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1. EXECUTIVE SUMMARY

The BIMERR project will provide as a final result an ICT-enabled Renovation 4.0 toolkit consisting of tools that work together towards supporting the renovation processes of existing buildings. Therefore, task T3.5, whose first outcomes are reflected in this document, is of high importance. This initial version of the BIMERR system architecture reports on the definition, specifications and functionalities of BIMERR main tools and their interactions.

The BIMERR platform is built upon the goal to provide a vertical solution to efficient building renovation through the use of BIM modelling, energy efficiency monitoring through IoT sensors, simulation and analytics on the implementation of different renovation measures and the provision of concise recommendations and tools to different stakeholders in the renovation process to facilitate an optimal and cost-effective solution while keeping both residents and workers safe and informed at all stages. To that effect, the architecture of BIMERR consists of 5 main components:

- The **BIMERR Interoperability Framework (BIF)** is responsible for the storage, manipulation and interconnection of all other BIMERR components. It provides services for the semantic data modelling of building information, secure provisioning of building information, query building facilities and the enrichment of raw data
- The **BIMERR Middleware** handles the connectivity of IoT sensors, the aggregation of raw data from different networks and protocols, the processing of this raw data in order to anonymize them and then hand them over to the BIF, which in turn propagates them to the rest of the system components
- The **Digital Building Modelling Tools** are responsible for the generation, visualization and profiling of building data models in order to support the renovation simulations, operation process management and support of different actors within the building
- The **Renovation Support Tools** provide energy/cost/Life Cycle Assessment as well as process management and a multi-level decision support system that allow workers and project managers alike to optimize the renovation process both in the planning stage and on a day-to-day operations basis.
- Finally, the **BIMERR UIs** consist of all the end-user oriented applications that use the components outlined above to provide access to the information generated within them. These UIs include online interfaces to the data provided by BIF, visualization of Renovation Simulation, process management applications, resident and worker support mobile and web apps and more.

This deliverable has been strongly supported by previous tasks of WP3 results. Specifically, it used as inputs the defined use cases and requirements of the stakeholders from T3.1, the survey of existing data models and ontologies from T3.2, the evaluation methodology from T3.3 and the analysis of regulations and markets from T3.4. The purpose of this task is to define the architecture of the BIMERR solution, which will be updated in the D3.6, and to describe in detail all the components of the platform and their functionalities. In particular, this report introduces the initial architecture of BIMERR framework and simultaneously displays the information flow between the different key components. Moreover, the processes specified in each use case through detailed sequence diagrams are presented, while the structure of each component that composes the overall architecture is highlighted, including the functional and technical specifications, the APIs that use for the communication between them, and finally its software and hardware requirements.

This report is a thorough effort to define the system's architectural design. The design follows an iterative approach, so it is expected to be updated and finalized in more detail in the course of the development phase of BIMERR ICT modules in D3.6.

2. INTRODUCTION

2.1 SCOPE OF THE DELIVERABLE

This deliverable provides a high-level overview of the BIMERR software architecture, presenting the functional and technical specifications and the detailed design of the individual components. It defines the complete set of system requirements, both the functional and non-functional. Moreover, the deliverable addresses the knowledge transformation of use cases and requirements into concrete components and high-level interactions, which take place between the users and the components.

With regards to the latter, the deliverable describes the basic functionalities of the components of the BIMERR system. The identification of the major system components, along with their corresponding subcomponents are included in the description of the architecture. Moreover, internal interactions between subcomponents and external communication with other components, using appropriate interfaces, are also highlighted. In general, every component is described with the presentation of its architectural internal design, containing description of its functionality and interfaces as well as the software, hardware and communicational requirements, finally making the functional and technical specifications clear.

2.2 STRUCTURE OF THE DELIVERABLE

The aim of the deliverable is to describe the BIMERR's Conceptual Architecture Design, Modules Functional and Technical Specifications as well as the Detailed Design of Individual Components of the System. In order to tackle successfully each task, the report is structured as follows:

The first part of the deliverable presents the principles and methodology that have been followed to achieve and document the architecture as well as the relations to other activities in the project. The methodology used in the design phase of architecture is introduced in Section 2.4. This process is influenced by the system requirements as they represent the stakeholders' needs. In Section 3, the conceptual architecture of the BIMERR framework is introduced. It consists of the structural view, describing the core components of the system in the form of software modules, and dynamic view, which presents the already defined use cases with the corresponding sequence diagrams. The purpose of the sequence diagrams is to clarify how the BIMERR system will operate and which components are responsible for each task. Section 4 contains the descriptions and specifications of each architectural component, including their functionality, APIs, software, hardware and communication requirements, and their relevance with the corresponding use cases. The main body of the deliverable is concluded with Section 5, where the implementation, integration and deployment planning for each component is outlined. In addition to the main document, this deliverable also contains 5 Annexes. The data handling methodology, data protection policies, privacy issues and the provisions for GDPR are being addressed in Annex I while Annex II covers the data protection impact analysis. Annex III contains the

list of provisional services that will be updated, finalized and presented in greater detail in the final version of this deliverable, while the template used in order to gather the component descriptions is included in Annex IV.

2.3 RELATION TO OTHER ACTIVITIES AND DELIVERABLES

T3.5 refers to the design and development of the whole BIMERR ICT system architecture and it completes the WP3. It defines the high-level architecture of the BIMERR system as well as the specifications of the major components, including their functionalities and interactions. It also presents external systems that will be deployed and the information that will be exchanged in order to identify personal or sensitive data.

As it would be expected, T3.5 associates deeply with the rest of WP3 tasks. Specifically, it receives from T3.1 the requirements of the stakeholders and the use cases that define the aim of the BIMERR solution. T3.2 provides a survey of existing data models and ontologies, which some of them will be used by the ICT tools and they will affect the design of the BIMERR Interoperability Framework. Moreover, the necessary input parameters for the calculation of the KPIs will be specified on T3.3 that must be included on the design of architecture to measure the impact of BIMERR ICT Tools on the renovation works. T3.4 introduces limitations on utilizing existing technologies due to legal and regulatory frameworks affecting the proposed architecture of T3.5. Except WP3, WP2 also provides input to T3.5, through T2.3, by outlining and choosing the way the data collected and generated will be handled.

By determining the BIMERR system architecture, the high-level structure of each component is presented enabling their development by taking into consideration the limitations and requirements which are specified in this document. Therefore, most of the tasks of the WP4 - BIMERR Interoperability Framework, excluding T4.1, all of the tasks of WP5 - As-is Building Information Extraction & Model Population Tools, WP6 - Process Management Tools & End-User Apps for On-site Stakeholders, WP7 - Renovation Decision Support System and T8.2 of WP8 - ICT System Integration, Testing & Pre-Validation depend on T3.5 and will use the outcome of this deliverable.

2.4 ARCHITECTURE PRINCIPLES & METHODOLOGY

This section analyzes the principles and methodology that have been adopted to define the BIMERR architecture. The architectural descriptions detailed in this report includes the first consolidations of dependencies, input and outputs interactions and specifications of the complete set of components. Regarding the definition of BIMERR architecture, an iterative approach is followed in order to further refine the system with more detailed and specific description. The task uses 2 iterations. In this

deliverable, the first version of the architecture is presented, while the architecture will be finalized in the second iteration on M20.

The description and design of the BIMERR architecture has been based on the international standard IEEE 42010 "Systems and software engineering - Architecture description". This standard indicates that the whole process is based on a set of relevant elements, such as architecture views and viewpoints. The architecture definition methodology has involved three main phases, starting from the stakeholders requirements and evaluation methodology definition, as well as from the extraction of information related to the available data models, ontologies and market conditions, following with the description of a high-level architecture view, consisting of structural and dynamic view, towards the final detailed descriptions of the architectural elements comprising the BIMERR solution, as depicted in the Figure below. As it can be observed, the whole methodology is an iterative procedure, as inputs such as stakeholder requirements or market conditions may be altered or redefined several times on project's lifecycle.

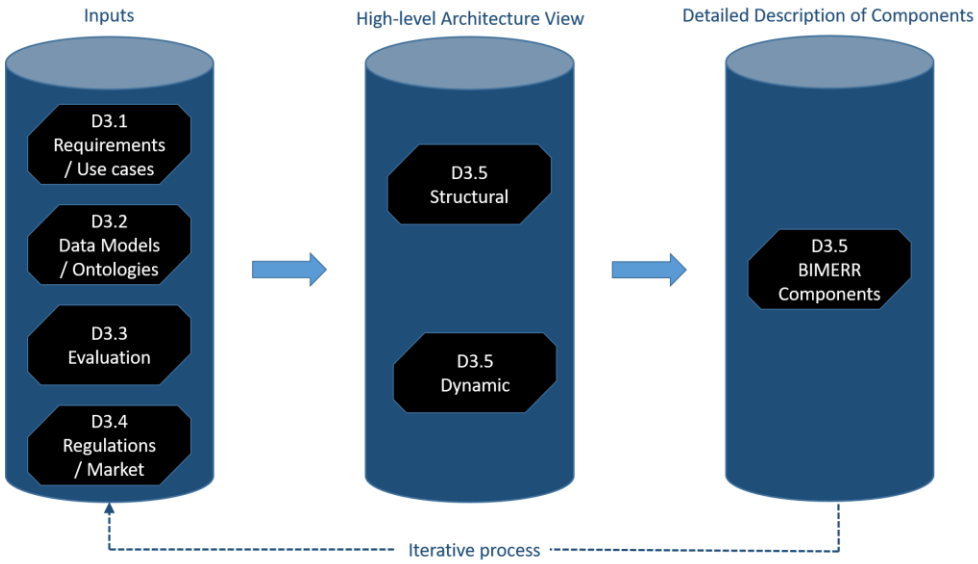

Figure 1: Design Methodology for System Architecture

The BIMERR architecture should be accurately defined and separated into distinct components, so that the stakeholders will be able to exploit the different offered functionalities of the proposed system. Several technologies will be employed in BIMERR, either open source or commercial, and it is crucial to keep these technologies independent to implement the architecture. A set of design principles have been followed on the description and definition of BIMERR architecture to minimize the complexity, cost and maintenance requirements, while simultaneously promotes usability, extendibility and modularity. These principles are the following:

- **Minimize upfront design**

Redundant design of components and functionalities should be avoided, especially in the early stages of design process. Following this principle leads to less time spent on each release, while it allows the better development of the main features of the system. It must also be taken into consideration that the design is likely to change over time, so the system architects should refrain from making a complicated and large design effort.

