m^2. The technical characteristics of the A/C split units and the convectors are described in the following Table 19 and Table 20.

Room/Space	Model	Capacity	SEER	SCOOP
Living Room	TOSHIBA RAS-24UKHP-ES4	24.000 BTU/h	2.7	2.6
Bedroom 1	TOYOTOMI TDN-A35VR5	12.000 BTU/h	6.1	5.1

Table 19. Technical characteristics of CONKAT pre-validation A/C split units.

Room/Space	Model	Capacity
Kitchen	Convector	2000 W
Bedroom 2	Convector	2000 W

Table 20. Technical characteristics of CONKAT pre-validation convectors.

4.1.4 Energy Footprint

CONKAT's pre-validation site is a building constructed in 2000 and consumes energy in two forms. The first type of consumed energy is electrical energy which can be measured through the readouts of the energy meter of the apartment, which can be seen in the energy provider bills received every four months. All the apartment's equipment and appliances are powered with electricity, except from the radiators, which are powered directly with hot water through the central gas burner. This consumption can be measured by multiplying the total kilowatts of the radiators with the hours that they have been operating each year. The operating hours of the radiators are available in the heating and services bill that the apartment receives each month from the building administrator.

In Table 21 the annual energy consumption data of the building is presented, both for electricity and heating. The energy consumption comes from electricity for all the appliances and oil which is used only for heating. As it was mentioned in subsection 4.1.3 this heating system covers the whole apartment, so from the central system all the 90 m^2 of the apartment are covered. Finally, it is worth mentioning that electricity usage for heating and cooling the apartment is minor, and the main consumption is from the heater that covers the whole apartment.

Year	Electricity Consumption (kWh/m^2)	Electricity Consumption per conditioned area (kWh/ m^2)	Heating Consumption from the central burner (kWh/m^2)	Total Consumption (kWh/m^2)	Total Consumption per conditioned area (kWh/m^2)
2019	25.8	42.77	35.12	60.31	102.42
2020	17.16	29.15	31.41	48.57	82.49

Table 21. Total annual energy consumption of CONKAT's pre-validation site.

4.2 BUILDING MONITORING AND EVALUATION

This subsection describes the Wireless Sensor Network Installation process in CONKAT pre-validation site as well as the Middleware Deployment in the same site.

4.2.1 Wireless Sensor Network Installation

The equipment installed in the pre-validation site according to D5.7 [13] and D5.8 [8] was:

- 1 Raspberry Pi 4 Model B;
- 1 Home Center Lite Z-Wave Gateway;
- 1 MCO MH9 – Temperature, Humidity and CO2 sensor;
- 6 FIBARO FGMS-001 ZW5 Motion/Luminance Sensor, one for each room;
- 5 FIBARO FGDW-002 Door/Window Sensor;
- 2 Aeotec Home Energy Meter Gen5 - Clamp Power Meters;
- 3 FIBARO Type E/F Wall Plug (One for A/C and 2 for convector heaters);
- 2 Instesis IS-IR-WMP-1 AC units with IR receiver to Wi-Fi interface; and
- 1 Boiler thermostat MH-3901Z.

The procurement procedure for the equipment started in August 2020, when CONKAT started communicating with the official resellers and other resellers of the equipment in order to find the best prices and the shortest delivery times. After this procedure, it was made clear that parts of the proposed equipment were not immediately available in the Greek or European markets due to a shortage by the manufacturer. From the proposed list of equipment, the following were immediately available:

- 1 Raspberry Pi 4 Model B;
- 1 Home Center Lite Z-Wave Gateway;
- 6 FIBARO FGMS-001 ZW5 Motion/Luminance Sensor, one for each room;
- 5 FIBARO FGDW-002 Door/Window Sensor;
- 3 FIBARO Type E/F Wall Plug (One for A/C and 2 for convector heaters); and
- 2 Instesis IS-IR-WMP-1 AC units with IR receiver to Wi-Fi interface.

While the rest components below were available by the end of 2020:

- 1 MCO MH9 – Temperature, Humidity and CO2 sensor;
- 2 Aeotec Home Energy Meter Gen5 - Clamp Power Meters; and
- 1 Boiler thermostat MH-3901Z.

Thus, after communicating with all partners it was agreed to visit the apartment and install the equipment in two phases, first in September 2020 for the equipment that was immediately available and then when the rest of the sensors became available.

In September 2020, the Raspberry and the Gateway were installed in the living room area, close to the entrance of the building and the already installed DSL router of the apartment, as presented in Figure 82 (left).

Moreover, in September the installation included the door and window sensors in all external openings, the motion sensors in every room except the bathroom, the A/C controllers, and the smart plugs.

Figure 82. left) Gateway installation in CONKAT's pre-validation building, right) The sensor installed in the southeast door of the living room and the living room A/C controller

In Figure 82 right) the sensor installed in the southeast door of the living room and the living room A/C controller are presented, while in Figure 83, one can see the installed motion sensor in the corridor of the apartment and the smart plug installed on the kitchen convector.

Figure 83. left) Motion sensor installed in the corridor, right) smart plug installed on the convector.

The topology of the installed equipment in September 2020 is presented in the following Figure 84.

Figure 84. Topology of installed equipment in September 2020.

Following this first stage of installation, the system commissioning was done by the end of September 2020 and the system was online from October 1st, 2020. In the following Figure 85, a screenshot of the Fibaro home app is presented, in which the user can see the status, change the settings, and manage the installed sensors.

After this first phase installation, the remaining part of the equipment became available by the supplier, in January 2021. Following the restrictions applied during that period due to the Covid-19 health crisis, it was not possible to visit the apartment and install the remaining sensors immediately when they became available, to guarantee the health and safety of the occupant and the installers. As a result, in the next period we followed the changing rules applied nationwide and we were in constant communication with the occupant to find the best opportunity for the installation. Thus, after some changes in the restrictions applied and with the consent of the occupant, we visited the apartment to install the remaining equipment in March 2021.

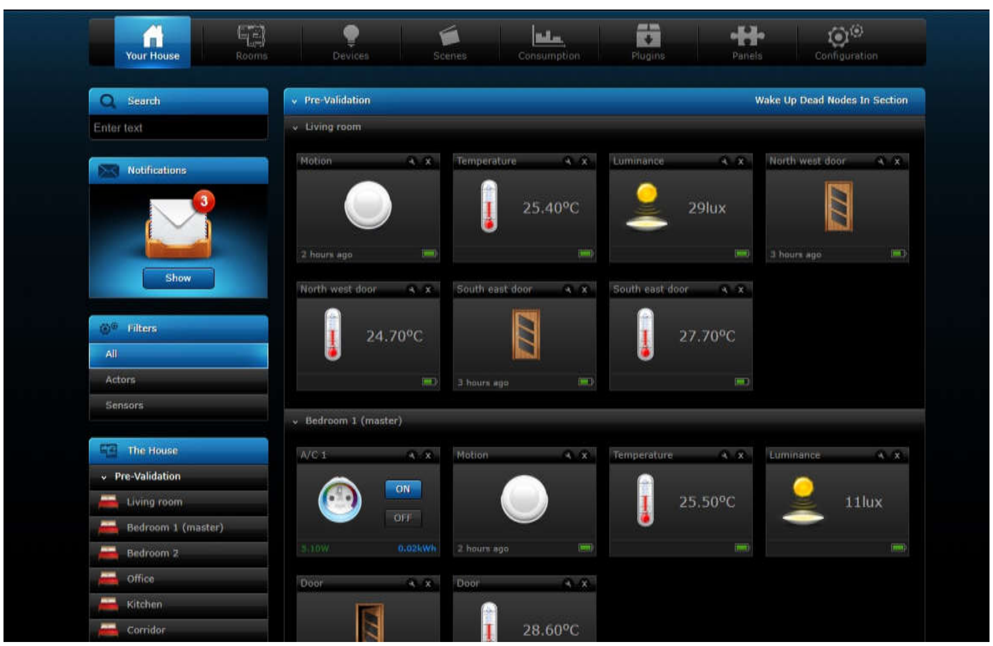


Figure 85. Screenshot from Fibaro home application, presenting online the status and results from the installed sensors.

Figure 86. left) Clamp meter and boiler thermostat, right) Temperature, Humidity and CO2 sensor.

During this visit the MCO MH9 – Temperature, Humidity and CO2 sensors were installed in the living room, the clamp meter (monitoring the living room A/C consumption) was installed on the electric board and the new boiler thermostat replaced the existing old thermostat. Those are presented in Figure 86.

Finally, the layout and topology of the sensors including both phases (September 2020 in yellow, orange, green and blue, March 2021 in red) of the installation are presented in the following Figure 87.

Figure 87. Final sensors topology

The selection of Fibaro Home Center Lite as the Z-Wave controller provides a useful range of user-friendly management tooling, however, the unreliable operation of the device added significant other challenges. In particular, the validation resulted in the discovery of an unknown issue with the controller, causing random and frequent crashes. The Fibaro support could not identify the cause and failed to offer any solution of permanent fix. Instead, first we had to rely on occupants for a manual reboot and eventually, we found a workaround to reboot the device remotely using an undocumented API endpoint which works on the device with the current firmware version v4.600.

4.2.2 Middleware Deployment and Testing

Figure 88 shows the deployment of middleware components. On the local side (on-premises), the CONKAT Gateway is powered by a Raspberry Pi 4, hosting middleware components for data processing, storage, and remove access. This Data Processor on CONKAT site interfaces with two types of connectors:

- Z-Wave Controller (Fibaro Home Center Lite) which manages many wireless sensors. The Data Processor discovers the controller within the local network and collects status information about its lifecycle. During onboarding, the Data

Processor queries sensor metadata and transforms them to W3C Web of Things (WoT) Thing Descriptions[11] - the standard picked by the project to describe sensing devices and gateways - and submits them to the central Registry component. Periodically, the Data Processor retrieves raw sensor measurements and converts them into RFC8428 Sensor Measurement Lists[12] (SenML) - chosen by the project to model sensor data efficiently – and submits them to the local Storage component. Lastly, the Data Processor monitors the status of the controller and reacts when it is not responsive by using an internal API to remotely reboot it. The automatic reboot only works when the controller is in a partial failure where network access and the internal module accepting the reboot call remains operational.

- Air-Conditioning (AC) Controllers which are connected over WiFi. The Data Processor discovers these devices within the network and periodically queries raw sensor data, before converting them to SenML and storing locally.

[11] https://www.w3.org/TR/wot-thing-description

[12] https://datatracker.ietf.org/doc/html/rfc8428

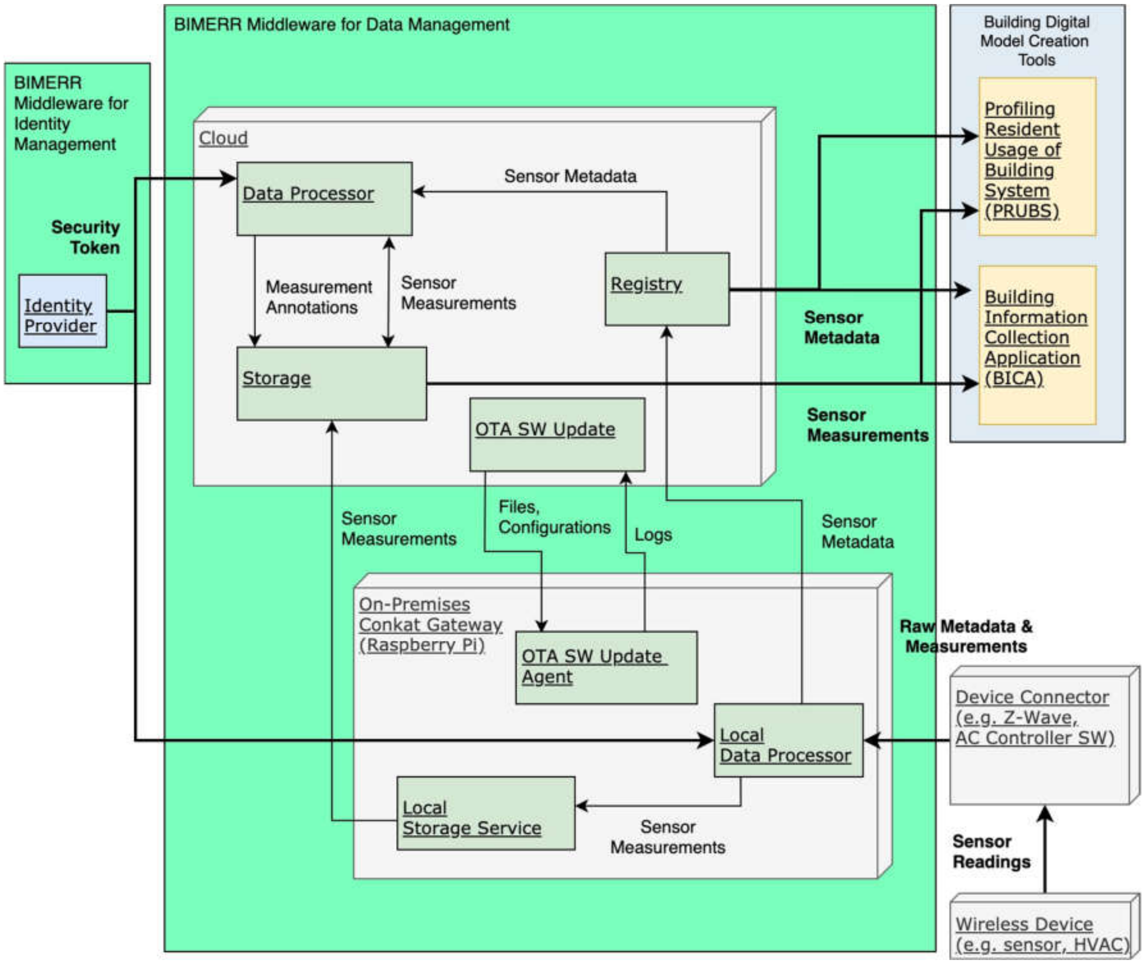


Figure 88. Middleware deployment for the CONKAT site.

On the cloud side, middleware interfaces with other BIMERR components such as PRUBS to securely deliver stored metadata and sensor measurements. One major extension to the cloud components was the addition of an alerting mechanism to receive emails whenever devices go offline, or batteries run lower than a given threshold. The alerting mechanism is fully configurable, and the subscription is based on user roles and groups extracted from the Identity Provider.

In general, the CONKAT site prepared the middleware for the actual pilots by offering heterogeneous sensors and a remote pilot site with very limited possibility of physical access for maintenance. The middleware components were tested with larger amounts of data and the functionalities were improved to add better awareness into remote pilot site conditions. Moreover, the middleware was proven to be extensible with limited programming effort to accommodate new sensor types and communication interfaces. The details of the implementation are available in D8.2 - BIMERR Middleware prototype [1].

4.3 IFC Creation

For the CONKAT pre-validation site the IFC was created in both ways. A laser scanning procedure took place in the early stage of the project and the generated point cloud was exploited in the next stages of the project. In addition, an IFC was also created by using the BIM authoring tools (Revit 2021). In the next subsections these two processes will be described.

4.3.1 Building Laser Scanning

The pre-validation site laser scanning was agreed to be executed by CONKAT, without physical presence of other partners in the apartment, to keep the safety measures applied due to the Covid-19 health crisis, and to guarantee the health and safety of the occupant. Thus, all the details for the laser scanning had to be agreed in advance with all relevant partners. To do so, a series of teleconferences were organized in May and June 2020, under the coordination of CONKAT. During the discussion it was proposed by CONKAT to use either the GeoSLAM ZEB-REVO or the Z+F IMAGER® 5016, for the apartment laser scanning. The GeoSLAM ZEB-REVO is a portable handheld laser scanner, which is more common and easier to use, but provides less detailed results. From the other side, the Z+F IMAGER® 5016, is a high-definition scanner, needing a positioning system to be fixed on the floor in each room, which is more difficult to use as it requires preparation, but it produces more detailed results. After discussion with the consortium, it was agreed to use the handheld GeoSLAM ZEB-REVO scanner, to test the project technologies on a more challenging point cloud, that is produced with a more common, easy to use and less detailed scanner.

The laser scanning of the apartment took place on the 4th of June 2020. During that visit, also detailed photos of the apartment were taken along with the measurements to create the 3D CAD and Revit files. Parts of the point cloud file produced by the laser scanning are presented in Figure 89, while a part of the produced 3D CAD model is presented in Figure 90.

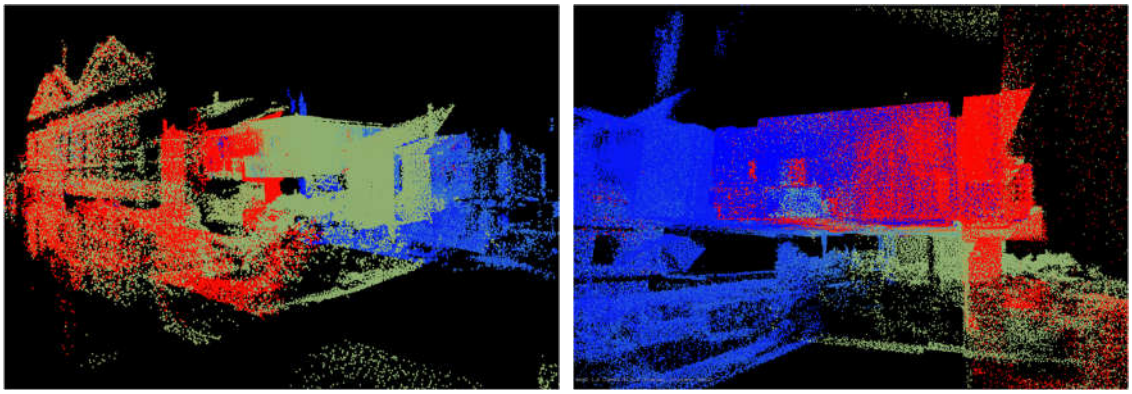


Figure 89. CONKAT's pre-validation point cloud.