- **Separation of concerns (SoC)**
  The system's components should be divided into specific features with as little overlap in functionality as possible. This principle aims to avoid the interdependency among components to facilitate the maintenance of the system, to minimize interaction points, and lastly to achieve increased cohesion and low coupling.
- **Principle of Least Knowledge**
  Any architectural element should not have the knowledge about the internal details of other components or direct access to them. The adoption of this principle could help maintainability and avoids interdependency.
- **Don't repeat yourself**
  The same functionality or intention should not be repeated, but it must be specified in one place only. Duplication of functionality within an application can make the implementation of changes a difficult process, while it can decrease clarity and introduce potential inconsistencies.
- **Single Responsibility**

3. HIGH-LEVEL ARCHITECTURE

3.1 STRUCTURAL VIEW

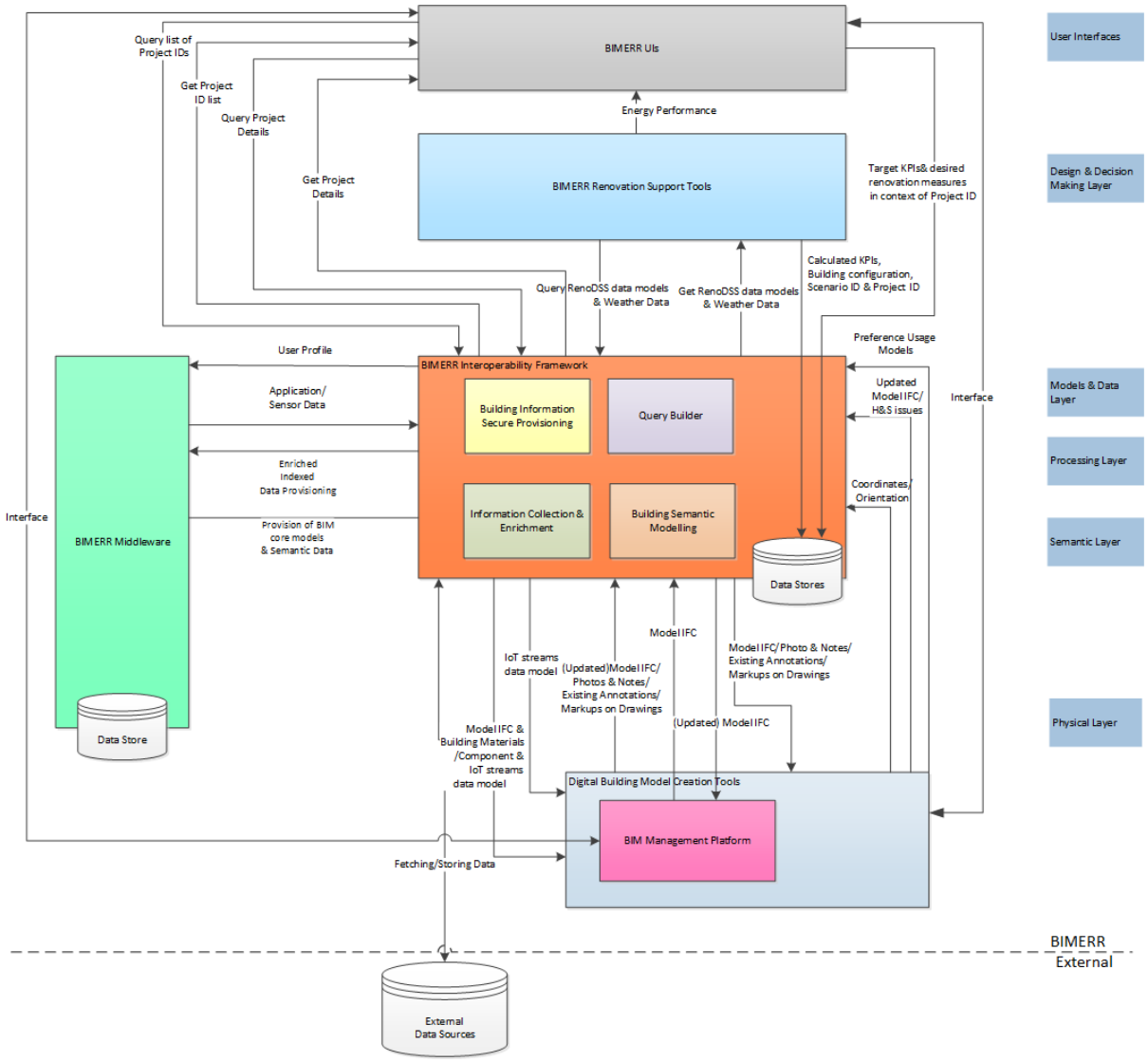

Figure 2: BIMERR High – Level Architecture

This section provides an overview of BIMERR Architecture's structural view presented in Figure 2, while introducing the layers and components that make up BIMERR's platform. Each component connections and functionalities will be thoroughly examined and explained in the following chapters. BIMERR architecture is composed of BIMERR Middleware, BIMERR Interoperability Framework, BIM Management Platform, BIMERR Renovation Support Tools, Digital Building Model Creation Tools and BIMERR UIs. It contains six different layers, the physical, semantic, processing, models and data, design and decision making layers and lastly, the user interface. The physical layer consists of the Digital Building Model Creation Tools and the BIM Management Platform. The semantic, processing, models and data layers, all three of them, contain the BIMERR Interoperability Framework. Design and

decision making layer corresponds to BIMERR Renovation Support Tools, while user interface to BIMERR UIs. BIMERR also communicates with external data sources through BIMERR Interoperability Framework that does not belong to the BIMERR architecture.

3.1.1 BIMERR Middleware

The Middleware's purpose is to provide services to facilitate the communication flows between applications and to enforce the appropriate data privacy & security requirements. The services offered by Middleware can either be computed on cloud or on edge or on both. It is composed of six components, Service Registry, OTA software update & monitoring, gateway security, data processor, Registry & data storage and device abstraction. The Service Registry provides a collection of the available services and the details about their endpoints and API definitions. OTA software update & monitoring module allows software updating and monitoring of mobile devices over a wireless network. Gateway Security module offers protection against online security threats by enforcing security policies. The data processor module converts the transmitted data into another data type, depending on the application that receives them. Registry service holds information about current maintained services, physical data sources and their locations, while storage service allows data storage, mainly raw derived from sensors, on middleware. Device abstraction ensures merging with IoT systems or sensors.

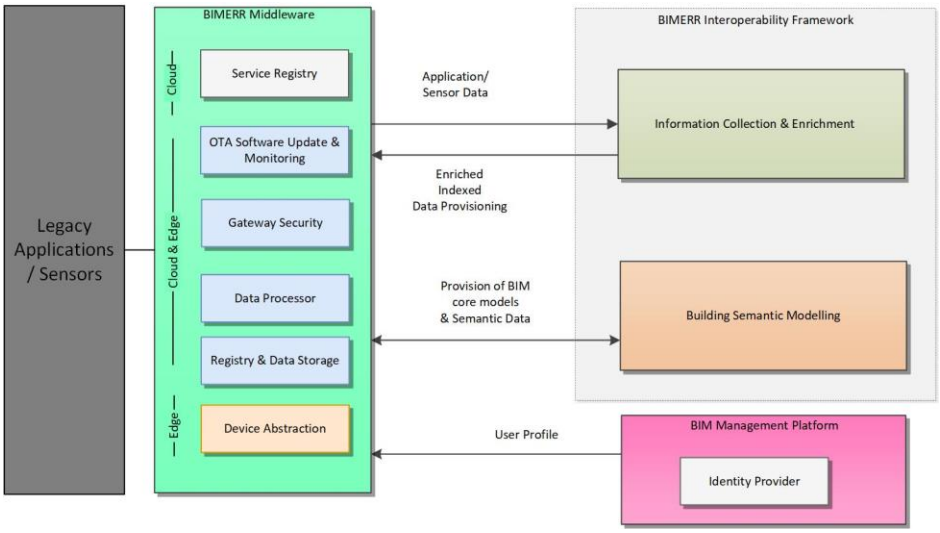

Figure 3: BIMERR Middleware

The devices may run on different protocols, but with the abstraction the protocols are formatted into a single protocol that is recognized by IoT. The middleware is in constant communication with the IoT network of sensors and with legacy applications. It accepts as input the user profile from BIM Management Platform, as it is needed to check the user's rights to his/her access to each application. It also sends application and sensor data, which have been processed and stored, to Information

Collection & Enrichment, sub-component of BIF, which in turn sends it back to middleware, after enriched and indexed. Lastly, there is constant communication with the Building Semantic Modelling, sub-component of BIF, and middleware to exchange BIM models and semantic data.

3.1.2 Digital Building Model Creation Tools

Digital Building Model Creation Tools contains applications and tools responsible for the creation of the necessary building models for the delivery of the renovation and ultimately the operation of the building. These tools aim at successfully extracting sufficient information to populate the necessary data models. They are meant to be used complementarily to ensure that the generated models contain sufficient detail and accuracy. They consist of the *BIM Management Platform, Scan-to-BIM*, *Augmented Reality enabled In-situ Building Feature Annotation (ARIBFA)* using smart glasses, *Profiling Resident Usage of Building System (PRUBS)*, *Building Information Collection Application (BICA)* for residents and *Legacy Systems*. They communicate with the rest of the BIMERR platform through the BIMERR Interoperability Framework (BIF).

Figure 4 showcases the subcomponents comprising the Digital Building Creation Tools

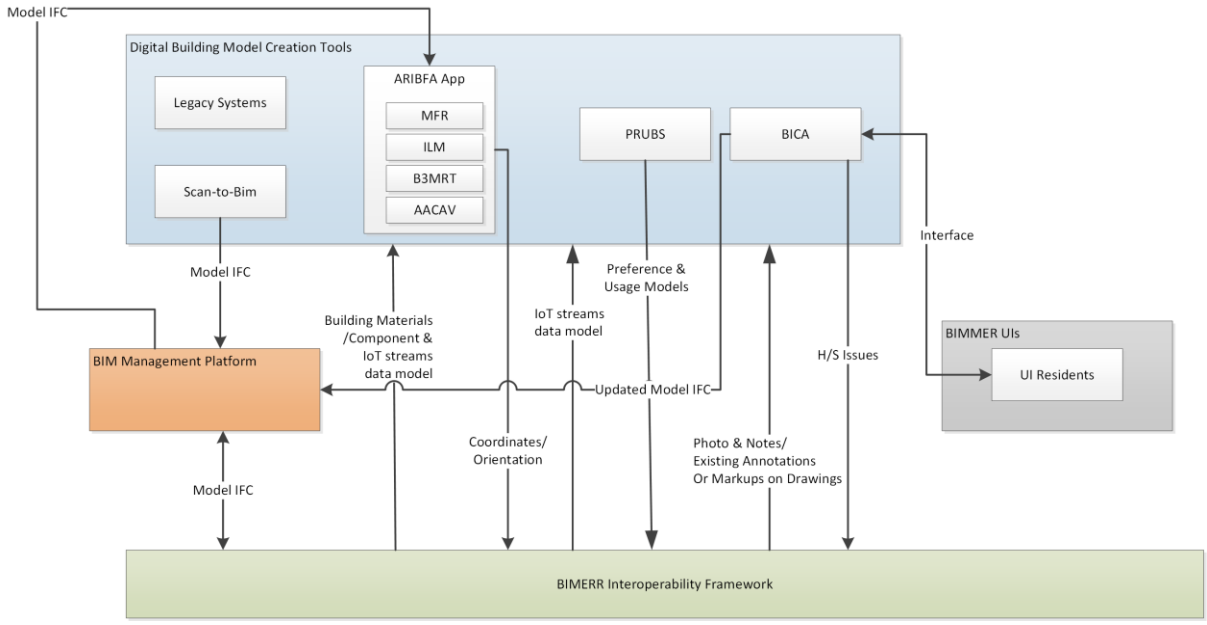

Figure 4: Digital Building Model Creation Tools

3.1.3 BIMERR Renovation Support Tools

The Renovation Support Tools contains two applications that will facilitate the entire renovation process. The applications are the Renovation DSS (RenoDSS) and the Process & Workflow Modelling & Automation (PWMA) toolkit.

The former provides to the renovation designer an accurate estimation of the energy/cost/Life Cycle Assessment trade-offs of various alternative renovation scenarios, based on the available renovation options in terms of components. It is composed of three sub-components/modules and it has its own UI. These are the Building Energy Performance Estimation (BEPE) module, the Life Cycle Cost/Life Cycle Assessment (LCA/LCC) module and the Urban Planning module. Building Energy Performance Estimation module aims to estimate the energy consumption of the building before and after the renovation interventions, in the form of key performance indicators (KPIs). To estimate energy consumption, it receives energy data models, such as structural and geometrical properties of building, materials, HVAC systems, including residents' usage profile, as well as weather data. The purpose of LCA/LCC module is twofold, to calculate both the cost and environmental impact of the renovation. The calculation requires as input data models relevant to building renovation products, current building configuration, project's budget and target energy level. The results of the procedure will be displayed on the RenoDSS UI. The Urban Planning module treats the building as part of a residential area and provides information on its energy use patterns, how it interacts with utility networks and generally how it fits in its surroundings. This module displays the information through RenoDSS UI and receives the same input as the LCA/LCC module. RenoDSS, as a whole, by using BEPE, LCA/LCC and Urban planning modules, calculates the KPIs and building configuration and redirects them to the project repository that resides in BIF. All the information calculated in the RenoDSS becomes available to the user through RenoDSS UI, while he/she can also provide as input to the project repository the desired renovation measures and KPIs for each project.

On the other hand, PWMA provides to the stakeholders a multi-level decision support system that offers many functionalities within the context of a renovation project including its planning, execution, monitoring, analysis, improvements and adaptations. It allows the renovation designer/planner to define different workflows for the work processes that have to be fulfilled, while it also supplies to the workers and residents dedicated applications to provide on-site guidance. The modelling and adaptive monitoring of the entire renovation process is achieved through the Innovative Business Process Modelling component, which it consists of the Design component, Evaluation component and Improvement component. The Design component is responsible for the design of the renovation processes and for analyzing and modifying accordingly the models representing them. It accepts the modelling specifications from the users, through the user interface, and from APIs of other components. The Evaluation component collects data to monitor the behavior of executed processes. The data comes from other components through BIMERR Interoperability Framework, while it also accepts the results and status of the processes by the Execution component and On-site Renovation Worker Support Tool to quantify the workflow behavior.

The monitoring is achieved by calculating the predefined KPIs. The Improvement component aims at analyzing and comparing the expected renovation process behavior with the actual one, extracted by the design and evaluation component correspondingly, in order to provide corrective measures to the

design procedure to optimize workflow behavior. The monitoring and execution of the processes on different runtime environments is achieved through the workflow automations tools and on-site guidance component that contains the Execution component and on-site renovation worker support tool. The Execution component receives the full workflow from the Design component, decomposes it and orchestrates the execution of each action, while providing information to other components via notifications. It also provides feedback, based on the results, to the Evaluation component. Lastly, the on-site renovation worker support tool facilitates the workers' job by providing instructions and notifications for each task. To display the proper instructions it receives the work order ID, while simultaneously it accepts as input data streams from IoT devices.

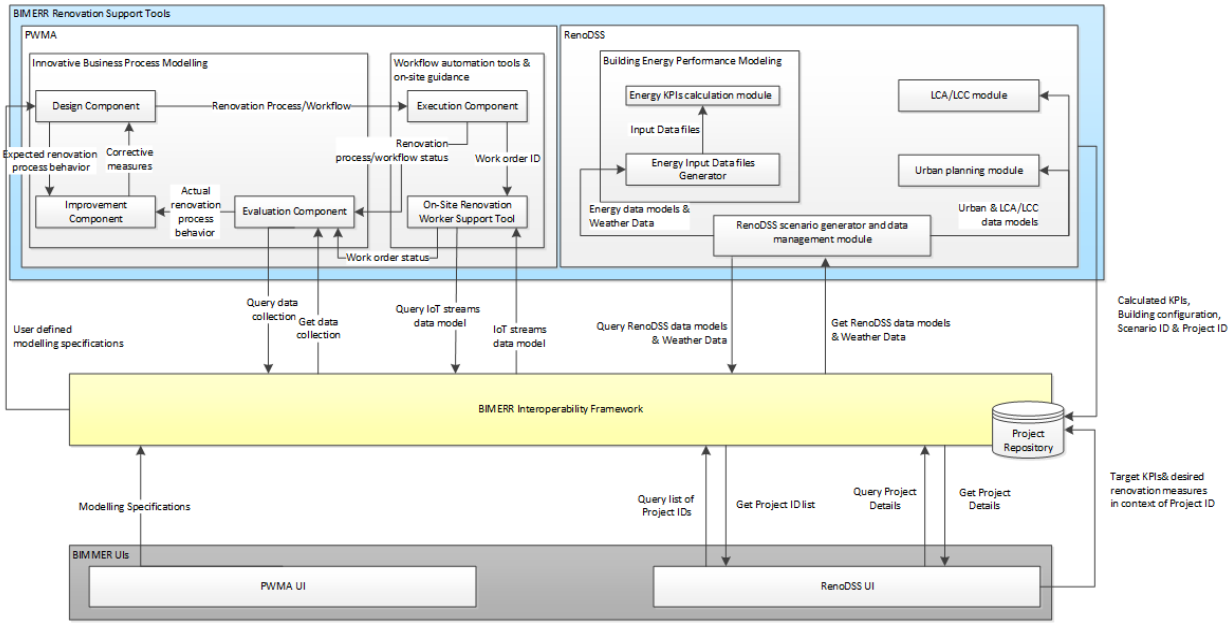

Figure 5: BIMERR Renovation Support Tools

3.1.4 BIMERR Interoperability Framework

The BIMERR Interoperability Framework lies at the heart of the BIMERR platform, ensuring the seamless and secure data exchange among the individual BIMERR tools and applications. The BIMERR Interoperability Framework leverages mechanisms that enable semantic and syntactic interoperability, while access control policies are enforced to prevent any illegitimate data exchange. Figure XX shows the typical data exchanges that take place between BIF and other BIMERR tools but also among the BIF subcomponents. In particular, the BIF comprises four subcomponents, namely: (a) the Building Semantic Modelling, (b) the Building Information Collection & Enrichment, (c) the Building Information Query Builder, and (d) the Building Information Secure Provisioning.

The BIMERR Applications (Renovation Support Tools and Building Digital Model Creation Tools) request from the BIF all the building information from other applications they need for their operation.

Subsequently, the BIF activates the necessary preparatory processes at “design” time and provisioning processes at run-time in order to provide them with up-to-date information to which they are authorized. In reverse, the BIF also receives data from the applications either at batch level, in predefined intervals, or at real-time level. This happens either directly or through the Middleware, which is responsible to perform the required transformations based on a configuration file, that includes the necessary mappings and transformations to ensure information compatibility and consistency within the BIMERR data model. The BIF also communicates with external open and linked open data sources, which provide complementary data for the enrichment of the BIMERR data exchanges. The role and functionalities of each subcomponent comprising BIF, along with an architecture diagram per subcomponent, are presented in more depth in the following sections.