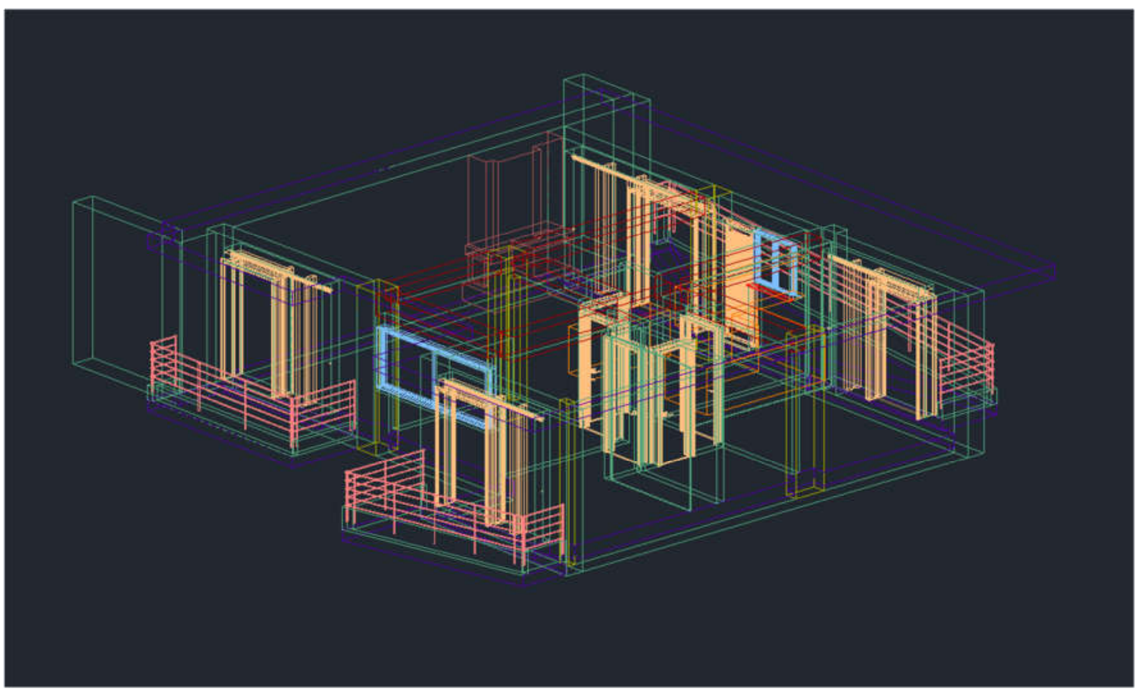


Figure 90. CONKAT's pre-validation 3D CAD model.

4.3.2 BIM Authoring Tools

As the CONKAT's building that was used under the BIMERR project as pre-validation site, was built in 2000, there was no existing BIM model. As a result, a new IFC file had to be created using a professional BIM authoring tool. To create this model, the existing 2D floor plans and sections were taken into consideration, along with measurements taken during the onsite audit that took place during the laser scanning in June 2020. The IFC file was created using the Autodesk Revit 2021 suite.

During the creation of the Revit model, and to meet the requirements of the BIMERR project, the general principles, and guidelines for IFC creation from Deliverable 5.2 were followed. These instructions walk the reader through the first stages in Revit to develop a generic BIM model that includes all the relevant thermal parameters for each material. Many key procedures are also outlined in these guidelines, such as the definition of building areas and their types, as well as the grouping into zones. In addition, the exportation procedure as well as the processes required by the designer are detailed in that deliverable.

Thus, considering the guidelines provided by the project and the measurements taken during the onsite audit, the IFC model of the pre-validation apartment was created. The characteristics of the building material, glazing and mechanical equipment described above, were defined in the model created. Views of this model in the Autodesk Viewer can be seen in the following Figures.

Figure 91. View of the CONKAT's pre-validation 3D model.

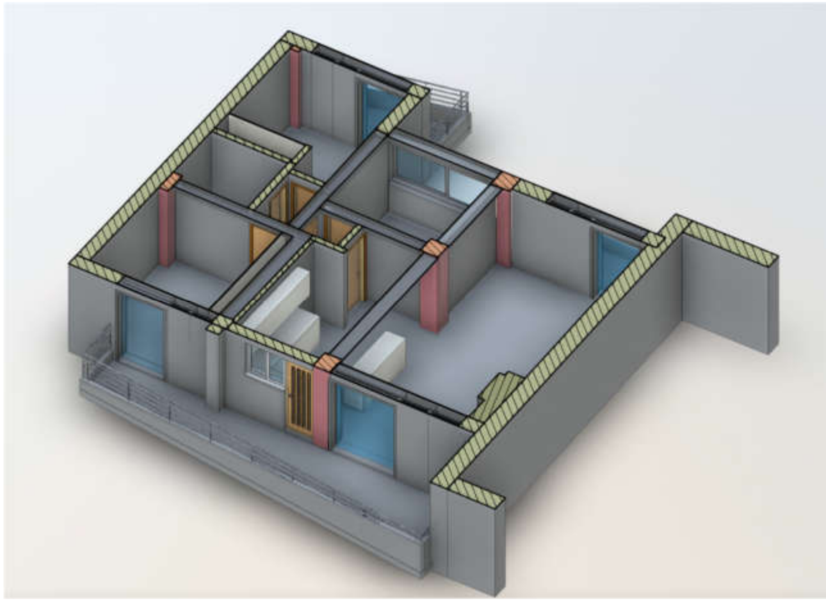


Figure 92. View of the CONKAT's pre-validation 3D model.

4.3.3 Scan-to-BIM

As mentioned in Section4.3.1, a laser scanning device of different nature of the one used for documenting the KRIPIS Smart Home was employed for digitising the CONKAT apartment. The mobile device used in this pre-validation site delivered a point cloud with lower precision and higher levels of noise (see Section 5.3 for further details). After pre-processing (i.e. cleaning) the point cloud, the *Scan-to-BIM Structural* tool was executed to extract semantic information on the architectural components of the building and create an IFC model. Results for the pre-validation site are illustrated in Figure 93.

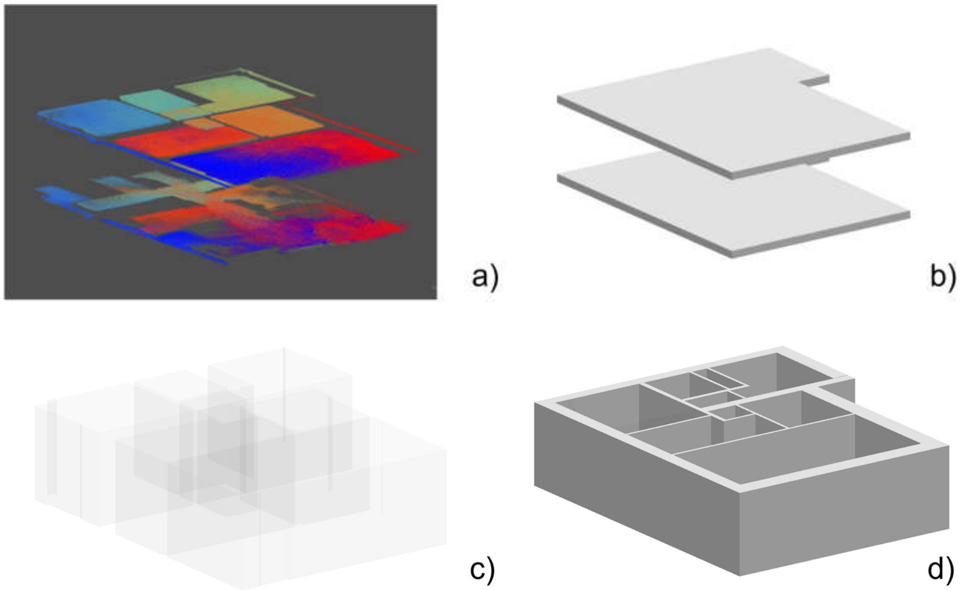


Figure 93. Results of Scan-to-BIM structural for the CONKAT apartment. a) Floor and ceiling points extracted from the cloud, b) Slabs, c) Spaces and d) Walls.

Note that openings (and subsequent 2LSBs) have not been calculated because of the nature of the point cloud whose [lower] quality challenges the algorithm. Additional work will be performed on the tool to try to mitigate the effect of the quality of the clouds in the resulting models.

Another disadvantage of the mobile scanner is that color information or photographs are not provided. This, together with the lack of pictures to produce photogrammetric models of the rooms, caused an incomplete test of the *Scan-to-BIM MEP* tool. Although different MEP objects were identified in images of the apartment, as illustrated in Figure 94, calculating their pose with respect to the point cloud was not feasible. Besides, while radiators were, in general, properly identified, Air Conditioning units were sometimes mislabeled as sockets (e.g. top left image) or as radiators (bottom right image) (a weakness we know is simply due to the limited dataset available for training the Air Conditioning detection module; an issue easily resolved by increasing the dataset).

Figure 94. MEP objects identified in the CONKAT apartment

4.4 IFC CHECK AND ENRICHMENT

In this subsection the tests that took place in the CONKAT pre-validation site, regarding the BIM-MP BIMERR tool are presented.

4.4.1 B-rep Generation

BIMERR's pre-validation site CONKAT, was also processed by BIM-MP's B-rep generation tool to extract the geometry of the site's architectural elements, as displayed in Figure 95.

Figure 95

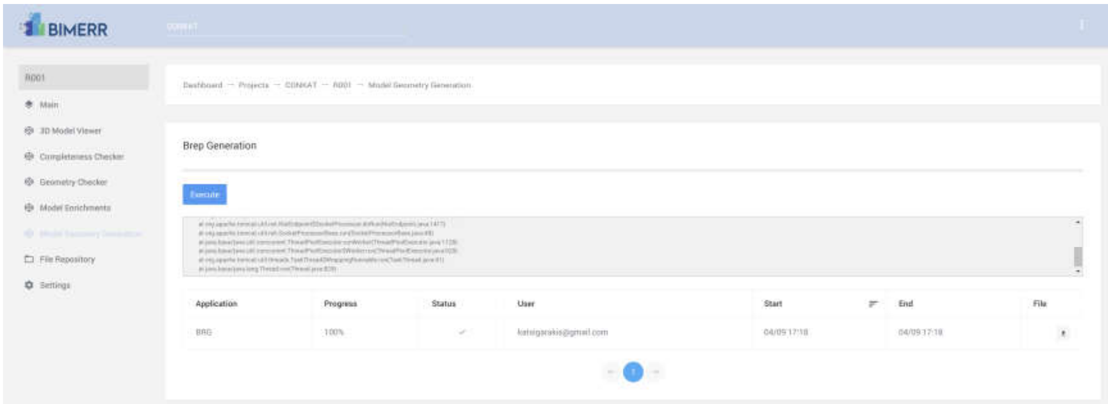


Figure 95. Execution of BIM-MP's B-rep generation tool on CONKAT's pre-validation site.

As displayed, using BIM-MP's viewer, in Figure 96, the extracted architectural elements of CONKAT's site, are contained in a single floor among two horizontal slab elements.

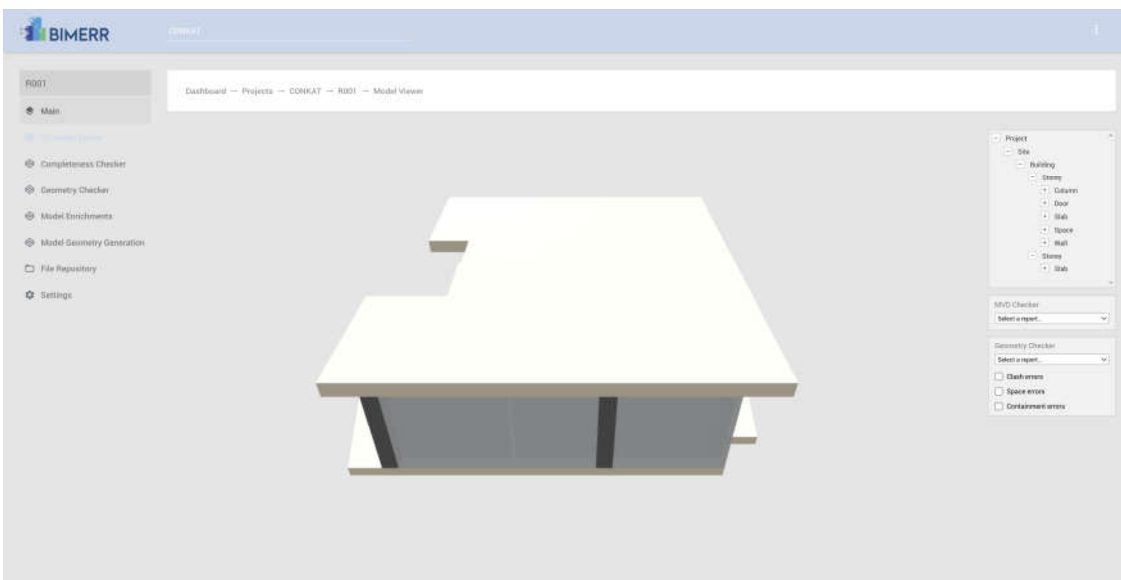


Figure 96. Extracted architectural elements of CONKAT's site by BIM-MP's B-rep generation tool.

The extracted boundary representations of the building elements are presented in Table 22:

Element Type	Total Number
Spaces	6
Walls	19
Windows	1
Doors	10
Slabs	2
Columns	5

Table 22. Extracted B-reps of CONKAT pre-validation site.

The overall building model and its respective building tree is displayed using BIM-MP's viewer in the right part of Figure 96.

4.4.2 Geometry Error Detection

CONKAT's pre-validation site IFC model was uploaded to BIM-MP platform without any geometrical errors affecting the automatic BEPS model generation process. The execution of BIM-MP's GED tool verified this, as evidenced in Figure 97.

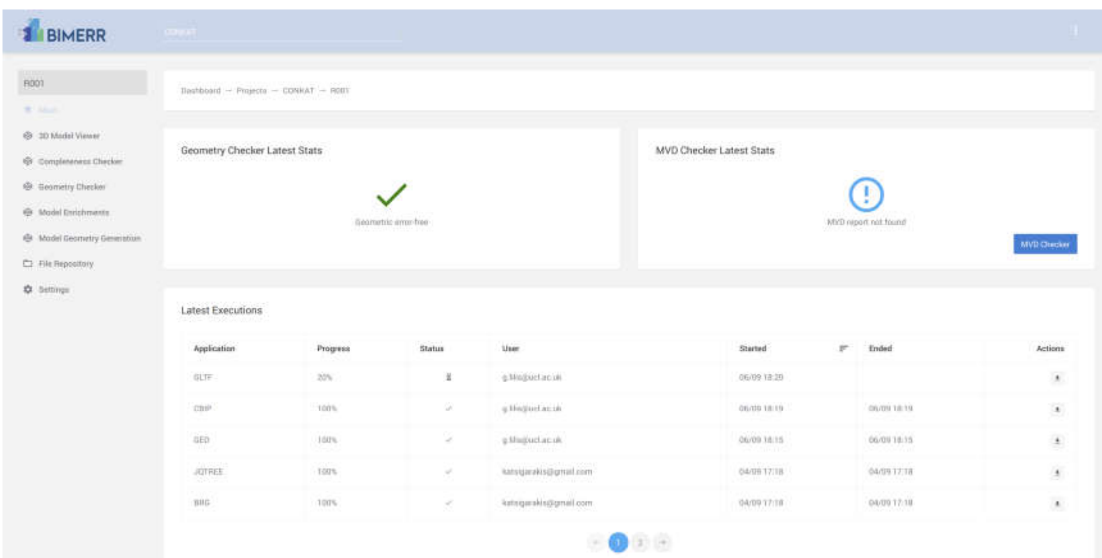


Figure 97. Verification of the geometric Error-free IFC model of CONKAT pre-validation site, using BIM-MP's GED tool.

4.4.3 *MVD Checking for Thermal Properties and Schedules*

CONKAT's geometric error-free IFC is checked for completeness regarding the thermal properties of materials and schedules. The completeness checking for thermal properties is performed using BIM-MP's MVD service. To trigger the MVD checking for thermal properties the user should select the original IFC file on the first drop-down menu, choose the Thermal Properties option on the second menu and press the Execute button of the Completeness Checker page as shown in Figure 98.

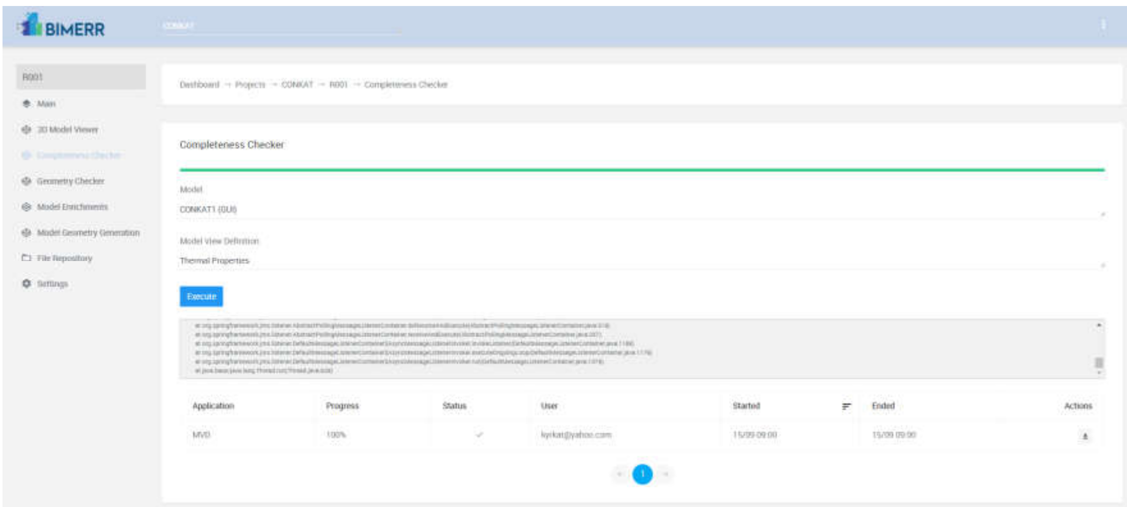


Figure 98. Thermal properties checking of CONKAT building.

When the process in completed, the error report of the CONKAT building is available in three ways: a) Through the 3D model viewer as shown in Figure 99 b) In textual format as shown in Figure 100 and c) Through BIM-MP's file repository in .JSON format as shown in Figure 101.

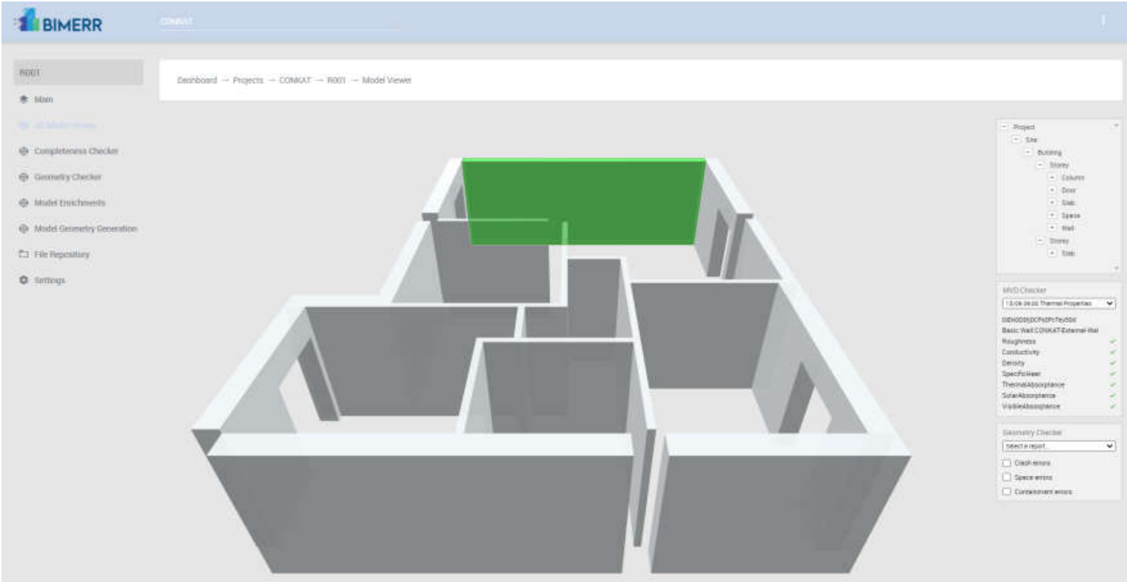


Figure 99. Thermal properties visual report of CONKAT building.

15/09 09:00 Report (Thermal Properties)

Opaque_Materials_Thermal_Properties [BuildingElement_MaterialUsage_MaterialLayerSet_Properties] [IfcBuildingElement]

ExpressId	GlobalId	Name	Result	
#1380	0vCJzqlxn0xAh01xtNUO2N	Floor:CONKAT-floor:255948	✓	
#2098	0iENGDStjDCPsSPcTeu57r	Basic Wall:CONKAT-External-Wall-30cm:258109	✓	
#2411	0iENGDStjDCPsSPcTeu51R	Basic Wall:CONKAT-Inter-Wall-12cm:258451	✓	
#2575	0iENGDStjDCPsSPcTeu5FJ	Basic Wall:CONKAT-Inter-Wall-12cm:258587	✓	
#2679	0iENGDStjDCPsSPcTeu5EB	Basic Wall:CONKAT-Inter-Wall-12cm:258627	✓	
#2789	0iENGDStjDCPsSPcTeu5Bc	Basic Wall:CONKAT-Inter-Wall-12cm:258862	✓	
#2889	0iENGDStjDCPsSPcTeu5Ac	Basic Wall:CONKAT-Inter-Wall-12cm:258926	✓	
#2993	0iENGDStjDCPsSPcTeu5NZ	Basic Wall:CONKAT-Inter-Wall-12cm:259115	✓	
#3095	0iENGDStjDCPsSPcTeu5JP	Basic Wall:CONKAT-External-Wall-38cm:259345	✓	
#3284	0iENGDStjDCPsSPcTeu5IR	Basic Wall:CONKAT-External-Wall-38cm:259411	✓	
#3388	0iENGDStjDCPsSPcTeu5GB	Basic Wall:CONKAT-External-Wall-38cm:259523	✓	
#3488	0iENGDStjDCPsSPcTeu5Gd	Basic Wall:CONKAT-External-Wall-38cm:259567	✓	
#3590	0iENGDStjDCPsSPcTeu5TI	Basic Wall:CONKAT-External-Wall-38cm:259738	✓	
#3692	0iENGDStjDCPsSPcTeu5Rc	Basic Wall:CONKAT-External-Wall-38cm:259886	✓	

Figure 100. Thermal properties textual report of CONKAT building.

```
[
    {
        "entities": [
            {
                "valid": true,
                "name": "Floor:CONKAT-floor:255948",
                "global": "0vCJzqIxn0xAh0lxtNUO2N",
                "express": 1380,
                "rules": [
                    {
                        "valid": true,
                        "description": "Roughness"
                    },
                    {
                        "valid": true,
                        "description": "Conductivity"
                    },
                    {
                        "valid": true,
                        "description": "Density"
                    },
                    {
                        "valid": true,
                        "description": "SpecificHeat"
                    },
```


Figure 101. Thermal properties .JSON report of CONKAT building.

4.4.4 CBIP – Second Level Space Boundaries

Based on the geometric error-free architectural topology and using BIM-MP's CBIP enrichment tool (displayed in Figure 102), the second-level space boundary topology was extracted. This extracted surface topology (displayed in Figure 103), is used to populate and produce an enhanced IFC model suitable, as far as geometry is concerned, for BEPS model generation.

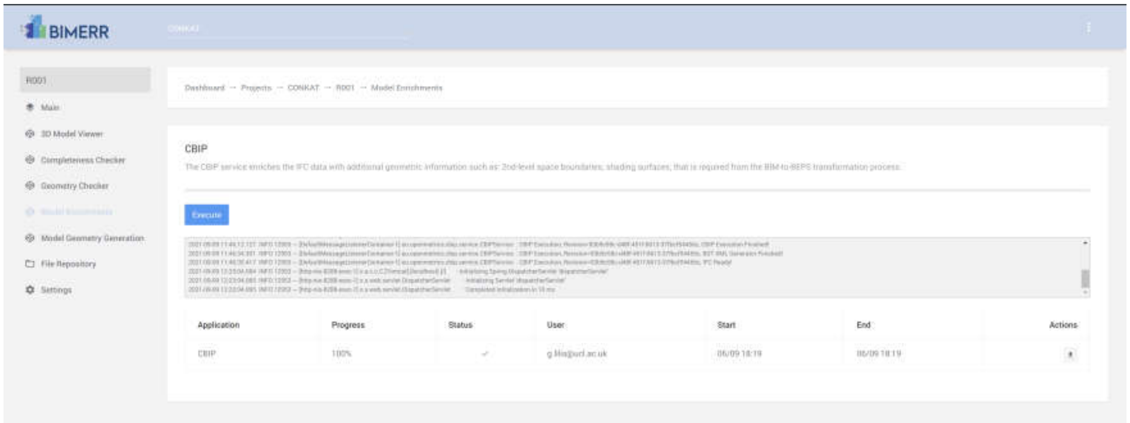


Figure 102. Execution of BIM-MP's CBIP tool on CONKAT pre-validation site.

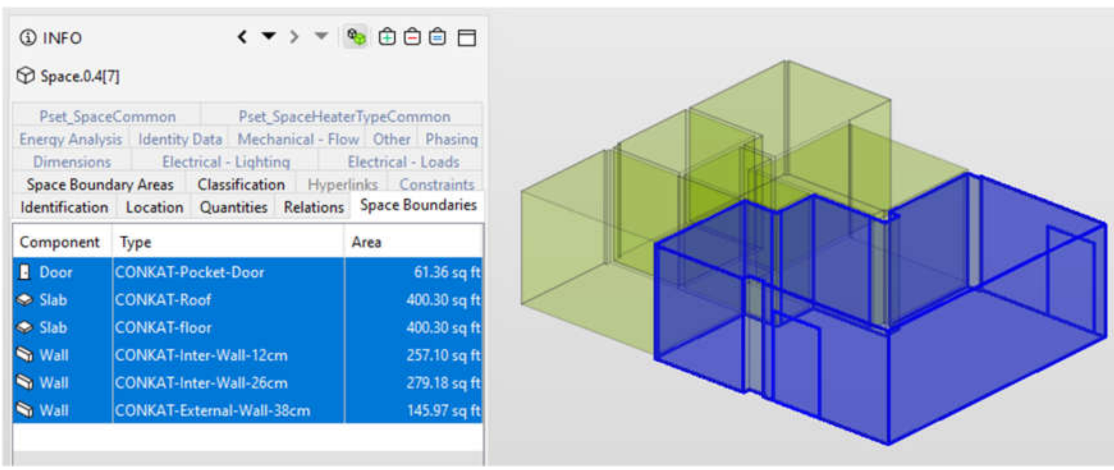


Figure 103. CONKAT's site extracted second-level space boundary topology by BIM-MP's CBIP service

4.4.5 MVD Checking for Semantic Enrichment

When the CBIP process is completed, the IFC model of the CONKAT building is checked against a set of rules which validate the existence and the semantics of the 2nd-level space boundaries instances. The semantic checking is performed using the BIM-MP's MVD checking service. To trigger the MVD checking of the 2nd-level space boundaries, the user should select the enhanced IFC on the first drop-down menu, choose the Space

Boundaries option on the second menu and press the Execute button of the Completeness Checker page.

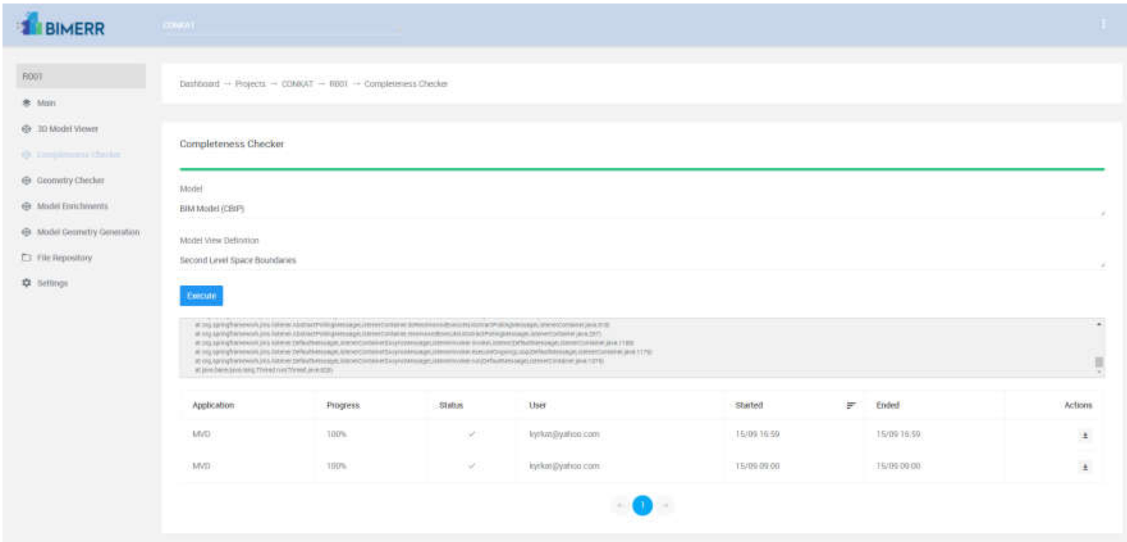


Figure 104. 2nd-level space boundaries checking of CONKAT building.

When the MVD checking is completed, the error report of the CONKAT building is available in three ways: a) Through BIM-MP's file repository page in .JSON format as shown in Figure 105 and b) In textual format as shown in Figure 106.


```
[
    {
        "entities": [
            {
                "valid": true,
                "name": "2ndLevel",
                "global": "1Q7eAAJNyQrXpH7DxB8Mkp",
                "express": 24259,
                "rules": [
                    {
                        "valid": true,
                        "description": "Corresponding space boundary is required for internal walls"
                    }
                ]
            },
            {
                "valid": true,
                "name": "2ndLevel",
                "global": "8CMkN1ILIKBNY91GVTwmQW",
                "express": 24273,
                "rules": [
                    {
                        "valid": true,
                        "description": "Corresponding space boundary is required for internal walls"
                    }
                ]
            },
```


Figure 105. 2nd-level space boundaries .JSON report of CONKAT building.

15/09 16:59 Report (Second Level Space Boundaries)

Internal_Walls [IfcRelSpaceBoundary2ndLevel]

ExpressId	GlobalId	Name	Result	
#24259	1Q7eAAJNyQrXpH7DxB8Mkp	2ndLevel	✓	
#24273	8CMkNIILIKBNY9IGVTwmQW	2ndLevel	✓	
#24287	3YxyzGIS3rsQLe9uZPcyCa	2ndLevel	✓	
#24301	FXOAOjWDfXBKw8qPYugri0	2ndLevel	✓	
#24315	FpsCeEaOMNJBoxUia7gJRM	2ndLevel	✓	
#24329	QizOKNd0LQpdsBRApEo8dM	2ndLevel	✓	
#24343	F72Oew32lB83nj18aqmC	2ndLevel	✓	
#24357	1bboPzw2ja7lWICrpELieT	2ndLevel	✓	
#24371	KzaLHka1V9d6y0D21Uc8d8	2ndLevel	✓	
#24385	sPyPsjvEafdkZSF7Uyg7CM	2ndLevel	✓	
#24399	5fP67Zfk6F8EuyXXc7bpra	2ndLevel	✓	
#24413	h4hbCvgcgmp3qw2FP6iVKK	2ndLevel	✓	
#24427	tFIFKT2a3heirPLH1Z1r2s	2ndLevel	✓	

Figure 106. 2nd-level space boundaries textual report of CONKAT building.

4.4.6 Interacting with BIF

The communication interface between BIM-MP and BIF of the CONKAT building is identical to the KRIPIS building as described in section 3.4.6.

4.5 On Site Checking

4.5.1 Visualization, Registration, Annotations and Task Visualization

Due to the Covid-19 pandemic and the restrictions that were imposed, the ARIBFA tool could not be tested on the CONKAT building. Despite that an actual validation of the application on the CONKAT building was not possible, some key functionalities of the ARIBFA tool were tested on the IFC file of the CONKAT building.

Evaluation of the 3D BIM model visualization. The visualization of the IFC file of the CONKAT building was tested in the ARIBFA application in Virtual Reality (VR) mode. The

ARIBFA application was fed to the IFC of the CONKAT building and the application was tested at the KRIPIS SmartHome. The IFC visualization functionality was successfully tested, as be seen in Figure 107.

Figure 107. The 3D BIM model visualization functionality of the ARIBFA tool was tested for the IFC of the CONKAT building while being at the KRIPIS SmartHome.

Evaluation of the 3D BIM model registration. The registration procedure was evaluated using an image marker that was placed on the top of a door frame in the living room of the CONKAT building in the 3D model in Unity Game Engine. A print of the image marker was placed on the top of a door frame in the living room of the KRIPIS building. From this procedure, the 3D BIM model of the CONKAT building was expected to be aligned using the image target. In Figure 108 the detected image target in the KRIPIS building is illustrated. Although we were not in the CONKAT building, the registration process was validated since the 3D BIM model was aligned to the position of the 3D BIM model in Unity. The anchoring capability was validated since the aligned 3D BIM model of the CONKAT building was successfully set as a spatial anchor using the speech command "Anchor" and was successfully loaded from the anchoring system of the Hololens device when the application was re-opened.

Figure 108. The registration functionality of the ARIBFA tool was tested for the IFC of the CONKAT building using an image target.

Evaluation of the IFC properties visualization. The menus that IFC properties visualization menus were tested for the IF file of the CONKAT building while running the ARIBFA application on the KRIPIS building in VR mode. An IFC properties menu that was visualized after performing the air tap gesture on a static building component of the BIM model of the CONKAT building is depicted in Figure 109.

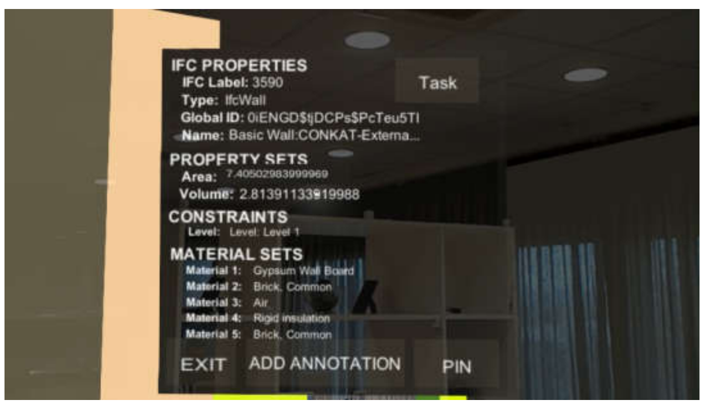


Figure 109. IFC properties menu as visualized after performing the air tap gesture on a static building component (wall) of the BIM model of the CONKAT building while the ARIBFA tool was tested on VR mode in the KRIPIS building.

Evaluation of the add annotation functionality. The menus for adding annotations were also successfully tested for the IFC of the CONKAT building, as demonstrated in Figure 110.