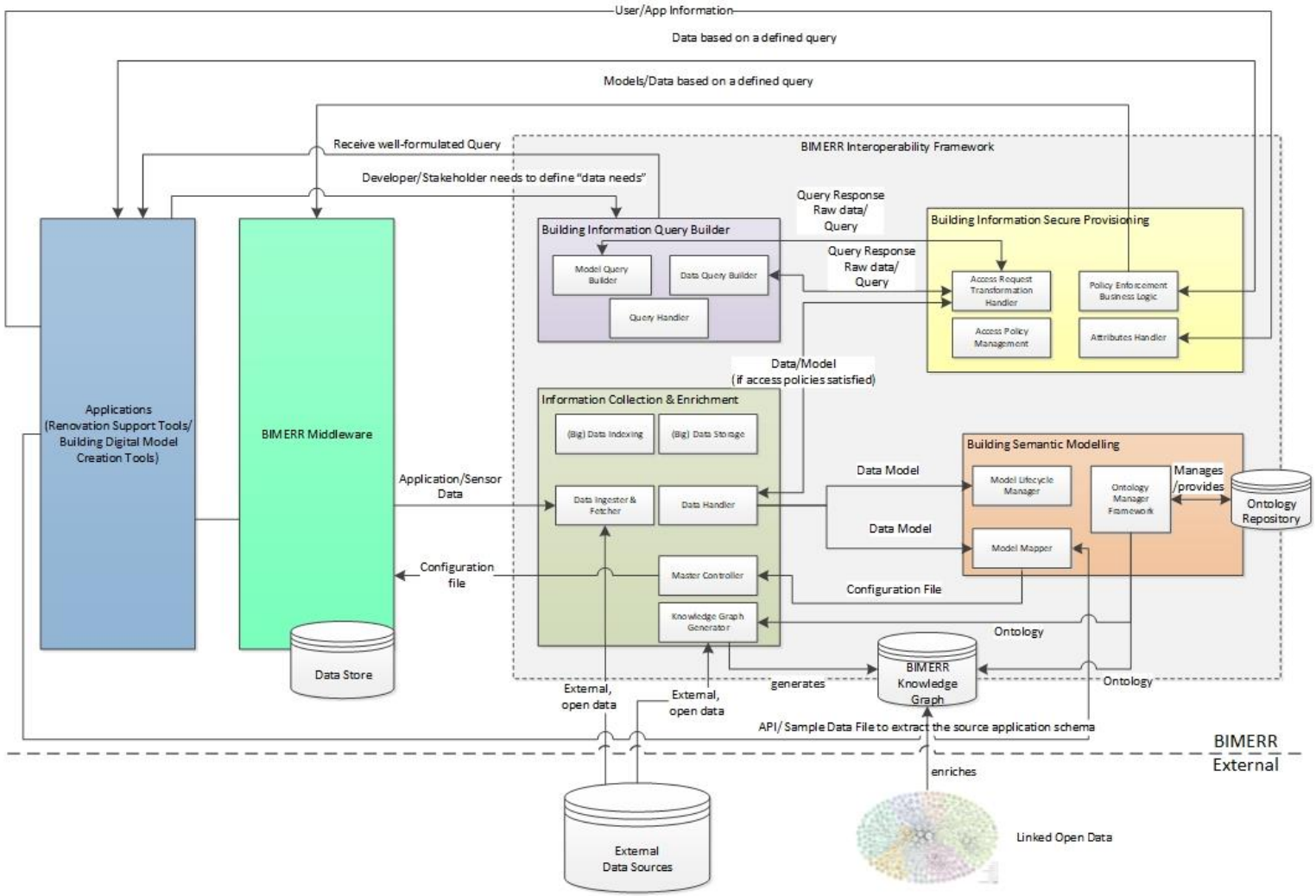

Figure 6: BIMERR Interoperability Framework

3.2 DYNAMIC VIEW

The following analysis is based on the Use Case description in D3.1 as well as the BIMERR overarching story. In this context, a brief description of each use case is followed with a simple diagram associating the user groups participating in the use case with the specific role they undertake and the main BIMERR tools. For reasons of simplicity and readability, some BIMERR components have been omitted (such as BIM Management Platform, BIF and Middleware) since they are present in almost all use cases. Finally, sequence diagrams are provided in order to illustrate how the system is working during utilization, depending on the various scenarios of use and use cases defined for the system, including the way each module acts within them.

3.2.1 UC-01: Rapid scanning of the geometry of the building, semantic modeling and accurate representation in a BIM

UC-01 is about generating the as-is BIM model, capturing information about building geometry as well as key building elements such as doors, walls, radiators, etc. Two user groups (actors) are involved: the surveyor, who uses the Scan-to-BIM tool and the Reality Capture Solution in order to produce the colored point cloud, and the BIM modeler, who validates the model and produces the as-is BIM model that is uploaded and stored in the BIMERR Interoperability Framework and also propagated to the BIM Management Platform.

Figure 7 illustrates the sequence diagram corresponding to the generation of IFC files by means of the Scan-to-BIM module and using data from reality capture technologies. This process can be subsequently divided into two different subprocesses: data acquisition and data processing. Regarding data acquisition, the initial task consists in the definition of the strategic locations for the Terrestrial Laser Scanning (TLS) device (i.e. Reality Capture System) to obtain, in an efficient and effective manner, visual information of the building. Then, for each TLS position, the device delivers a point cloud, containing both geometry and colour data. After the TLS device has obtained data from all the locations, the point clouds are registered under the same universal coordinate systems (UCS) and additional (i.e. post-processing) operations are performed. A similar strategy is followed for the generation of a photogrammetric (PG) model of the building. First, pictures are taken for key locations and these are input to a Structure-from-Motion (SfM) -based algorithm which delivers a coloured point cloud of the environment. Finally, the PG point cloud is post-processed (e.g. scaling to UCS). With respect to the data processing, this can be divided in two main tasks: first, the previously obtained point clouds are loaded into the Scan-to-BIM module, where a new BIM model is created and populated with structural and secondary (e.g. Mechanical and electrical Plumbing - MEP) components that are automatically identified by a segmentation and labeling algorithm. This 'automatic BIM model' is delivered to the building surveyor who manually corrects the model using his/her tool of choice

working with BIM models and loads the IFC file into the system through the Building Interoperability Framework (BIF) that also propagates the file to the BIM Management platform as well.

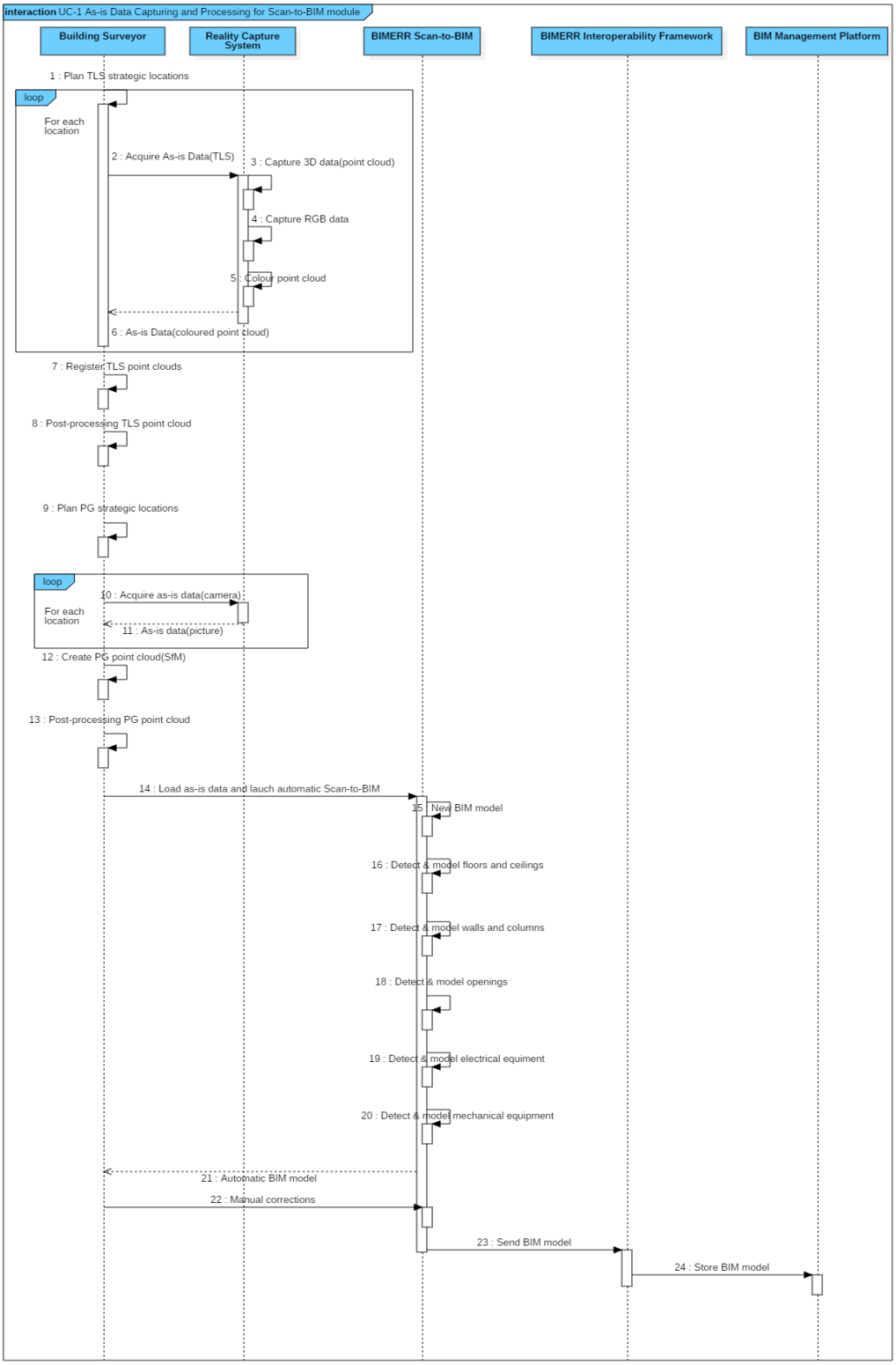

Figure 7: UC–01 – As-is Data Capturing and Processing for Scan-to-BIM module

3.2.2 *UC-02: Accelerate the collection of data about the building systems through BIM-based internal audit support tools and interaction with building managers and occupants*

UC-02 is about enriching the pre-designed as-is BIM model with energy related equipment, their characteristics and other related hidden components within the building (pipes, cables, etc.). Two user groups (actors) are involved in this use case: the building surveyor and the occupant (owner, manager, and consultant).

The building surveyor using appropriate equipment (e.g. HMD-AR glasses), walks around the building to be renovated and semi-automatically annotates the BIM model with energy related equipment and other related building materials; some components are detected and mapped automatically in the BIM model with AR sensors while others are introduced by the user via the ARIBFA app.

The occupant, upon request, uses the BICA application and uploads supplementary data (photo, notes, etc.) to the BIM model.