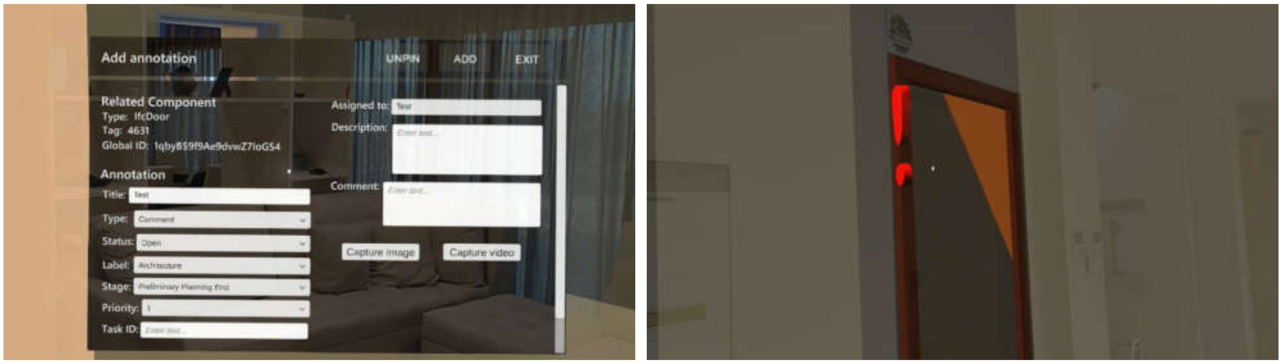


Figure 110. The add annotation functionality of the ARIBFA tool was tested for the IFC file of the CONKAT building while running the application on VR mode in the KRIPIS building.

4.5.2 Information Collection for Building Residents

The pre-validation activities of the BICA application for residents included the testing of the offered functionalities with data from the CONKAT building. More specifically, the data used for testing purposes was the CONKAT building data model JSON that has been produced by BIM-MP, and photos taken on-site. The validation was performed around the three main offerings of BICA:

- Apartment and components information visualisation;
- Issue reporting and log; and
- Comfort status update.

Figure 111. Building data JSON file to check the BICA on the CONKAT building.

4.5.2.1 APARTMENT AND COMPONENTS INFORMATION VISUALIZATION

The user was able to view in the BICA application the rooms and components that have been included in the building data of the CONKAT apartment, as well as any available information (ex. The name of a room). The underlying process for this visualization entailed the following: The CONKAT building data provided by BIM-MP through the BIF has been parsed by the BICA backend and the relevant tables have been populated with the available information.

Following the convention agreed at project level in BIMERR regarding the correspondence of an apartment to the ifcZone entity, the relatedApartment to the user of the BICA application can be identified using the respective Zone ifcIdentifier element. The rooms of the apartment and the installed components correspond to the relatedSpaces and relatedElements objects respectively and include their own entities, such as ifcIdentier, name and type. This information was communicated from the backend to the frontend of the BICA application, in order to be appropriately displayed to the user.

The building data from the BIMMP were made available in a data asset created in BIF and were retrieved by BICA through an appropriately configured data collection job. The Apartment ifcIdentifier has been added as query parameter in the query to filter the data according to the apartment that is associated to the user (association provided by Keycloak). The BICA backend performed GET requests to the endpoint provided by BIF (Figure 112), using the appropriate Apartment ifcIdentifier value (retrieved from Keycloak) in order to receive the apartment information.

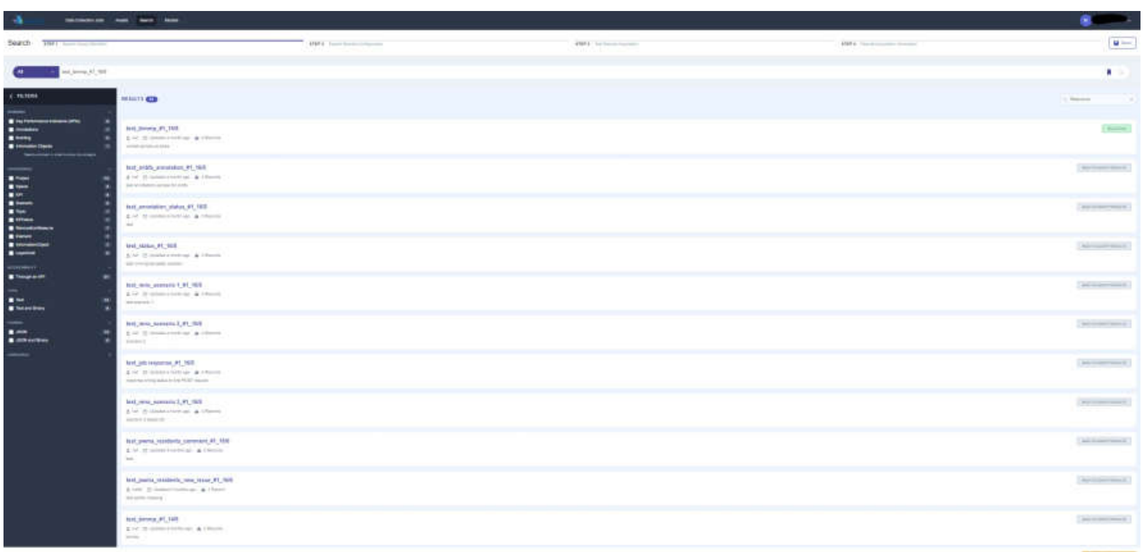


Figure 112. Selection of data asset containing the building data in BIF.

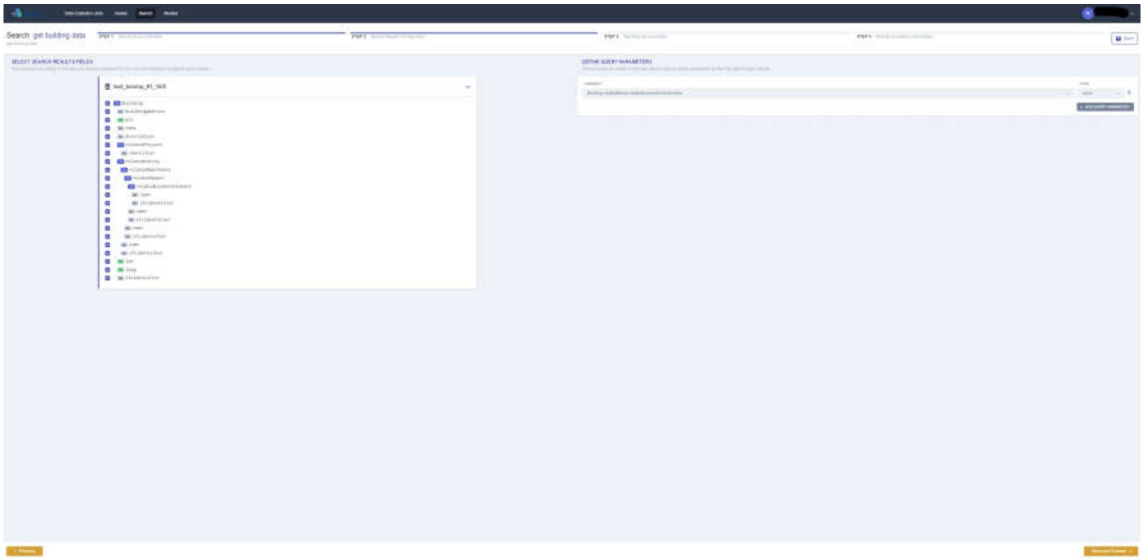


Figure 113.Selection of fields to be retrieved and addition of the Apartment ifcIdentifier as parameter.

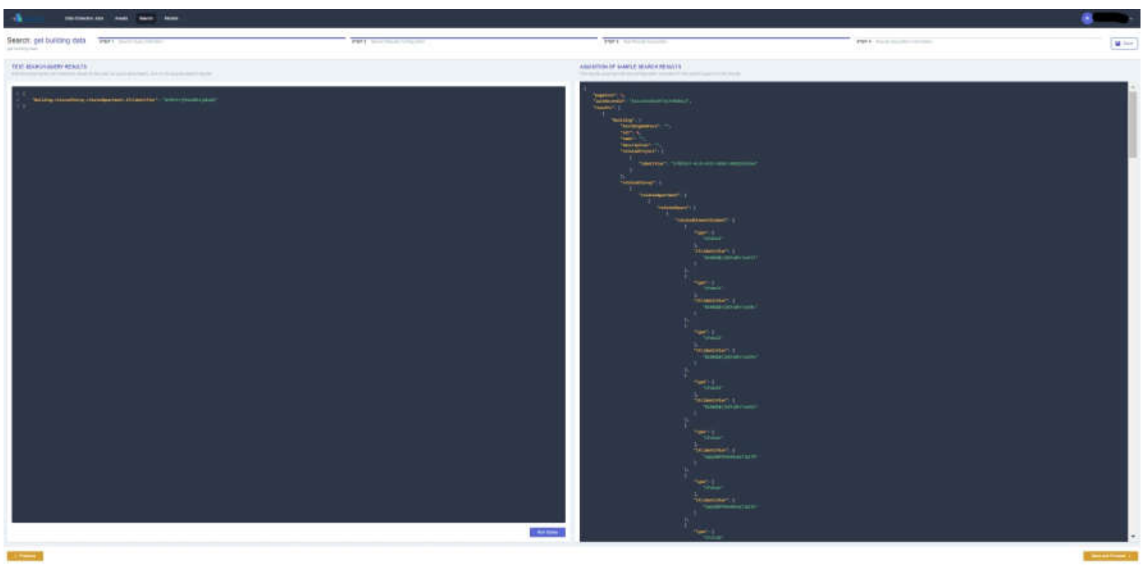


Figure 114. Query preview.

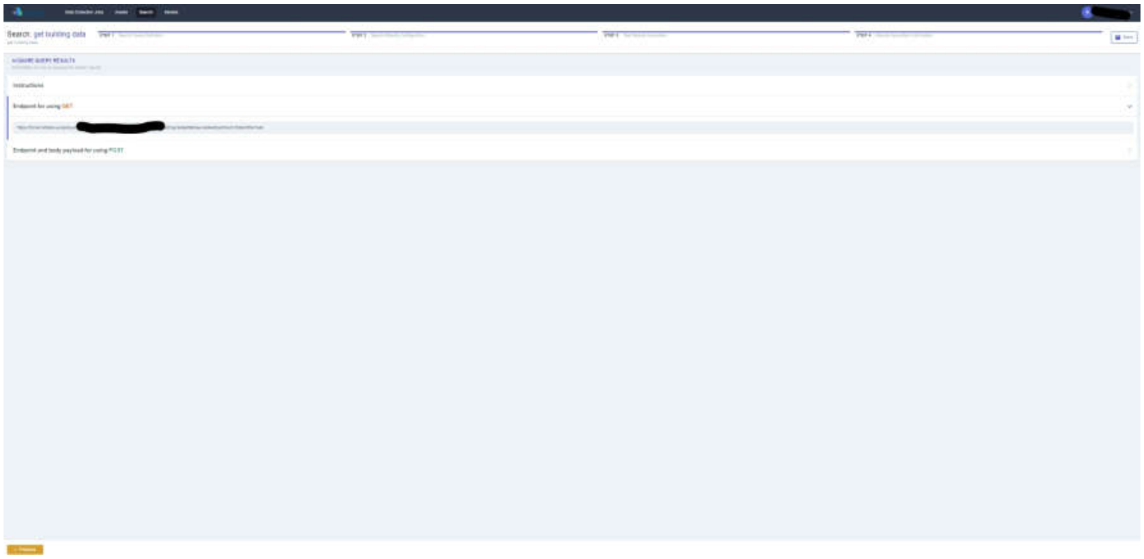


Figure 115. Endpoint provided by BIF for data retrieval.

After receiving the data from BIF, they have been parsed and forwarded to the BICA frontend for visualisation. The rooms list and names have been instantiated according to the actual data (i.e. six rooms, named using simple numbers). In cases of the room type (e.g., bedroom, kitchen, etc.) not included in the data, as in the case of the CONKAT building data used for the pre-validation, the BICA UI displays the message "Type: n/a" in the relevant field depicted in the room's page and the images used in the Rooms list is a generic photo instead of a photo depicting the corresponding type. Regarding the elements, BICA is mainly interested in HVAC and just a subsection of the rest of the building components (more specifically, windows and doors). Thus, from the elements in the building data available during the pre-validation, only those with type ifcDoor were handed over to the frontend for visualization in the components and relevant rooms pages. The elements in the data did not have a 'name' field. For this reason, a convention was followed on the BICA side to autocomplete the name of an element in case it is not included in the data, according to a mapping of types to names (i.e., ifcDoor corresponds to Door) followed by the BICA database identifier of the specific element (a simple number).

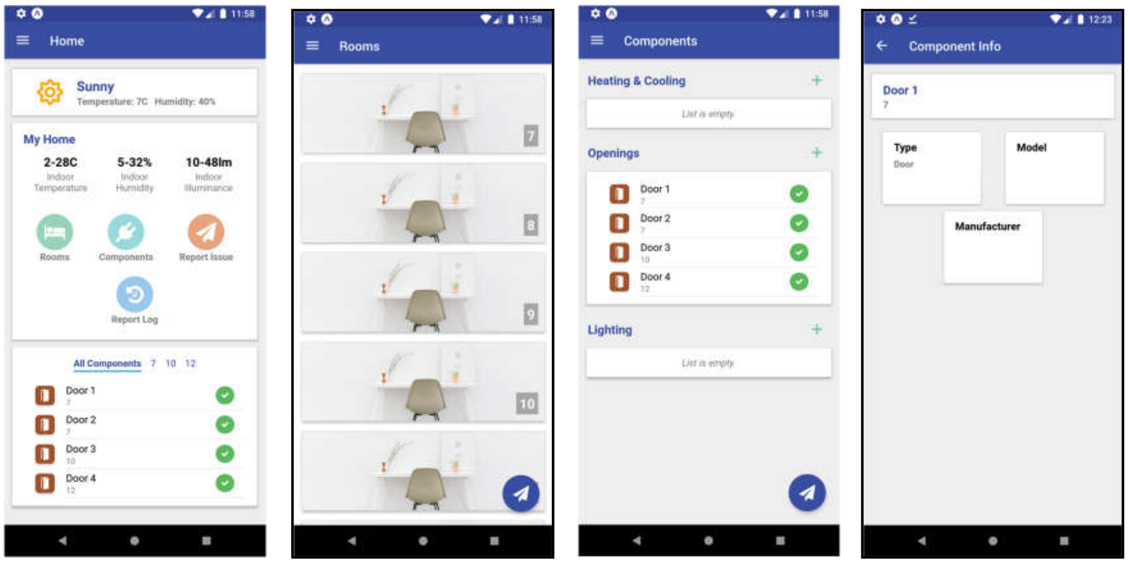


Figure 116. CONKAT rooms and components visualisation in BICA (from left: Home, Rooms list, Components list, Component Info).

4.5.2.2 Issue Reporting and Log

Afterwards the user created a new issue for a specific component. After filling the form and attaching the relevant photos from the CONKAT site, the user submitted the issue, and the backend was updated successfully with the new information. The new issue has been added to the list in the issue report log page of the BICA application.

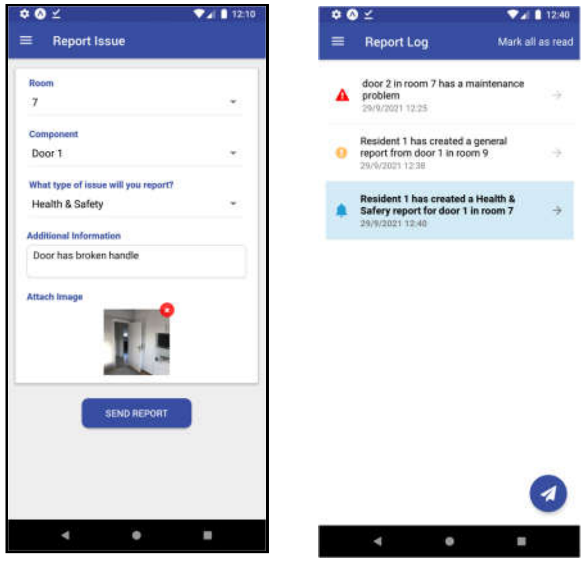


Figure 117. Issue Reporting in BICA (left: issue form, right: report log updated with the submitted issue).

An appropriately configured data collection job in the BIF using the 'Platform's API' method (Figure 118). The BICA backend used the endpoint provided by BIF in the specific data collection job, to make a POST request that activated BIF to collect the submitted information as data and accompanying file, map it to the Annotations data model and add it to the respective data asset, thus making it available to other BIMERR applications (Figure 119).

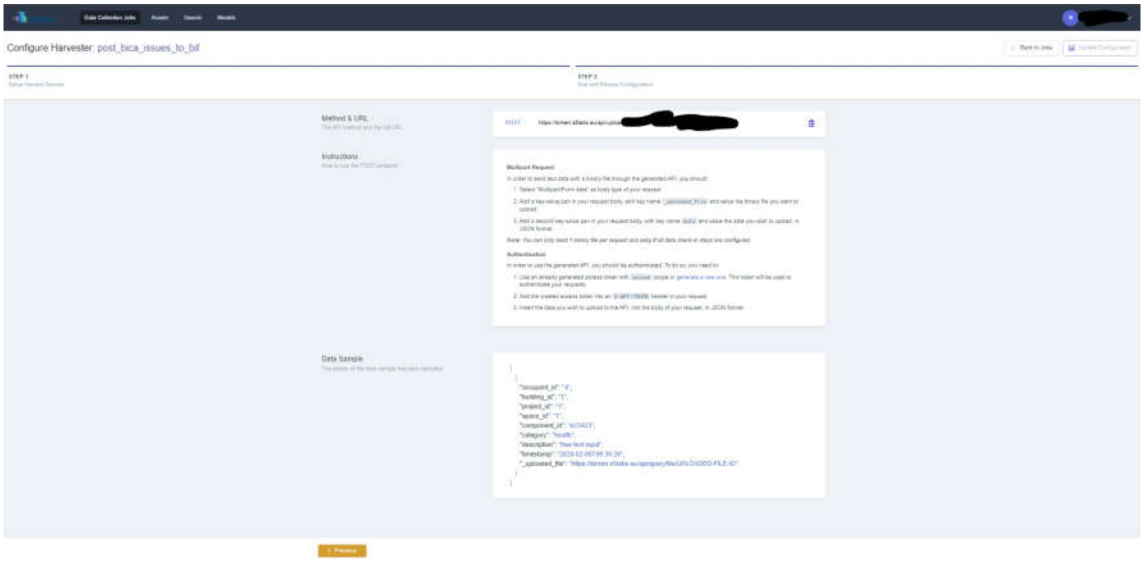


Figure 118. Data Collection Job to send issue data from BICA to BIF: Endpoint and data structure.