Figure 8 presents the sequence diagram corresponding to the virtual BIM Model mapping process to physical space and the annotation of unrecognized energy related equipment. The sequence is initialized with the movement of the building surveyor inside the renovation site while wearing the HMD-AR glasses. The RGB-D camera continuously captures the space and sends the frames to the Marker-less Feature Recognition Module to recognize the building components contained in each one. For the recognition task, the deep learning models are deployed to cloud to reduce the computational cost that burdens the AR glasses. The frames are sent to cloud and the building components labels are predicted and returned. To achieve the mapping, the corresponding models of the recognized objects are being returned to the BIF. Moreover, the pose of user and components are extracted by feeding the Indoor Localization Module with RGB-D camera frames, data streams from the IMU sensors of AR glasses, sensor data from IoT sensors network and the IFC model. The calculated coordinates and orientation, the building components models, the captured frames and the IFC model are being sent to the BIM 3D Model Registration and Tracking Module, where the mapping takes place. Visualization of the virtual model to the physical space occurs at the AR Annotation & Context Aware-Visualization Module. In the case of an unrecognized component, the building surveyor may initialize the annotation process by selecting the object's area in space. The area is sent to the AR Annotation & Context Aware-Visualization Module, which provides a user interface to allow entry of relevant information. Subsequently, the newly annotated object is sent to the BIM 3D Model Registration and Tracking Module to map it onto the IFC Model. Lastly, the model is visualized with the newly annotated object.

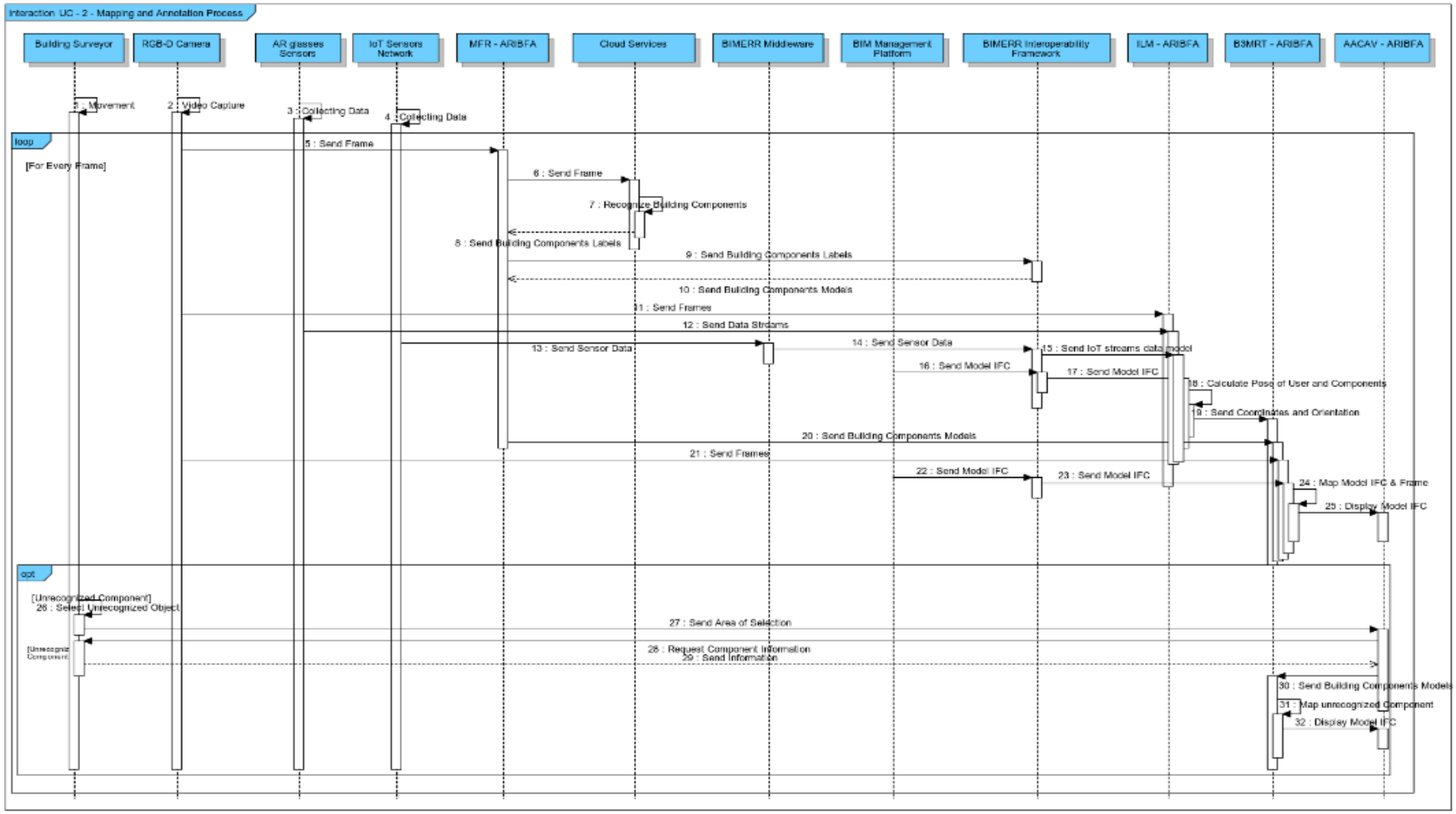

Figure 8: UC–02 – Mapping and Annotation Process

The following figure describes the process of adding supplementary data to the BIM Model. The process starts with the launch of the application. The application's first action is to display the corresponding Model IFC to the renovation site. For this reason, BICA requests from the BIF the corresponding

BIM model. The goal of BICA is to provide to Building Occupants with a way to upload supplementary data related to the renovation site. Therefore, it requests from them to provide additional text annotations and captured photo, whenever necessary, while getting informed about any open Health & Safety Issues. After receiving the data from the mobile device to its back-end, BICA sends the respective information to the BIF where it is available for the other applications to retrieve.

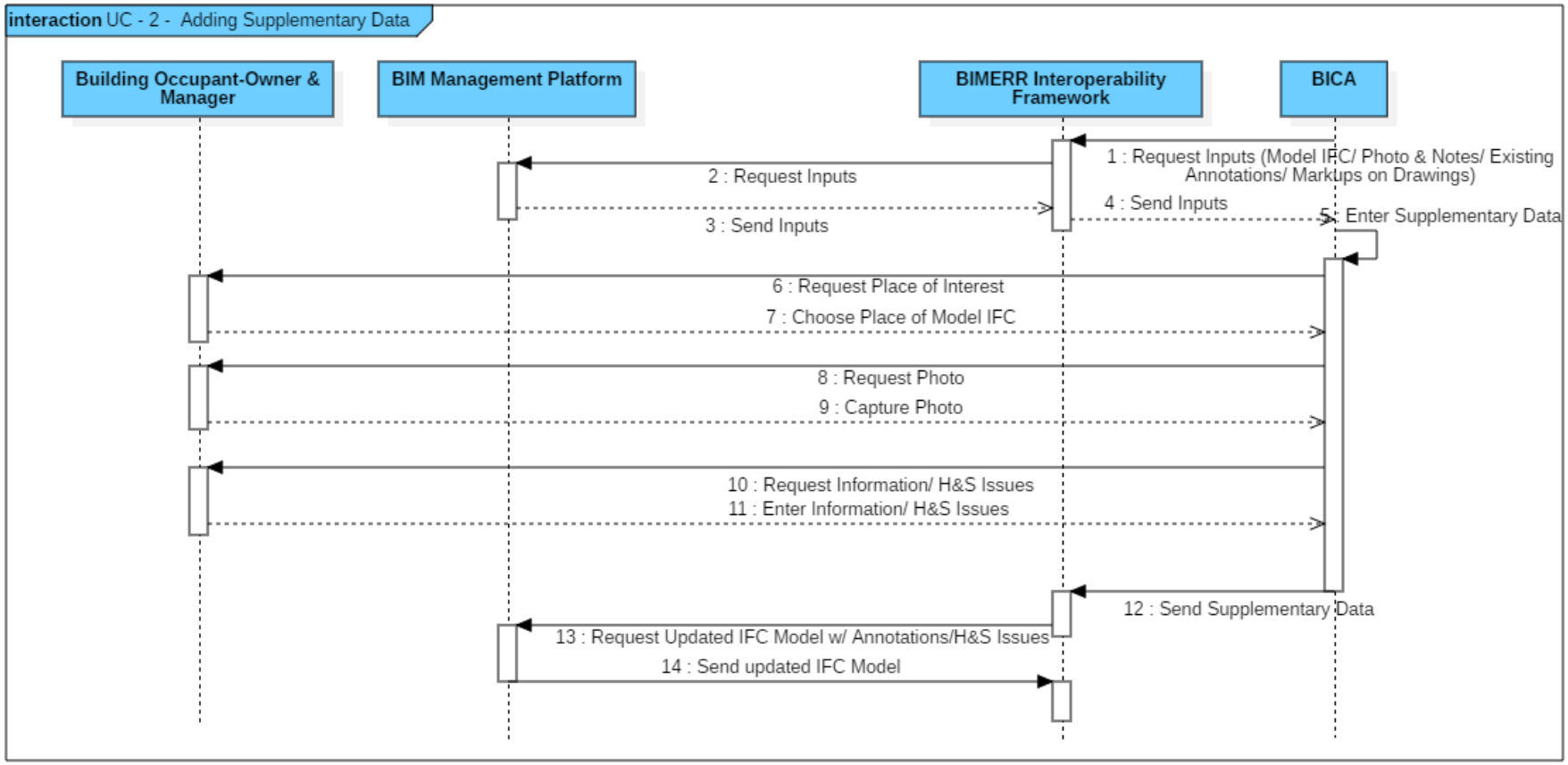

Figure 9: UC–02 – Utilizing BICA for enriching IFC with supplementary data

3.2.3 *UC-03: Adapt design to the actual building use, including accurate information about occupancy and schedules, comfort requirements/ preferences and energy uses*

UC-03 deals with the accuracy of occupancy schedules and profiles that will be used after the design phase of the project for evaluating the energy efficiency of the renovated building under the different renovation scenarios. The PRUBS tool will use data from sensors installed in the premises and provide detailed and dynamically updated comfort and energy behavior profiles. These profiles will be fed into the Building Energy Performance Simulation tool so that the Architect (Renovation Designer) will be able to run a series of simulations over candidate renovation scenarios she/he has already prepared.