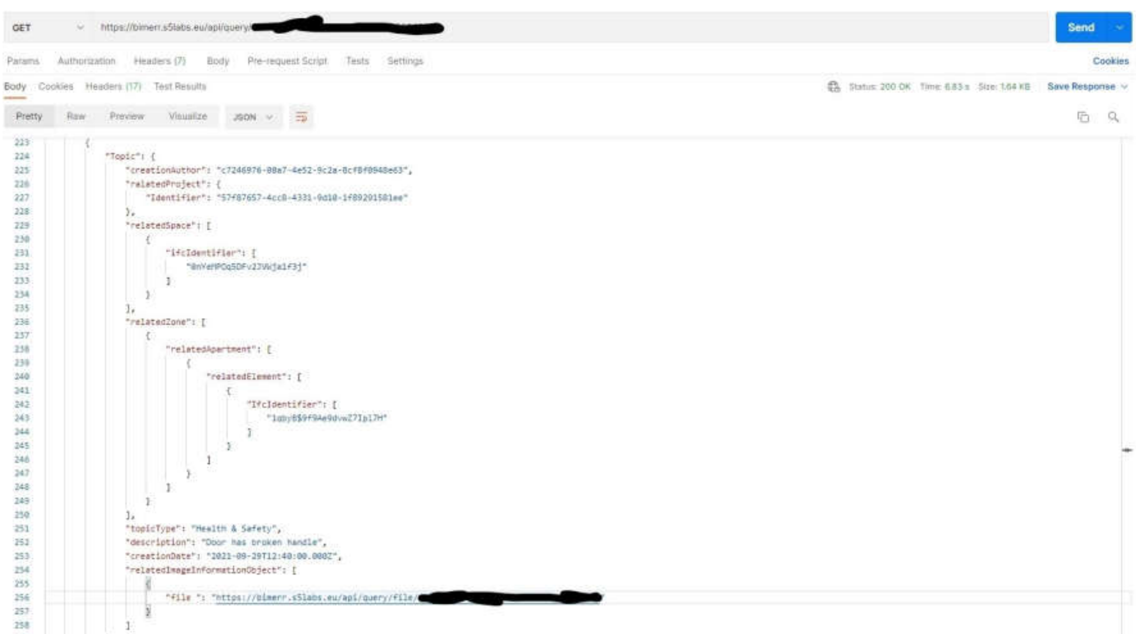


Figure 119. Response from querying the BICA issues data asset in BIF: issue data.

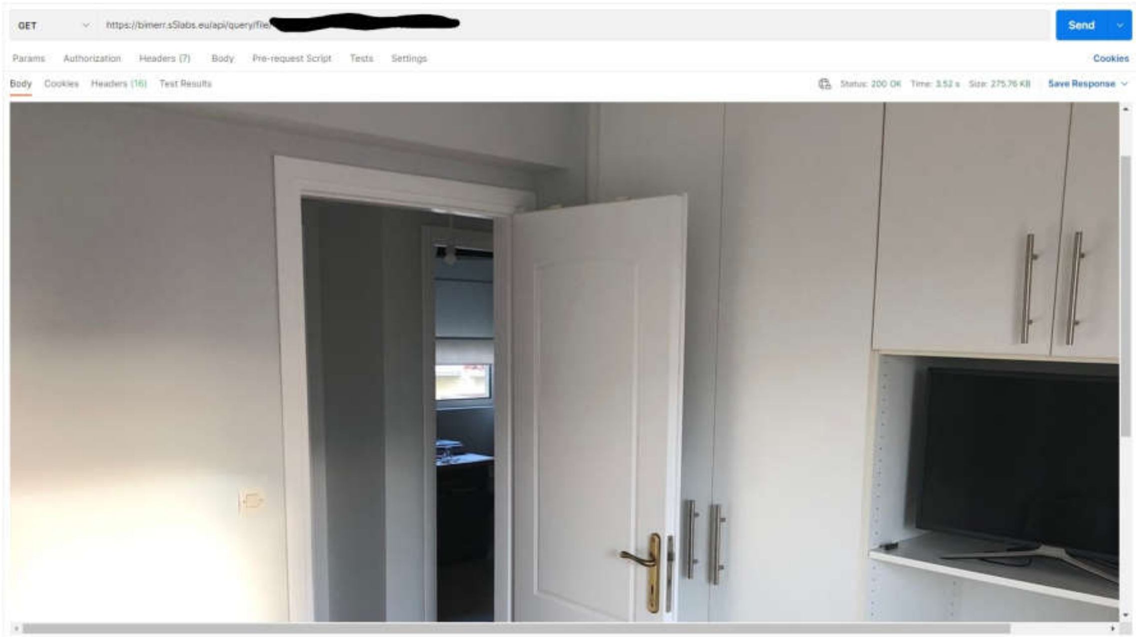


Figure 120. Response from querying the BICA issues data asset in BIF: attached image.

4.5.2.3 COMFORT STATUS UPDATE

The user browsed the rooms of the CONKAT apartment and updated the comfort status to match her actual comfort status. As integration with the rest of BIMERR tools is out of scope for the pre-validation activities, the initial projected comfort statuses were "hardcoded" through the backend.

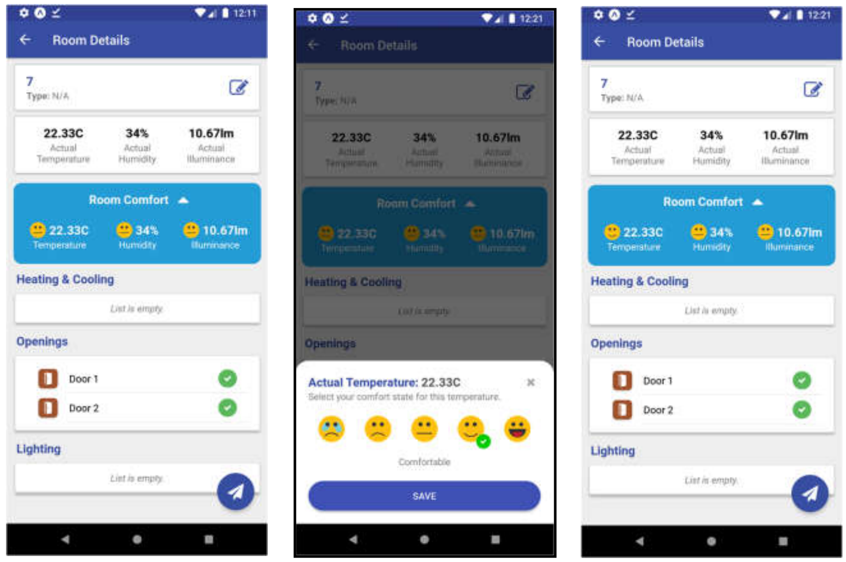


Figure 121. Change comfort status in room (from left: initial comfort, comfort selection, comfort update).

The updates performed by the user were passed on to the backend to update the respective entries with the actual user input, as well as to the relevant data asset in BIF through a configured data collection job, leveraging the Occupancy data model, in order to make the updated information available to any interested application.

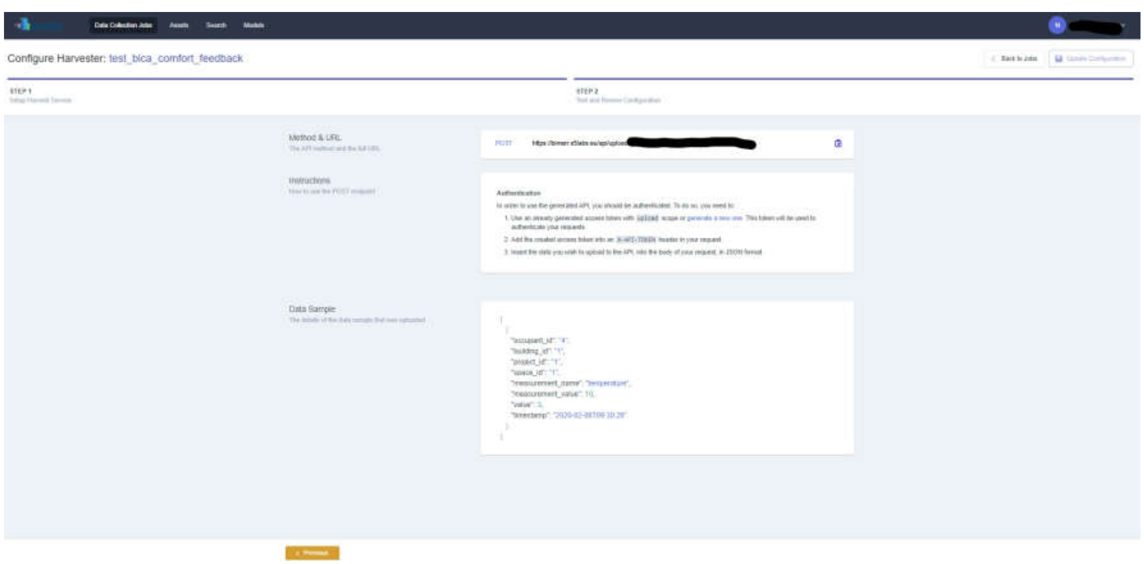


Figure 122. Data Collection Job to send comfort data from BICA to BIF: Endpoint and data structure.

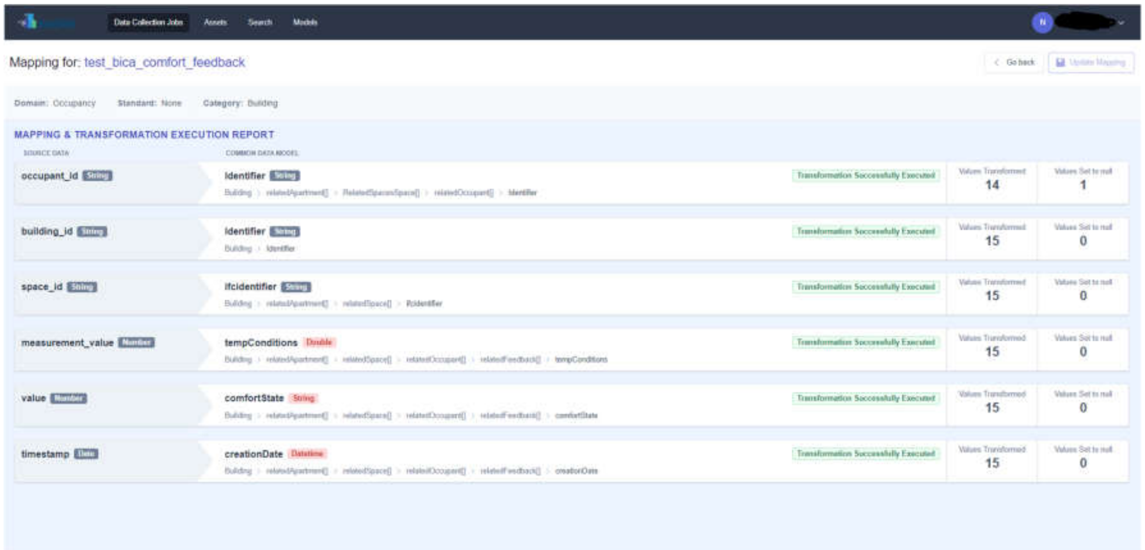


Figure 123. Data Collection Job to send comfort data from BICA to BIF: Mapping.

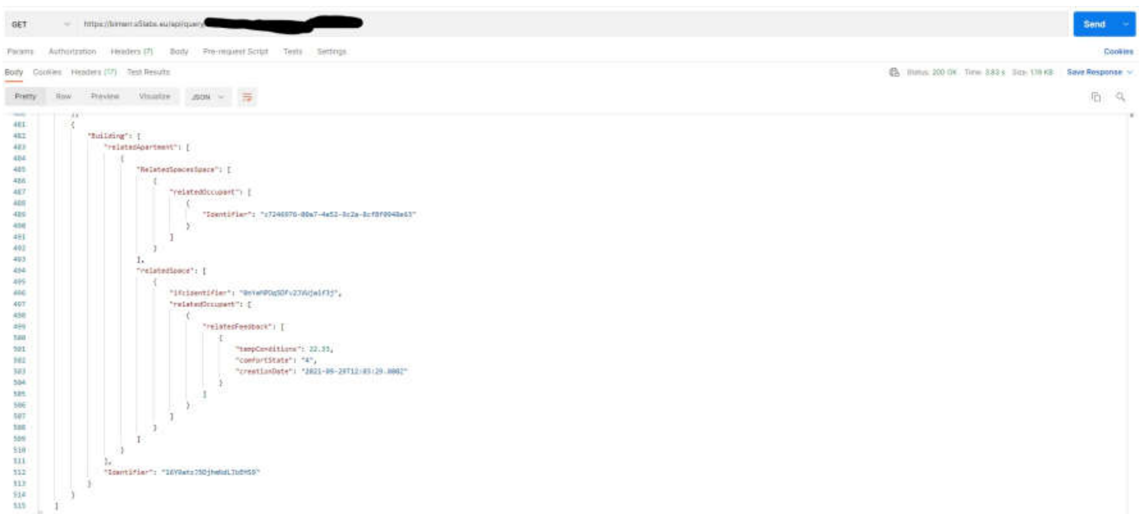


Figure 124. Response from querying the BICA comfort data asset in BIF.

4.6 BEP SIMULATION DYNAMIC DATA – PROFILING RESIDENTS USAGE OF BUILDING SYSTEMS

Having completed the preparation of a valid IFC4 file that includes the second-level space boundaries, materials' thermal properties, internal gains, HVAC components, renewables (optional) and their energy related properties, populated in alignment with the property sets that were introduced in D7.6 [14], another requirement for a successful and accurate energy simulation of the CONKAT building's baseline and potential renovation scenarios was the generation of its dynamic data.

Within BIMERR, these data are provided in a valid obXML form, containing occupant behaviour data for each space acting as predictors of the residents' usage of building systems. This file is generated by PRUBS, accommodating occupants' feedback on the trained models that is collected by BICA and becomes available through BIF. The following subsections present the pre-validation experiments of PRUBS as they were performed in CONKAT building to verify its core functionalities, including the data exchange with other components of the BIMERR ICT system (Middleware and BIF).

4.6.1 Collecting IoT Data – PRUBS interaction with Middleware

With the BIMERR Middleware acting as the IoT data space of the project, a Middleware-to-PRUBS IoT data wrapper has been developed and fully tested on the CONKAT building's WSN setup. This wrapper consists of two main parts: (1) the WoT-to-PRUBS data model's static configuration mapping, executed based on a scheduler every week to take into account any updates on the WSN of the building; and (2) the SenML-to-PRUBS IoT data mapping for the sensor measurement retrieval from PRUBS.

Figure 125 illustrates the results of the WoT-to-PRUBS data model mapping on the CONKAT building's WSN setup. As expected, the generated names of the building (prosumer) and rooms are identical to the ones that were used during the commissioning of the IoT devices (see Figure 85 to compare).

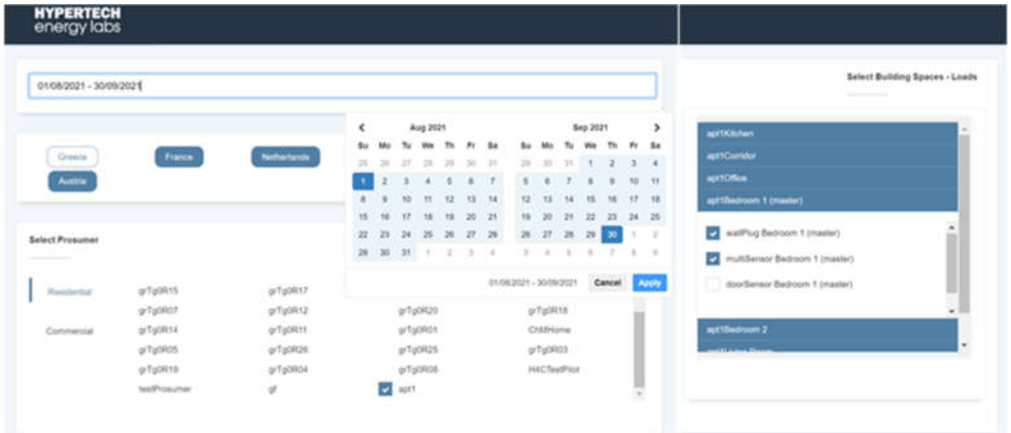


Figure 125. WoT-to-PRUBS data model mapping for CONKAT building (PRUBS data viewer).

Two devices, located in “Bedroom 1”, have been chosen to showcase the results of the SenML-to-PRUBS IoT data mapping: a multiSensor (sensing the temperature and luminance of the room) and a wallPlug (measuring the power consumption of an AC unit that cools/heats that room). As Figure 126 depicts, the IoT SenML data flow seamlessly to PRUBS allowing the collection of data that are used for the continuous maintenance and update of the obXML data.

Figure 126. SenML to PRUBS IoT data mapping for a multiSensor and a wallPlug devices in CONKAT building (PRUBS data viewer).

4.6.2 Occupant Behaviour Models Training and obXML Generation

For each building, the output of PRUBS (obXML) is automatically initialised with a combination of thermal comfort bounds, artificial lighting and electric equipment usage, extracted from standards (e.g. ASHRAE 55, ISO7730) and relevant information provided by the BIM model (relevant guidelines have been provided to include such data in Revit). Whenever meaningful IoT data that represent a season are available, the trained models replace the relevant objects of the populated obXML.

In that sense, although the first bunch of devices in CONKAT building was on boarded in October 2020, due to the pandemic, the building was unoccupied from October 2020 to March 2021. Lack of actual HVAC and other electric equipment power consumption data for that period made the evaluation of the trained algorithms biased, resulting to trained models with excellent evaluation metrics' values. For instance, the FIT[13] values of the trained Gaussian Processes for the Other Electric Equipment Usage prediction were approximating 99.8%. Despite the fact that the results of the trained models were biased for that period, they did reflect the actual status of the building; the co-simulation of the obXML with the BEP simulation IDF (see D7.6 [14]) estimated zero heating demands and thermal comfort boundaries that were significantly lower than the usual temperature setpoint limits.

Since April 2021, more reasonable IoT data has been collecting. In summer, the first non-zero HVAC power consumption data became available and based on the trained occupant behaviour models for that period, the obXML file of CONKAT building was updated

---

[13] $FIT = 100(1 - NRMSE)$, where $NRMSE = \left(\frac{1}{l}\sum_{i=1}^{l}\left(\frac{\hat{y}(i)-y(i)}{y(i)}\right)^2\right)^{1/2}$, $\hat{y}(i)$ the predicted value, $y(i)$ the measured value, and l is the number of samples of the training set.

accordingly. A snapshot of the building configuration and an updated occupant behaviour model in obXML are presented in Figure 127 and Figure 128, respectively.


```xml
<OccupantBehavior ID="obXML" Version="1.3.3">
    <Buildings>
        <Building ID="a14ebdfb-6846-4066-9029-9d391463438a" IfcGuid="16Y9ahzJ5DjhmNdLJbEHS9">
            <Type>Residential</Type>
            <Address>Greece</Address>
            <Spaces ID="apt1" IfcGuid="1u7JA6O4j8GRNLyvlNeDpJ">
                <Space ID="apt1Living Room" IfcGuid="0nYeMPOq5DFv2JVWja1f3j">
                <Space ID="apt1Kitchen" IfcGuid="0nYeMPOq5DFv2JVWja1f3f">
                <Space ID="apt1Corridor" IfcGuid="0nYeMPOq5DFv2JVWja1f3h">
                <Space ID="apt1Bedroom 1 (Master)" IfcGuid="0nYeMPOq5DFv2JVWja1f3r">
                <Space ID="apt1Bedroom 2" IfcGuid="0nYeMPOq5DFv2JVWja1f3t">
                <Space ID="apt1Office" IfcGuid="0nYeMPOq5DFv2JVWja1f3n">
            </Spaces>
        </Building>
    </Buildings>
```


Figure 127. CONKAT building obXML – building, zones, spaces, and their relations.

The Building ID corresponds to the CONKAT's keycloak group id. Having completed the IFC file generation and the building data model population in BIF, relevant metadata values of WoT were set and mapped to the PRUBS data model to properly generate attributes and properties' values of obXML.

```xml
<Behavior ID="BDR_2_TC1">
    <Drivers>
        <Environment>
            <Parameter ID="apt1Bedroom 1 (Master) Temp" Name="Room dry-bulb air temperature">
                <Type>RoomAirTemperature</Type>
            </Parameter>
        </Environment>
    </Drivers>
    <Needs>
        <Physical>
            <Thermal>
                <OtherComfortEnvelope>
                    <ParameterRange>
                        <ParameterID>apt1Bedroom 1 (Master) Temp</ParameterID>
                        <Min>24.05</Min>
                        <Max>27.78</Max>
                    </ParameterRange>
                </OtherComfortEnvelope>
            </Thermal>
        </Physical>
    </Needs>
    <Actions>
        <Interaction>
            <Type>SetToControlValue</Type>
            <Formula>
                <GaussianNaiveBayes>
                    <CoefficientA>26.32</CoefficientA> <!--MEAN-->
                    <CoefficientB>2.21</CoefficientB> <!--STANDARD DEV-->
                    <Parameter1ID>apt1Bedroom 1 (Master) Temp</Parameter1ID>
                </GaussianNaiveBayes>
            </Formula>
            <ControlValue>26.32</ControlValue>
        </Interaction>
    </Actions>
    <Systems>
        <Thermostats>
            <ThermostatType>Adjustable</ThermostatType>
        </Thermostats>
    </Systems>
</Behavior>
```


Figure 128. CONKAT building obXML – trained thermal comfort bounds and Gaussian Naïve Bayes thermostat model for the Behavior BDR_2_TC1.

To make these data available to BICA, and validate their accessibility through BIF, a data collection job was created in BIF, including the mapping of the obXML file to the occupancy data model of BIF (see Figure 129).


Domain: Occupancy Standard: None Category: OccupantBehaviour
MAPPING & TRANSFORMATION EXECUTION REPORT
SOURCE DATA
COMMON DATA MODEL
@ID String
OccupantBehavior > ... > Building > @ID
Identifier String
OccupantBehaviour > relatedBuilding[] > Identifier
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
@IfcGuid String
OccupantBehavior > ... > Building > @IfcGuid
ifcIdentifier String
OccupantBehaviour > relatedBuilding[] > ifcIdentifier
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
@ID String
OccupantBehavior > ... > Spaces[] > Space[] > @ID
Identifier String
OccupantBehaviour > relatedBuilding[] > relatedApartment[] > relatedSpace[] > Identifier
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
@IfcGuid String
OccupantBehavior > ... > Space[] > @IfcGuid
ifcIdentifier String
OccupantBehaviour > relatedBuilding[] > relatedApartment[] > relatedSpace[] > ifcIdentifier
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
@ID String
OccupantBehavior > ... > Occupant[] > @ID
Identifier String
OccupantBehaviour > relatedOccupant[] > Identifier
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
BehaviorID String
OccupantBehavior > ... > Occupant[] > BehaviorID
Identifier String
OccupantBehaviour > relatedOccupant[] > relatedBehavior[] > Identifier
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
@ID String
OccupantBehavior > ... > Behavior[] > @ID
Identifier String
OccupantBehaviour > relatedBehavior[] > Identifier
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
ParameterID String
OccupantBehavior > ... > ParameterID
Identifier String
OccupantBehaviour > relatedBehavior[] > relatedNeed[] > relatedPhysicalNeed[] > relatedThermalNeed[] > relatedParameterRange > Identifier
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
Min Number
OccupantBehavior > ... > ParameterRange > Min
MinRangeValue Double
OccupantBehaviour > relatedBehavior[] > relatedNeed[] > relatedPhysicalNeed[] > relatedThermalNeed[] > relatedParameterRange > MinRangeValue
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0
Max Number
OccupantBehavior > ... > ParameterRange > Max
MaxRangeValue Double
OccupantBehaviour > relatedBehavior[] > relatedNeed[] > relatedPhysicalNeed[] > relatedThermalNeed[] > relatedParameterRange > MaxRangeValue
Transformation Successfully Executed
Values Transformed 1
Values Set to null 0

Figure 129. PRUBS-to-BIF: Data collection job to meet BICA requirements (BIF UI) [8].

For a thorough description of this data collection job setup, we refer the interested reader to Section 3.6 of D5.8 [8].

While BICA requires an obXML to BIMERR occupancy data model mapping to be performed, for the BEP simulation, the whole obXML file is required to setup the co-simulation. To meet this requirement, another data collection job was created in BIF that allows PRUBS to send the latest version of CONKAT building's obXML (or of any other building using the corresponding keycloak group id) in a regular basis (based on a scheduler), to a BIF endpoint (see Figure 130).

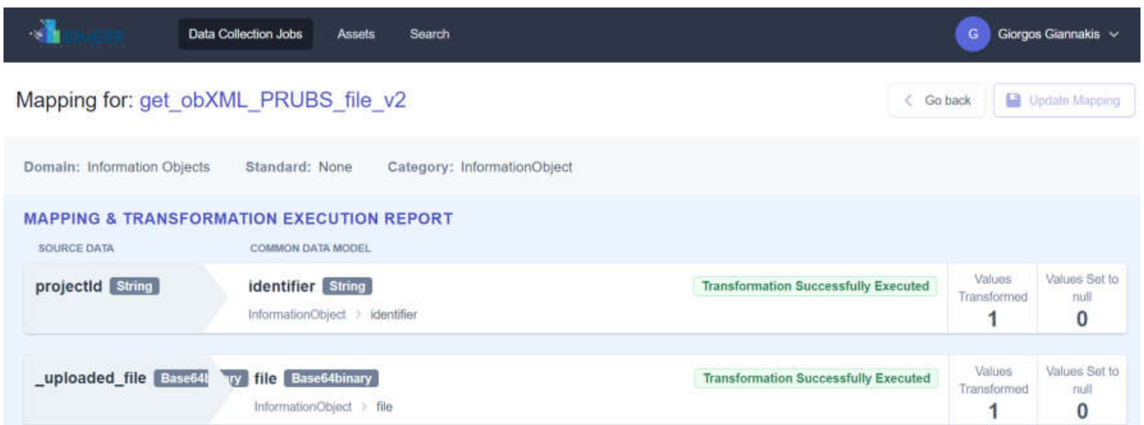


Figure 130. PRUBS-to-BIF: Data collection job to meet BEP-RenoDSS requirements (BIF UI).

4.7 RENOVATION SCENARIOS AND KPIS CALCULATION

The IFC and the obXML file of the CONKAT building (as described in Section 4.4 and 4.6, respectively) was used as input for RenoDSS to (i) extract building material and component information, (ii) enrich this information with missing material information from the BIMERR Material and Component Database, (iii) calculate the baseline KPIs of the building, (iv) generate potential renovation scenarios, (v) calculate renovation scenario KPIs, and (vi) provide the user with tools to compare renovation scenarios by its KPIs.

Figure 131 shows the RenoDSS base data view of the CONKAT building. Material and component properties which are relevant for the energy performance and LCA/LCC analysis were extracted from the IFC file. Missing property values are added by the user manually or by mapping existing materials from the BIMERR Material and Component Database.

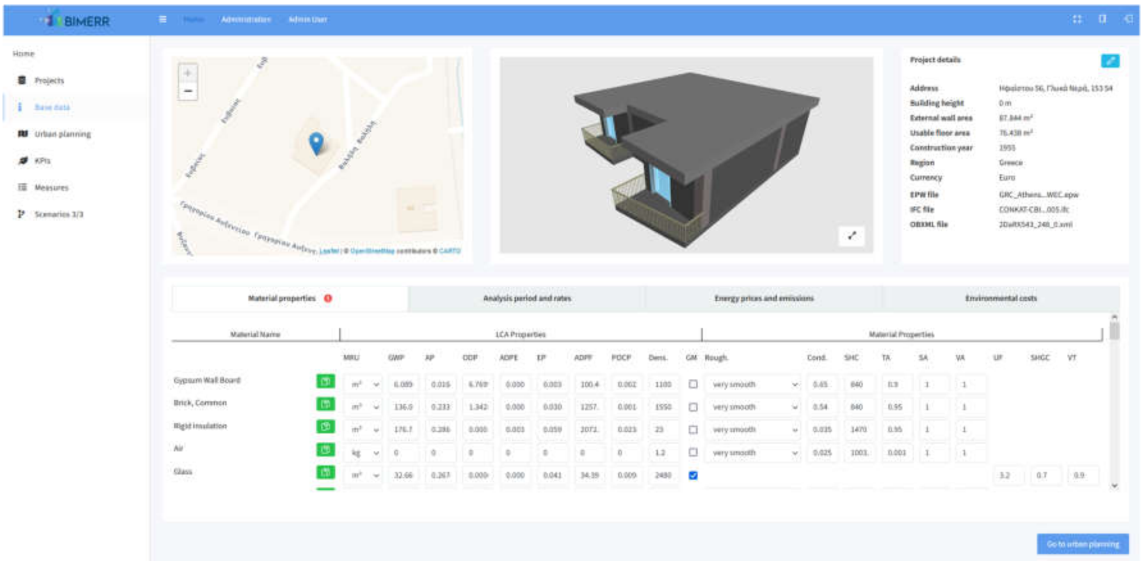


Figure 131. CONKAT base data view.

Figure 132 shows the energy performance and LCA/LCC KPIs of the current CONKAT building configuration. The KPIs are calculated by the RenoDSS BEP and LCA/LCC module based on the IFC file and the provided material and component properties.

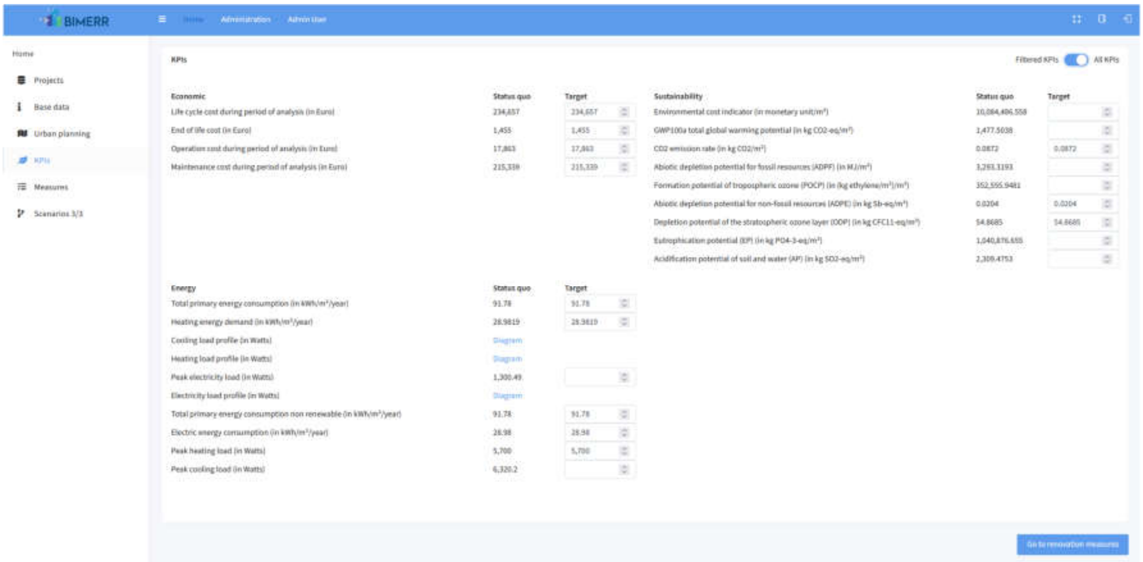


Figure 132. CONKAT KPI view.

Figure 133 shows the renovation measures view, in which potential renovation measures were configured for the CONKAT building. For pre-validation purposes we selected renovation measures from each renovation measure category (wall, roof, solar system, etc.).

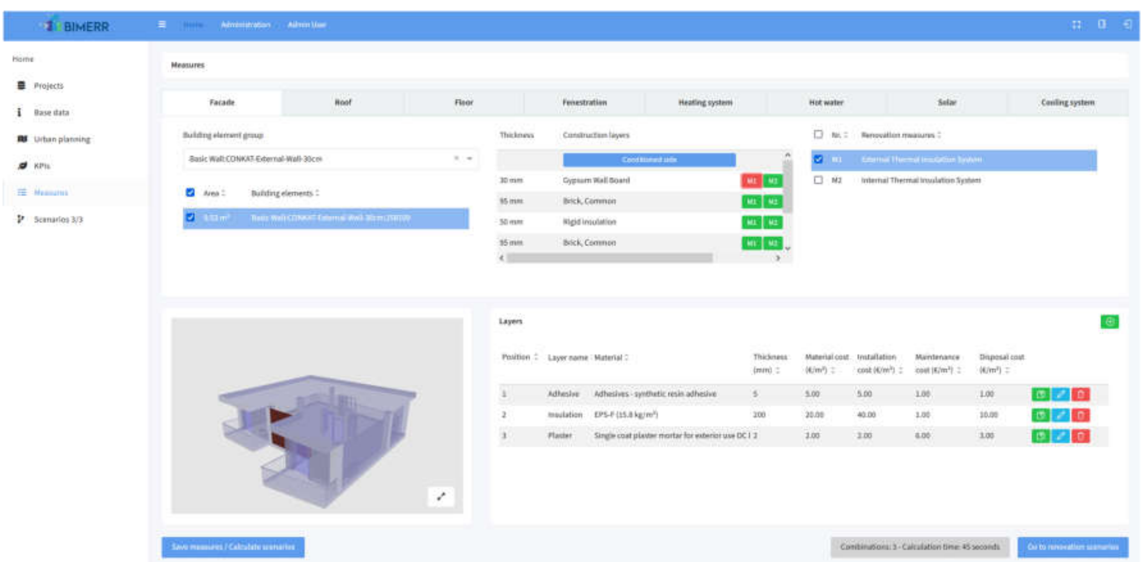


Figure 133. CONKAT renovation measures view.

Based on the selected renovation measures Figure 134 shows the generated renovation scenarios and their KPIs. The KPIs were calculated by the RenoDSS BEP and LCA/LCC module based on the building and component properties configured in the RenoDSS renovation measures view or retrieved from the BIMERR Material and Component Database.