In this use case the participating user groups are the architect and the occupant. However, only the architect interacts with the system; the occupants consent to the sensor installation on their residences.

Figure 10 depicts the sequence diagram for the occupant's behavior data model generation. Whenever a RenoDSS user requests for a baseline (as-is) evaluation, a process that consists of 7 steps is initiated: (1) the request is send to the RenoDSS Data Management Module, (2) which is forwarded as a request for the respective obxml data model to the BIF; if the respective obxml file has been previously generated, (7) it is send back to the RenoDSS Data Management Module; (3) else, the BIF sends a new request to the Middleware for the relevant IoT streams data model and (4) when it is received, (5) it is forwarded to the PRUBS module; (6) the PRUBS populates the obxml file (occupant profiles, comfort levels), based on the IoT space names.

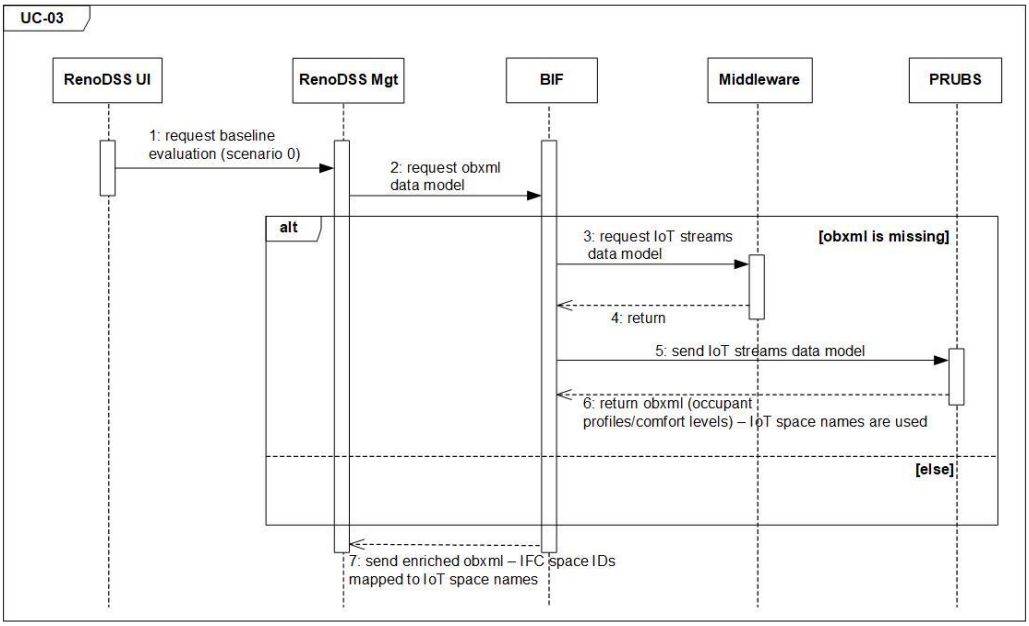

Figure 10: UC–03 – Adapt design to the actual building use

3.2.4 *UC-04: Consider new materials and technologies in any design and simulation activity through appropriately configured BIM-compliant models residing in relevant open repositories*

UC-04 is about using and extending the material and component database that is used by RenoDSS during the optimization of the building energy performance by the renovation designer.

After the renovation initialized RenoDSS UI, is authorized and has loaded the IFC of the renovation building, the material and component classification tree is requested from the RenoDSS management module. The renovation designer selects a specific material or component category and the RenoDSS management module queries the material or components from the material and component database. RenoDSS management module returns the materials or components as objects to the RenoDSS UI and the renovation designer can select a specific material or component as renovation measure for the renovation scenario. In this case the RenoDSS management module modifies the IFC with the selected renovation measure and sends it back to RenoDSS UI and keeps it memory for further modifications or transmissions to other RenoDSS modules such as the Building Energy Performance Estimation (BEPE) module.

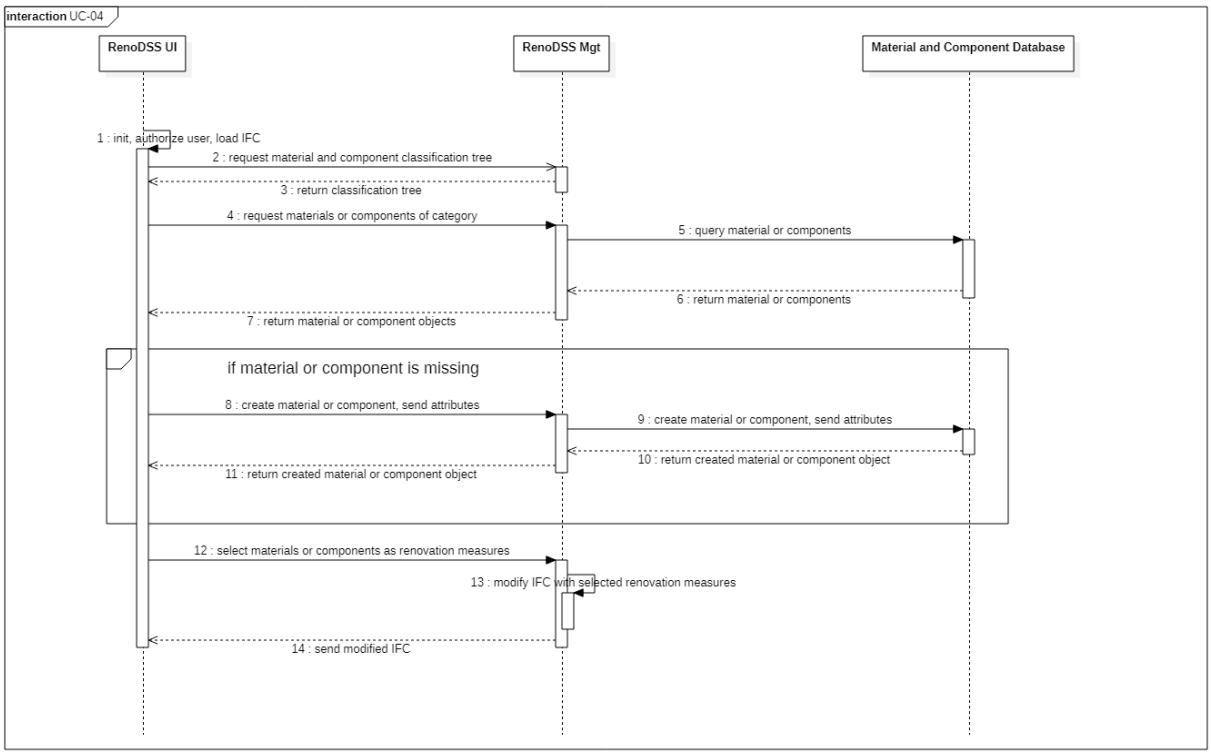

Figure 11: UC–04 – Consider new materials and technologies in any design and simulation activity through appropriately configured BIM-compliant models residing in relevant open repositories

In case the required component is missing, the Renovation Designer initiates the addition process, by creating the missing material or component and sending it with relevant attributes from the RenoDSS UI to RenoDSS management module which creates it in the database. Please note that the renovation designer is not allowed to change or delete existing materials or components as they might be used in other renovation scenarios of other users. If the renovation designer creates a material or component it is set to 'private' and can only be used by the renovation designer who created the material/component. If it is set to 'public' other renovation designers can use it as well.

3.2.5 UC-05: Accurate scheduling of activities and assessment of their efficiency through simulation and verification

UC-05 focuses on reaching an optimized project plan with respect to time and cost requirements. The final design for the renovation has been completed prior to this use case and the Project Manager, who is the only user (actor), imports all the activities in the BIMERR Renovation Process Simulation and Formal Verification Tool allowing the re-engineered BIMERR renovation process to be simulated and an initial estimation of the time and cost requirements of the project to be derived. Cost and time deviations can be detected during this use case.

For this use case, tooling support is provided as part of the PWMA Toolkit based on a to-be engineered domain-specific modelling method. The modelling method combines a diagrammatic modelling language for user interaction and (semi-)automatic processing. For model processing, mechanisms & algorithms are provided. Modelling procedures are formulated as a part of the modelling method to specify the modelling steps that produce modelling results.

The Process Simulation and Formal Verification Tool interacts within the PWMA Toolkit primarily with the workflow engine required for UC6. This interaction is to a high degree exclusively relevant within the PWMA Toolkit. However, as the technology readiness level increases, it is possible to make use of the interoperability framework. Further information can be found in D 6.1, which is in part dedicated to a description of the PWMA Toolkit architecture.

Additionally, the Process Simulation and Formal Verification Tool interacts with the interoperability framework go gather data from other BIMERR components. This enables monitoring capabilities on the process level similar to UC9. However, there is no fixed interaction with other BIMERR components that should be addressed on an architectural level, as the user of the Process Simulation and Formal Verification Tool will be able to specify what data is aggregated and monitored.