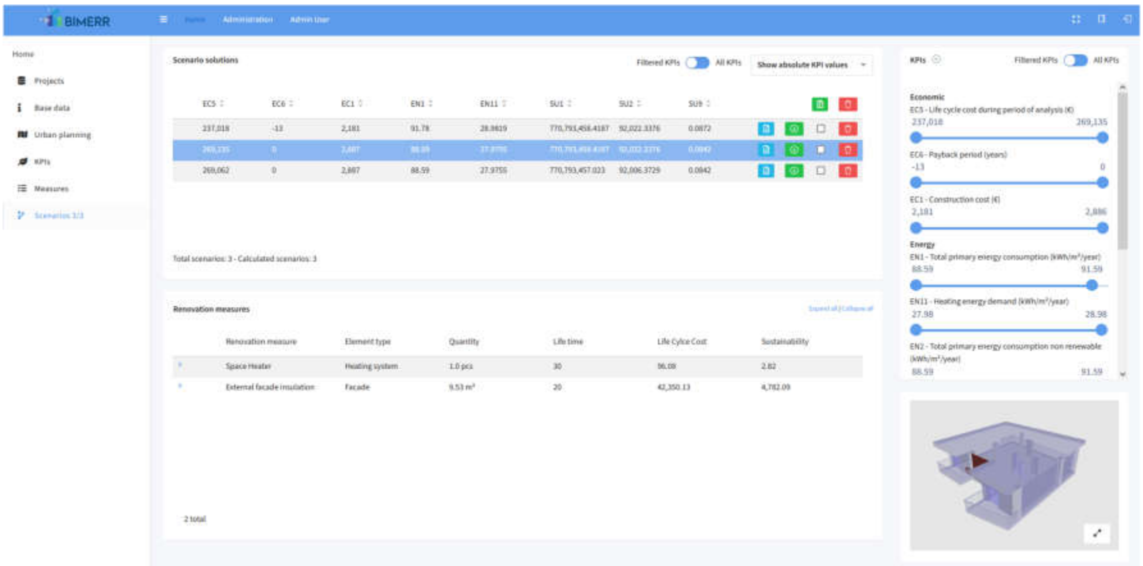


Figure 134. CONKAT renovation scenario view.

4.8 Renovation Process Modelling, Progress Monitoring And Alerting

As mentioned in 3.7, in this subsection are presented the tests that took place in the CONKAT pre-validation site regarding the generation of the Renovation Process workflow, based on the scenario derived from the RenoDSS tool. Furthermore, the tests conducted by the PWMA tool-kit applications (for project managers, construction contractors/ workers and residents) are also described for the same pre-validation site.

4.8.1 Renovation Process Generation

For the pre-validation of the PWMA modelling and simulation toolkit in the CONKAT scenario a demonstrative renovation process model has been created following the process template for the renovation of the outside façade of a building. Different from the KRIPIS scenario, this process involves the installation of insulation panels for the specific project of CONKAT, identified in BIMERR with id 250 (Figure 135).

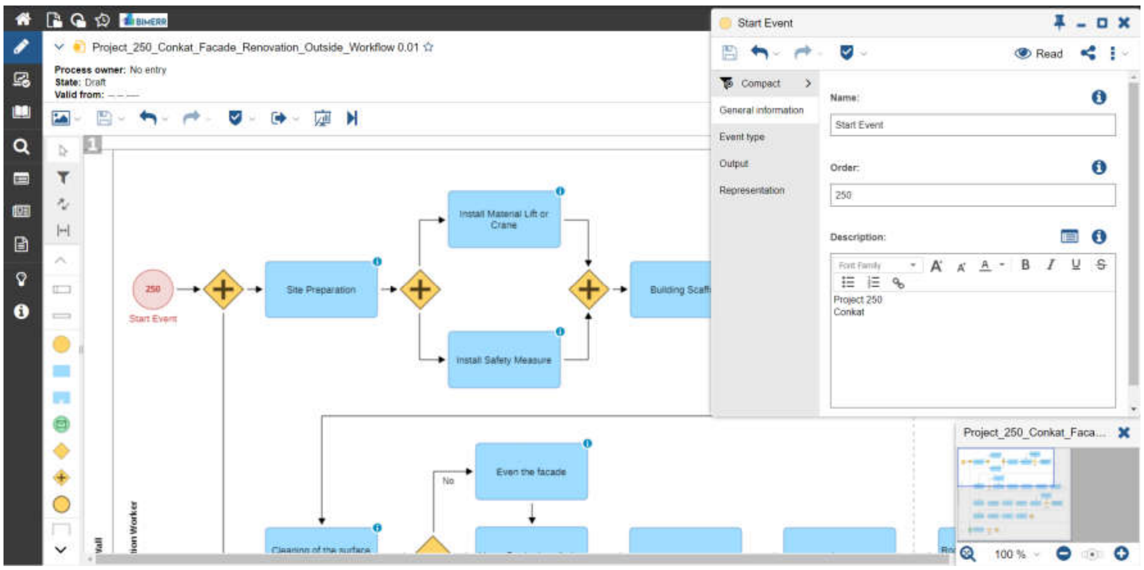


Figure 135. CONKAT renovation process.

Three simulation scenarios have been created also for the CONKAT renovation process with risk factors details for an optimistic, moderate, and pessimistic case, using parameters different from the KRIPIS site and related mainly to weather conditions and supply delay risks. The renovation process simulation has been successfully validated over the three scenarios.

In addition, a specific model for the KPIs related to the CONKAT renovation process has been created and connected with (a) the RenoDSS in order to retrieve the area of the façade to renovate and (b) the PWMA execution engine in order to retrieve the current status of the renovation process. This information will be used in the KPI model as metric for the calculation of a specific and demonstrative KPI, related to the renting cost of the needed scaffold. Like in the KRIPIS case, the integration with the RenoDSS and the PWMA execution engine has been verified also in the CONKAT scenario, correctly retrieving respectively the façade area dimension of the building and the current execution time of the process, using them in the KPI calculation of the scaffolding cost (Figure 136).

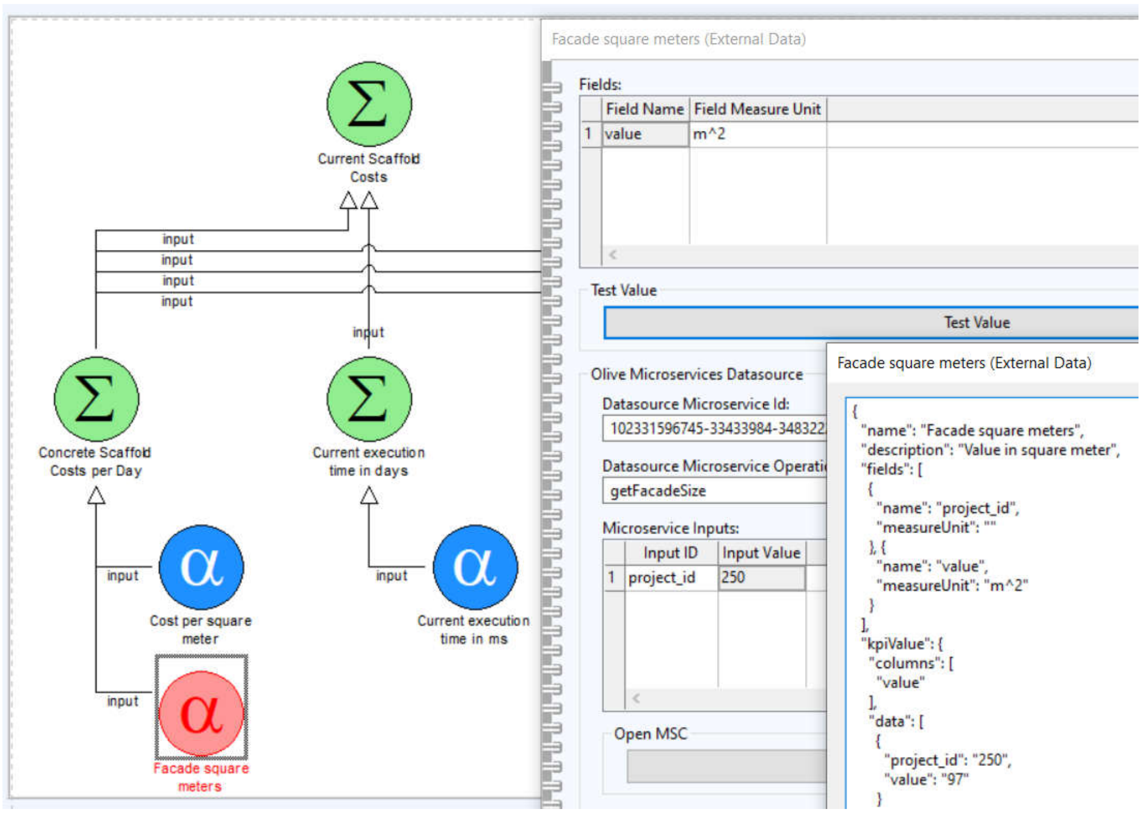


Figure 136. CONKAT KPI model.

The KPI model, as well as the simulation results, have been used as foundation for the definition of a specific dashboard for the CONKAT scenario, where the KPI values are calculated, relying on the information contained in the KPI model and visualized comparing them with the simulated costs and times (Figure 137).

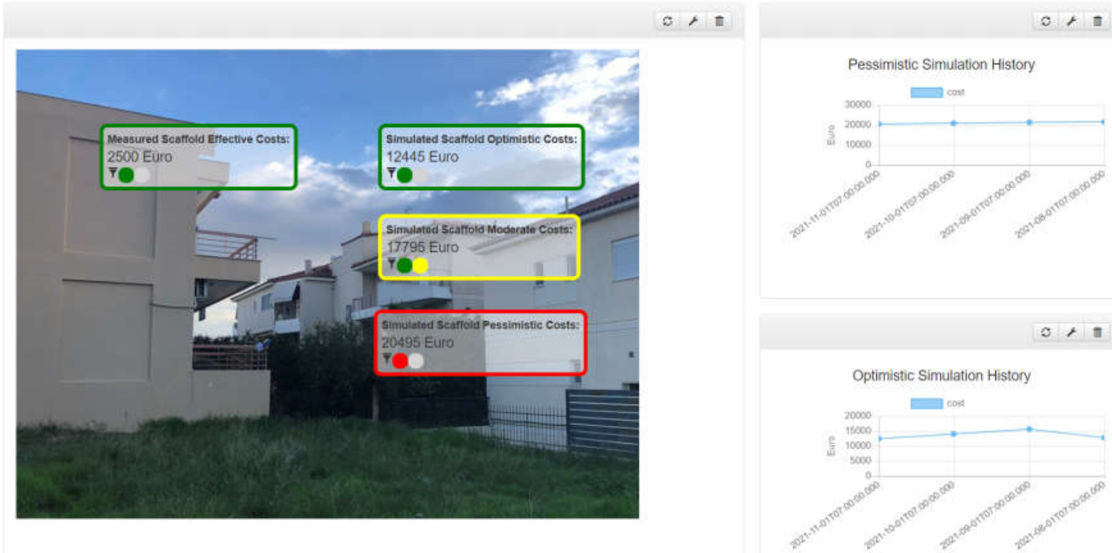


Figure 137. CONKAT KPIs and Simulation Dashboard.

Finally, also for the CONKAT case, a renovation workflow has been created, refining and detailing the process model, and has been sent to the PWMA execution engine validating the integration between the two components.

4.8.2 PWMA For Managers

The CONKAT project provided a similar situation and results as the KRIPIS project (subsection 3.7.2). The workflow was once again gathered using a rest web service and parsed to the system by an internal ETL service. Loading the workflow resulted in a similar data import, albeit somewhat different tasks.

```
                }
            ],
            "name": "Ground Floor",
            "ifcIdentifier": "3_GOL1J6n3NO89DzBVsWqZ"
        },
        {
            "relatedApartment": [
                {
                    "relatedSpace": [
                    "name": "Appartment 2:1529298",
                    "ifcIdentifier": "0iu_CkyFP2FOiYioy2HCw3"
                }
            ],
            "name": "FIRST FLOOR 1",
            "ifcIdentifier": "3_GOL1J6n3NO89DzBVrQoQ"
        },
        {
            "name": "Top",
            "ifcIdentifier": "3_GOL1J6n3NO89DzBVtqz5"
        }
    ],
    "lat": "[40, 37, 0, 119999]",
    "long": "[22, 56, 59, 999999]",
    "ifcIdentifier": "3_GOL1J6n3NO89Dz8W9VFb"
}
```


Figure 138. Example of IFC file's spaces.

4.8.3 PWMA For Workers

Aside from the aforementioned features, the PWMA For Workers also contains a module called Notification System. This system allows users and managers to create and send various notifications and issues. The system itself exists as a standalone component, accessible either from a web browser, or the PWMA App For Workers. It is mainly designed to be used by managers informing and notifying workers about various status changes, upcoming issues, and other information. For better functionality, the users can be grouped into notification user groups.

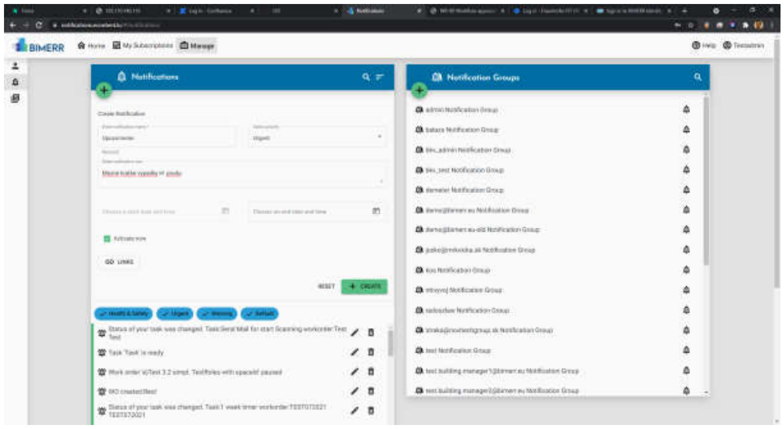


Figure 139. A web browser version of the Notification System frontend.

There are two main sorts of data – notifications and issues. The former being focused on short and direct information bursts without any needing to reply or directly react to the sender. The latter representing a more serious topic needing to be addressed be both or all parties. In other words, issues need to be resolved in some way, while notifications are just information interchanges.

All notifications and issues can be paired to a specific workorder or task. Doing so will automatically inform any relevant party about the context where the specific problem takes place. This allows users to communicate efficiently and straightforwardly. When receiving such notifications, the user can automatically see the relevant workorder or task that is essential for the message. This also allows for a broadcast option, which allows to send the notification to all persons assigned to the particular workorder. This way there's always an option to inform all relevant people about any changes, hazards, unforeseen events, or updates, when they're directly linked to a certain workorder or its subpart.

There is also an option for issues to be labeled as Health & Safety (H&S), bearing a strong priority and warning about safety hazards. Such issues are regarded as the highest priority and must be resolved before resuming the work. Some of them can be regarded as a reminder to focus on the specific hazard, while others can inform about newly occurred safety breaches.

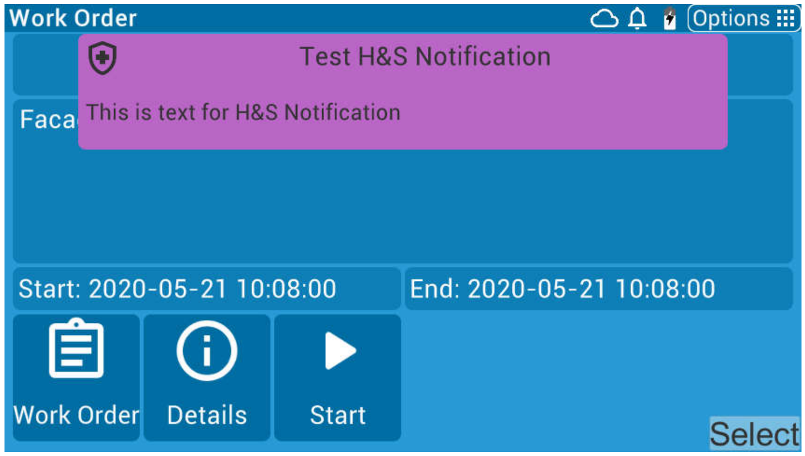


Figure 140. Incoming H&S notification inside the App.

4.8.4 PWMA For Residents

The CONKAT building is a similar case with KRIPIS; therefore, similar tests had to be done on the CONKAT pre-validation site as described in Section 3.7.3 in order to verify the functionality of the PWMA application. Another JSON file containing dummy workorder data was also provided for testing the notifications' part. However, as already mentioned in the relevant Section4.1.1, the CONKAT building contains only one floor; hence the resident should have received all the annotations because all of them were related to him.

Besides the receiving data, the sending data was tested too at this stage. As is depicted in Figure 141, it was also tested submitting issues (uploading comments and acquired photos on site) regarding a malfunctioning thermostat of the apartment, in order to confirm that the relevant data were successfully uploaded to the BIF.

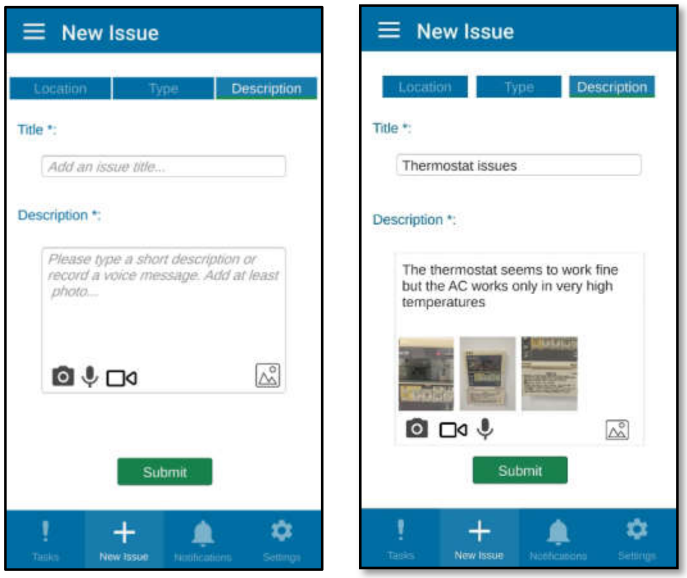


Figure 141. Checking the reporting issues and task commenting function of the app on CONKAT building.