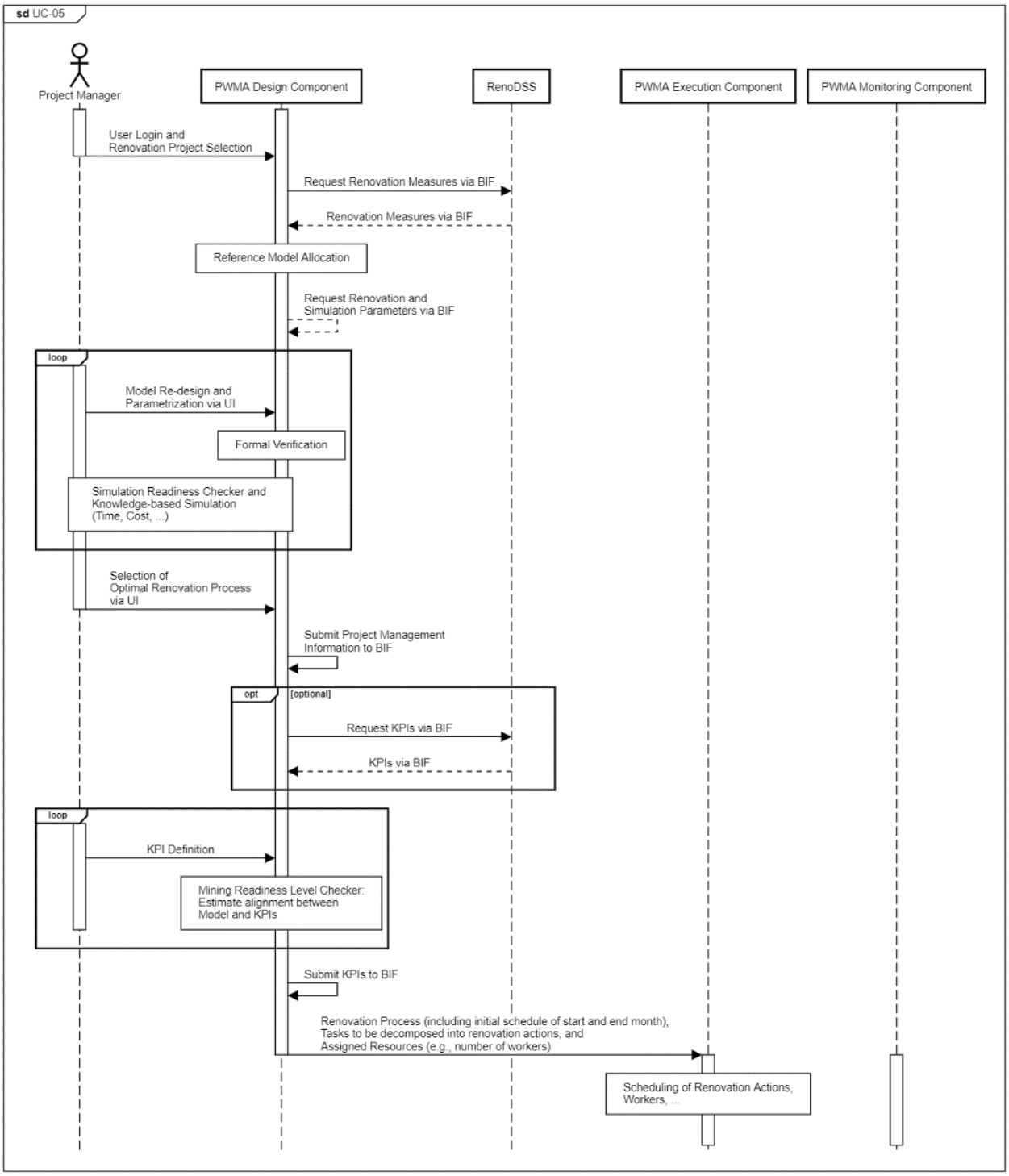

Figure 12: UC–05 – Simulation of renovation process and optimal scheduling

3.2.6 *UC-06: Process automation and execution on a workflow-based approach (exchange of information and documentation on a BIM-based approach) with a sequential initiation of sub-processes, once specific activities have been completed*

UC-06 is about the automation of the renovation process and the sequential execution of sub-processes in a workflow approach.

The Project manager, who is the only actor of this use case, launches these processes, and constantly monitors and revises the steps in order ensure operational efficiency regarding time and cost requirements and constraints.

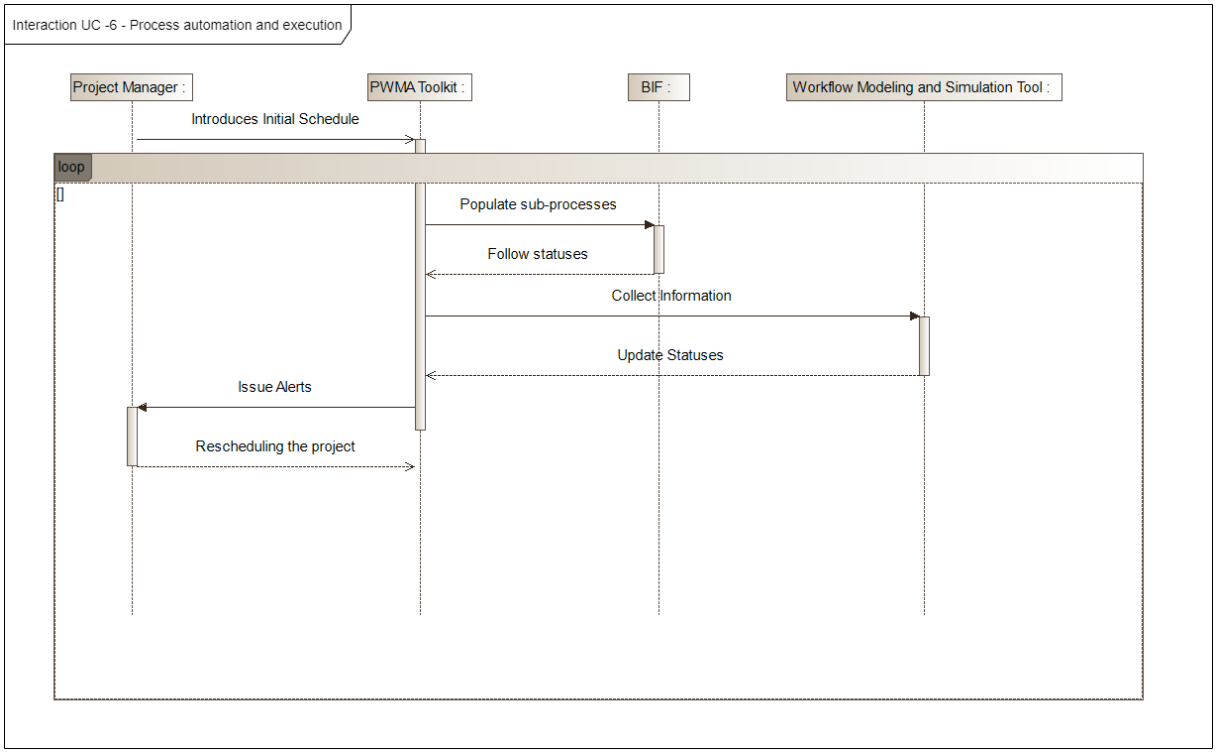

Figure 13: UC–06 – Revision of project workflow processes

3.2.7 *UC-07: Stakeholders' systems exchange appropriate and "understandable" data between each other*

UC-07 is about information exchange among different internal and external stakeholders (authorities, vendors, etc.), facilitated by the BIMERR Interoperability Framework (BIF). The external interested stakeholders, i.e. vendors, material manufacturers etc., are able to perform semantic mapping of their systems information models to the reference BIMERR data model that is utilized in the BIMERR platform, while stakeholders and applications that have already performed the required mapping, can

upload or request data to the BIF. Consequently, UC-07 has been stripped down to three core processes: Model Mapping, Request Data/Model, Upload Data.

Figure 14 presents the sequence diagram of the Model Mapping process. This process is initiated when a stakeholder decides to interact with BIF for the first time. Prior to any other action, like uploading or requesting data, Model Mapping must be performed in order to ensure semantic consistency between the stakeholder's legacy systems and applications and the BIMERR data model. The procedure is the following: The stakeholder uploads a data sample directly to BIF. The Building Semantic Modelling subcomponent derives the underlying data model and semi-automatically maps the concepts of the external data model to the BIMERR data model. The initial mapping is viewed by the stakeholder, who can suggest through the UI any needed corrections and reconciliations. These reconciliations are performed by the Building Semantic Modelling subcomponent, which updates the mapping configuration file accordingly. Furthermore, the stakeholder can add any transformation rules she wants to be included in the configuration file, regarding the data format, units etc. In case the options provided to the stakeholder by the BIMERR data model do not cover the scope of her data, she can request the addition of missing concepts. The administrators of BIMERR receive the request and investigate their applicability to BIMERR and whether the added value offered by these concepts is substantial. If the concept request is accepted, the administrator must update the BIMERR ontology and data model and the mapping configuration under progress and take care of possible inconsistencies in other existing mappings. Once this procedure is completed and the stakeholder views and verifies the mapping as final, the BIF continues with the finalization of the configuration file, which is forwarded to the Middleware for future use. Lastly, the stakeholder can define through the UI the data access policies, that should be enforced on the data she will upload.