Finally, after all these tests, we concluded that the PWMA For Residents application seemed to function well in the CONKAT pre-validation site.

5. LESSONS LEARNED & CONCLUSIONS

In this section, for each BIMERR tool, a short description of the conclusions reached during the pre-validation phase are presented. The information derived during this stage of the project will be further analyzed in detail in D10.9, in combination with the derivatives and conclusions during the validation sites.

5.1 WSN INSTALLATION

The scope of the installation of the WSN on CONKAT pre-validation site was to identify any potential issues or problems and bottlenecks for the sensors installation, before the major validation activities on a larger scale. Thus, during the installation of the WSN on the pre-validation site of CONKAT several lessons were learned, which will be considered during the preparation, the installation and the operation of the sensors network in the validation sites. Those lessons learned include:

- The paring procedure between the sensors and the gateway could be challenging in some cases. Generally, the sensors are easy to be paired with clear instructions from the manufacturer. Nevertheless, for some sensors provided by different manufacturers the setup is more challenging.
- The paring of the A/C controllers was done with the gateway, but only some limited information and control options were available due to communication issues between the A/C controller provided by Intesys and the gateway provided by Fibaro. More precisely the HCL does not support all the features of the A/C controller. Instead, the HC2 gateway enables full control of the Intesys controller, as Fibaro support informed us.
- In a few cases the internet connection of the HCL was lost, which was resolved with a restart of the router provided by the local internet service provider. This issue was caused by the local internet landline, but to be resolved physical access was necessary for a hard reset. Thus, during the installation in the validation sites, physical access should be ensured, in case any hard reset of the equipment is required.

- Another important issue that should be taken into account during the major installations, is that a specific definition of the name of each room and each sensor should be provided during the sensor commissioning and setup, in order to avoid revisits on-site to clarify which sensor is which, and which IP corresponds to which sensor.
- Finally, form the end-users' perspective, an issue that should be considered is the visual disturbance of the occupants by the LEDs for visual notification installed on each motion sensor. In CONKAT's case complains were made by the occupants for the blinking LEDs, especially during the night. Thus, a new visit had to be arranged on the apartment to change the pre-set of those sensors and turn off the visual notification.

5.2 BIMERR MIDDLEWARE

The pre-validation phase contributed significantly to the development and testing of the middleware. Future projects may benefit from the same and further improve this experience by taking the following into consideration:

- Pre-validation data from the existing KRIPIS site provided valuable input to the implementation and testing of middleware prototypes during early stages of the project when the BIMERR wireless sensor network (WSN) was still in the design phase.
- The requirement gathering and design of a uniform access control mechanism should start at the beginning of the technical activities to produce a secure by design architecture.
- The WSN design of the pre-validation sites should closely reflect the one from the pilot sites. Any technical differences would result in deployments which are not fully tested, leading to high potential for technical failure and increased costs.
- It is important to consider all issues and the experience with respect to the WSN hardware and software in pre-validation as the basis for the design of pilots. Technical issues that may be easy to solve in pre-validation sites tend to get harder by multiple folds in large scale settings.

- Bulk software deployment tooling should be installed and used from the very beginning to be able to easily scale when large scale deployments begin.
- The availability of software connectors and compatibility of sensors should be well studies and analysed before the pre-validation phase.
- The pre-validation experience should be well documented and made available to pilot partners well ahead of the piloting phase.

5.3 SCAN-TO-BIM

The use of different TLS devices for the digital documentation of buildings results in varying outcomes (i.e. point clouds). A number of parameters, either chosen by the user (e.g. resolution) or intrinsic to the device (e.g. accuracy, precision), impact the quality of the cloud delivered by the scanning system, and ultimately the scan-to-BIM algorithm performance. In the particular case of the BIMERR pre-validation sites, two devices of different nature were employed. The KRIPIS Smarthome was scanned by means of a Faro Focus S150[14], whilst the CONKAT apartment was digitized with a GeoSLAM ZEB-REVO[15]. Figure 142 illustrates two zenithal views of the point clouds of KRIPIS and CONKAT sites. It particularly shows the connection between walls. As can be seen, precision is higher in the data provided by the Faro TLS, which delivers a cleaner point cloud. Additionally, spurious points (i.e. noise) appear between walls in the GeoSLAM data, areas that should be empty. The quality of the data affects the segmentation of spaces and, therefore, the identification of wall surfaces.

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[14] https://knowledge.faro.com/Hardware/3D_Scanners/Focus

[15] https://geoslam.com/solutions/zeb-revo-rt/

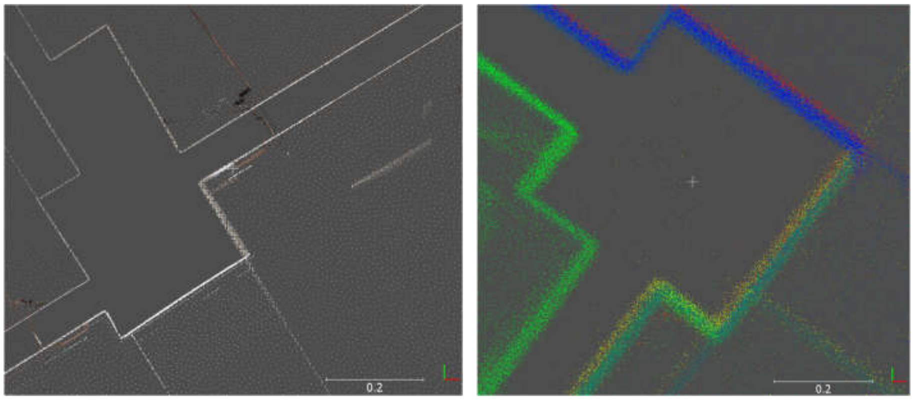

Figure 142. left) Detail of the point clouds delivered by a Faro Focus S150, right) a GeoSLAM ZEB-REVO

Another important aspect to be carefully considered is the pre-processing (mainly registration and cleaning) of the point clouds obtained by the scan. The selection of matching (i.e. corresponding) points in consecutive clouds, for registration purposes, needs to be done with care and the errors, both quantitative (e.g. RMS of the distance between points and their nearest neighbor in the reference cloud) and qualitative (e.g. non-aligned walls) in the resulting cloud after combining the original ones should also be assessed carefully. Figure 143 a) shows the effects of poor registration and cleaning of the original clouds into the spaces created by the Scan-to-BIM tool. After a correct registration of the clouds and removal of noise produced by, for example, specular surfaces, the spaces are more accurately defined by the tool, as illustrated in Figure 143 b).

Figure 143. Detail of the identification of spaces in the KRIPIS smarthome. a) After an inadequate registration of clouds, and b) a correct pre-processing strategy.

Finally, the strategy followed in the Scan-to-BIM tool for identifying openings is challenged in the case of windows or doors that are not opened or occluded (see Figure 144). The latter case however highlights an issue identified in nearly all pilot sites that the data acquisition was not done with knowledge of the scan-to-BIM tool and with clear definition of its requirements. For example, requirements should be stated that curtains should be open or rolled-up, and doors open (e.g. 90 degrees) to ensure the boundary of openings is clear visible in the scans. Similarly, the scanning team should ensure that any visible area of an occluded wall should be scanned to increase the chance of modelling success by the Scan-to-BIM tool.

Figure 144. Detail of KRIPIS top floor, where curtains cover the windows openings

Future work will include the generation of more robust algorithms, potentially based on artificial intelligence, to deliver accurate BIM models less dependent on the quality of the input point clouds. A set of guidelines will also be issued to help ensure that the scanning of a building leads to point clouds more likely to be successfully processed by Scan-to-BIM tools.

5.4 BIMERR INTEROPERABILITY FRAMEWORK (BIF)

The experimentation with BIF enabled applications and the respective partners to perform some early integration activities, even at the pre-validation phase, highlighted certain aspects to be handled in the context of integration activities. More specifically:

- Required updates to be performed or additional concepts added in the data models, using the Model Lifecycle Manager, to cover the data exchange needs of the BIMERR applications.
- Bug fixing to be performed on issues identified by the application during pre-validation, to ensure smooth operation in the actual validation activities in the pilot sites.
- Processes should be defined and agreed by the partners at project level regarding the management and identification of the various versions of a data asset (for

example the various versions of the building data model, as it is enriched and corrected by the BIM-MP and the ARIBFA tools). This most probably will be handled through a convention agreed regarding standard concepts (such as the Project id, or the file version) that should be included within the exchanged data to allow identification versions, and by leveraging on the capability of BIF to update data assets with new records that are “appended” to the existing asset.

- The BIMERR applications should appropriately setup multiple data collection jobs leveraging the functionality of BIF to send data as text accompanied by a binary file with an API request. Multiple requests may have to be initiated in order to work around the restriction of only one binary file per request.
- Data provided by the applications to the BIF need to follow a consistent structure within their whole extent (e.g. the various instances of the same concept are all objects or arrays, but not both), and according to the initial data sample provided during the configuration of the data collection job.

5.5 BIM Management Platform (BIM-MP)

BIM-MP offered successfully its services to support BIMERR’s operations. There were cases however where a number of modifications has to be performed on its tools, to achieve the desired results. These cases included:

- Modifications on GED tool to handle cases where openings were not exported correctly (the opening volumes were extended beyond their wall’s internal or external surfaces). In these cases BIM-MP’s GED tool implemented operations to align the opening surfaces parallel to the parent wall surfaces, which in some cases failed. Consequently, these operations were removed and appropriate opening product families (in which these surfaces were aligned), from the BIM-authoring tool (Revit), were selected.
- The visual inspection of the reported geometric errors using external OBJ viewers was tedious for the designer. The development of the embedded 3D model viewer helped the designer identifying the geometric errors easiest.

- The BIM model correction process involves model checking and geometric checking. BIM-MP produces multiple files for each revision, such as HTML reports, .JSON reports, and geometric error reports in OBJ format. The generated files are better organized in different file repositories per revision and not per project.
- Due to the designer may use external applications to inspect the model, e.g., Solibri for checking the placement of the 2nd level space boundaries, the naming of the generated files is based on ISO 19650 for better management of the local copies.

5.6 AUGMENTED REALITY ENABLED IN-SITU BUILDING FEATURE ANNOTATION (ARIBFA)

The lessons learned for the ARIBFA tool within the BIMERR pre-validation activities were:

- Registration accuracy is difficult to obtain with a single image marker for a large building. For buildings larger than the KRIPIS SmartHome, such as the Spanish and Polish pilot sites, the registration accuracy could benefit by splitting the 3D model to floors and using an image target per floor.
- The keyboard functionality on the Hololens can be tedious for large text. To minimize the keyboard use, drop-down lists are implemented in the menus and the dictation capability is leveraged.
- A strong Wifi network is vital to perform the object detection functionality of the ARIBFA tool, since the Hololens are paired to a local computer on the same network. The faster the network, the smaller the latency to depict the detected MEP components on the Hololens.
- The localization functionality is affected when the user stands at the edge of an IfcSpace. The localization accuracy is very important for the addition of a detected MEP component to the IFC file (since the detected component is added as a child of the IfcSpace where the detection took place). To this end, the users of the ARIBFA tool will be advised not to stand at the edges of two IfcSpaces (e.g., under or very close to doors and windows) when performing the object detection functionality.
- The pre-validation activities led to important conclusions regarding the effect of the speed of the user's movement to the various functionalities of the ARIBFA tool.

The efficiency of the 3D BIM model visualization and the registration accuracy are not affected by the speed of the user's movement. The localization functionality is only slightly affected by the user's speed, especially for quick movements between neighbouring IfcSpaces. The object detection functionality of the ARIBFA tool is strongly affected by the speed of the user's movement since there is already latency in the procedure due to pairing of the Hololens to a local machine.

- The IFC editing functionality is a challenging procedure for the ARIBFA tool, since the application runs on a device with relatively small cpu and ram specifications. When saving the modified IFC via the AR glasses, the user should wait for 2-3 minutes for the export of the IFC file to be completed. This was observed for the KRIPIS building. If the BIM model is split to floors, the time is expected to be decisively reduced.

5.7 PROFILING RESIDENT USAGE OF BUILDING SYSTEM (PRUBS)

The pre-validation activities undertaken within this task contributed significantly to the development, testing and refinement of PRUBS. Demonstration experiments of PRUBS functionalities in CONKAT building, a low-scale residential building, streamlined the communication and data exchange of PRUBS with other BIMERR components (Middleware and BIF) at early stages of the project implementation phase.

For instance, to perform the co-simulation between EnergyPlus and the obXML, as it has been described in D7.5, the obXML must be populated in a way that information about the IfcSpace, IfcZone and IfcBuilding GUIDs is included. According to the respective XSD schema, obXML can capture such data, while PRUBS is capable to populate it. Specific data requirements and guidelines were communicated to the Middleware developers so that the BIMERR metadata of the WoT, generated by the Middleware Registry, would be capable on providing information about the relevant attributes (IfcSpaceID, IfcZoneID and IfcBuildingID – see Section 3.1 of D5.8).

As far as the PRUBS trained Occupant Behaviour models' accuracy and validation are concerned, a representative dataset needs at first to be collected. Due to the pandemic, the extraction of such datasets was a non-trivial task that may result to faulty interpretations about how the building systems usually operate. For that reason, this subject and relevant results are going to be investigated in the context of T8.3 – *End-to-end ICT System Integration Testing & Refinement* [15].

5.8 BUILDING INFORMATION COLLECTION APPLICATION FOR BUILDING RESIDENTS (BICA)

The overall testing of BICA functionalities with data from the CONKAT building has been successful. However, as the pre-validation activities included the testing in an "isolated" manner (i.e., without the exchange of data with the other components) the following points are still pending and will be addressed in the context of the BIMERR integrated platform:

- The complete workflow of user authentication/authorisation and identification of the relevant apartments, involving Keycloak that will be instantiated with the residents and their respective apartment/zone ids.
- The retrieval of sensor data from Middleware and the identification of those that apply to the specific BICA user using the provided Keycloak token.
- The retrieval of the specific user's estimate comfort status from BIF through the setup of an appropriate search query that will utilise the Occupancy data model (based on data coming from PRUBS).

5.9 RENOVATION DECISION SUPPORT SYSTEM (RENODSS)

The lessons learned within the BIMERR RenoDSS pre-validation activities at the KRIPIS and CONKAT sites were the following:

- Mapping missing building material properties (e.g., sustainability information of insulation material) is sufficiently supported by the BIMERR material and component database - similar materials could be mapped to the materials used in the current building configurations.

- Mapping missing building component properties (e.g., sustainability information of ac units) was not a straightforward process as components differ a lot depending on their release year and the market they were launched in - within the pre-validation activities we started to obtain detailed data about the components from the manufacturers and enrich the BIMERR material and component database with this information.
- It was hard to obtain the financial data of existing material and components for the LCA/LCC module (maintenance cost and disposal cost) - as there was no clear information source these values had to be estimated.
- While RenoDSS provided renovation measure materials out-of-the-box, renovation measures components had to be added for the specific buildings (e.g., a heating system that fits the building).
- Although the setup, i.e., entering/mapping missing building material data and configuring the renovation measures takes around eight hours per building, the automated renovation scenario generation and KPI calculation compensate, compared to manual or semi-automated scenario generation and KPI calculation, the initial setup costs.

5.10 BIMERR Process & Workflow Modelling And Automation (PWMA)

5.10.1 Renovation Process Generation

Regarding the Renovation Process Generation activities in the KRIPIS and CONKAT pre-validation sites we can conclude the following:

- The integration with the PWMA execution engine component has been successfully validated.
- The integration with the BIMERR RenoDSS Toolkit has been successfully validated.
- The simulation component of the PWMA could use predefined simulation parameters for each process template that need only minor adaptations when a specific renovation process, that is instantiated from that template, must be simulated. This will simplify the definition of the simulation parameters.

- The usage of predefined template for the renovation process models reduced significatively the effort required in the definition of the two scenarios. Additionally, we saw that the same templating approach could be applied also to the KPI model that, in case of common KPIs, can accelerate the modelling process reusing existing knowledge.

5.10.2 PWMA For Managers

During the implementation of both projects, the PWMA For Managers deemed to be sufficient and effective as a general tool for managing workflows, workorders, and users. The only issue that prevailed was an unfinished integration of the BIF component, anticipated in the next months in the context of T8.3 activities. The data exchange had to be improvised and manually done in these cases, which should not be a problem in future project, as the full integration is in the works.

Aside from the BIF integration, no further issues or problems were found, which resulted in a positive lesson learned – the PWMA For Managers provides an effective and seamless experience for managers, allowing them to efficiently manage the work, data, and persons of interest.

5.10.3 PWMA For Workers

Regarding the PWMA For Workers application, there were no major issues to be found during the two projects. The workorder loading and execution worked fine without any apparent problems. The Notification System also didn't expose any design or implementation flaws and provided a seamless and effective usage. Overall, the lesson learned is that both the Worker's application and Notification system are sufficient for the work in the field, provided that the users are introduced to them and taught the work routines within them.

5.10.4 PWMA For Residents

The lessons learned for the BIMERR PWMA For Residents application during the pre-validation activities at the KRIPIS and CONKAT sites were the following:

- The management of the received data worked well and all the data related to the user were displayed during the functionality tests in the pre-validation sites. However, the application should be further tested to meet the requirements within the integrated BIMERR solution.
- Regarding the issue reporting and task commenting functionality, the data was collected successfully and prepared properly for uploading it to BIF. However, uploading multiple attachments per issue is a functionality that should be further tested in the integrated BIMERR solution.

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