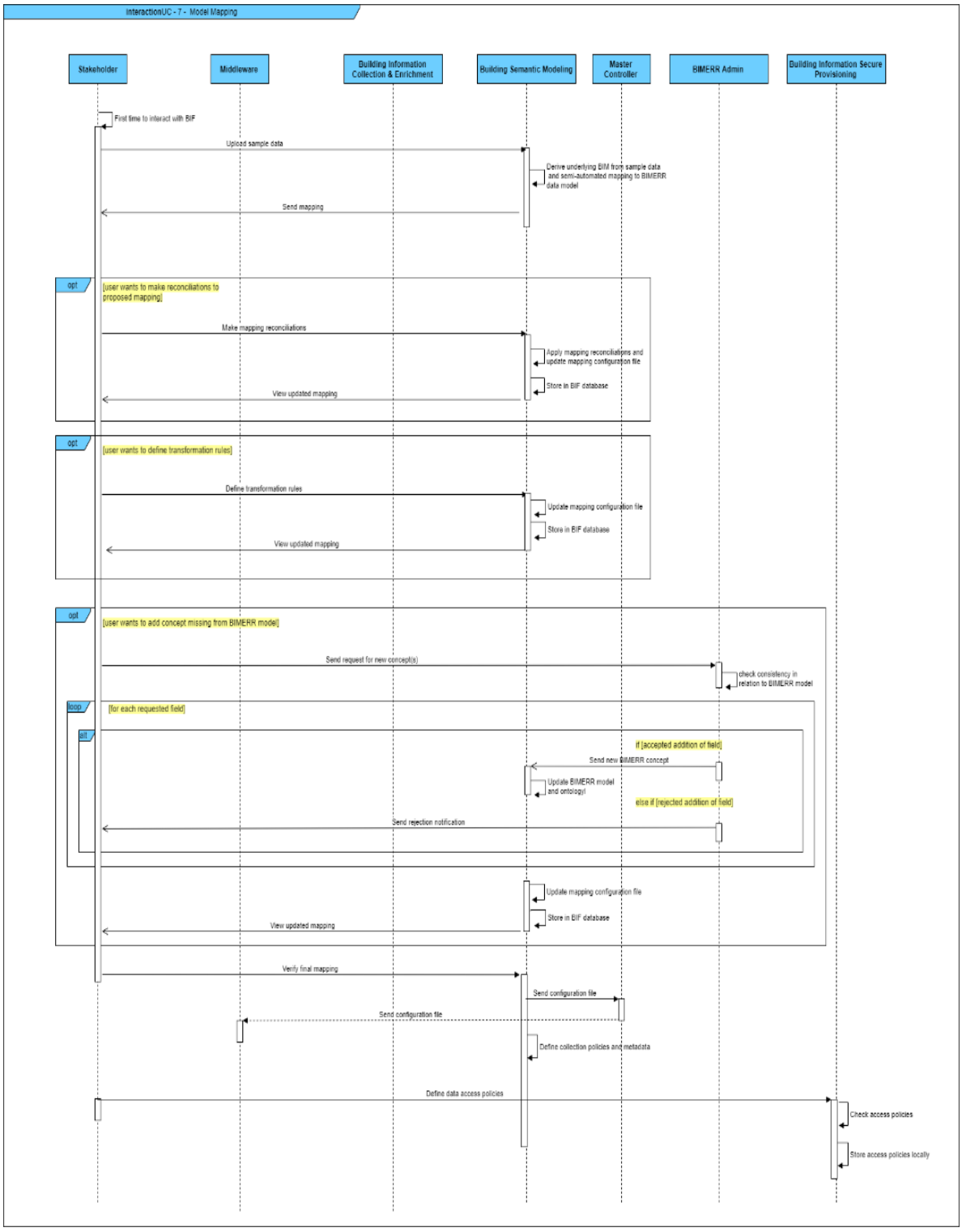

Figure 14: UC– 07 – Model Mapping

The following Figure 15Figure 16 demonstrates the sequence diagram that takes place whenever a data or model is requested from BIF. The request can be made by a stakeholder or by an application. If the requester is a stakeholder, she must define the parameters of her request through the UI provided by the Query Builder subcomponent. The query is built by the Query Builder based on this

input and then it is sent to the Building Information Secure Provisioning subcomponent. In case the requester is an application, it requests directly the required data from the Building Information Secure Provisioning subcomponent through the BIF APIs (based on an already formulated query). In the next stage, the Building Information Secure Provisioning subcomponent handles the query based on the applicable access policies. A query can include multiple data fields, with different access policies in effect, thus access to each requested data set or model should be separately assessed, so that the request is not rejected as a whole, because the requester is not authorized to access part of the information. Whenever access is granted, the required data or model is retrieved from the BIF storage. A well formulated query response is formulated during this process. Once it is completed, it is returned to the requester. Again, the format of the reply depends on the requester. If the requester is a stakeholder, she can view the visualized query response through the BIM Management Platform, wherefrom she can download it. She can also preview the raw response data on the Query Builder UI. If the requester is an application, the response data is directly sent to it through the BIF APIs.

Error! Reference source not found. illustrates the sequence diagram of the 'Upload Data to BIF' process. Having performed the model mapping is a prerequisite to this process, so that the mapping configuration file is available to the Middleware, if necessary, and the data access policies are defined. Data can be uploaded to BIF by stakeholders or applications. The stakeholder/application sends the data to the Middleware. It performs all data mappings and transformations defined by the mapping configuration file and afterwards sends the processed data to the Building Information Collection & Enrichment subcomponent of BIF. This subcomponent ingests the mapped and transformed data, performs any needed processing and finally stores and indexes the data, which will be available to all legitimate users and applications.

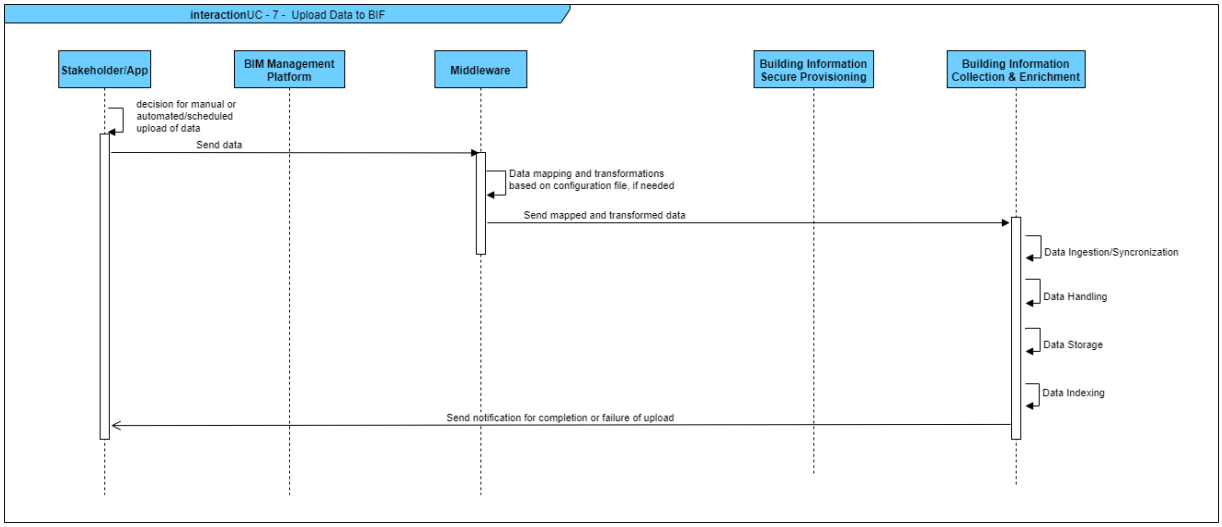

Figure 15: UC–07 – Upload data to BIF

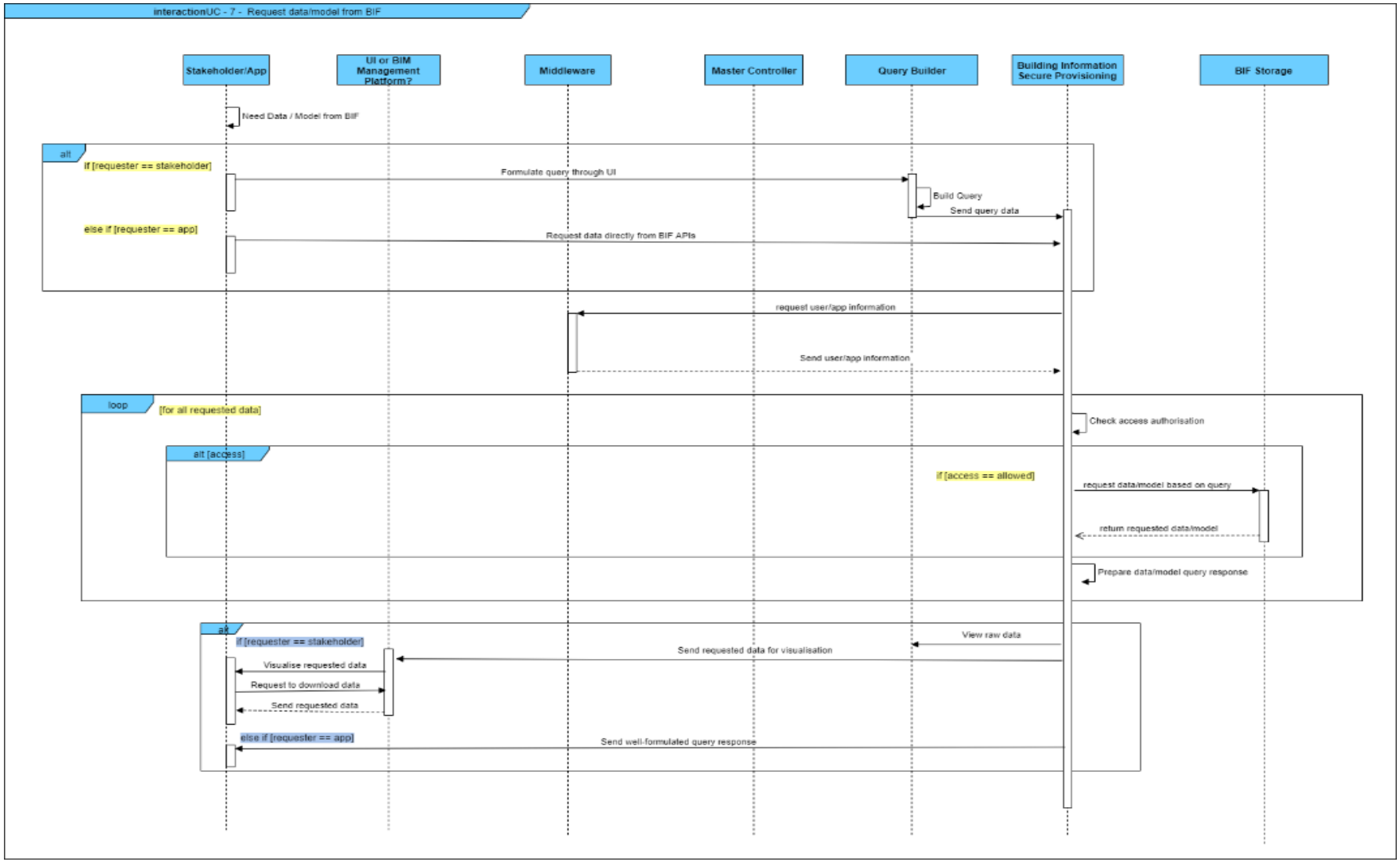

Figure 16: UC–07 - Request data/model from BIM

3.2.8 *Daily renovation activity schedules are automatically generated (based on accurate project scheduling) and individual guidelines are provided to the workforce responsible through ambient interfaces and apps*

UC-08 delves into the actual construction works that any renovation project entails. Daily schedules are derived in the context of workflows that are assigned to working crews around the construction site taking into account workers' location. Working crews are automatically notified about tasks assigned to them while new tasks are accompanied with all needed information (instructions, drawings, etc.) that can be superimposed on real world in AR.

At the end of each working day, workers (or foreman) get to fill in a quick check list indicating the completion or not of the tasks assigned to them.

Figure 17 represents the actions required to recognize the location of each worker. This process happens continuously from the moment the worker wears the AR glasses. The computations are being made by the Indoor Localization Module. It receives as inputs frames from the RGB-D camera, data streams from the sensors placed on the AR glasses, sensor data extracted by IoT sensors network and BIM model from BIM Management platform. The data captured by IoT devices is transmitted through Middleware and BIF, while the Model IFC is also sent via BIF.

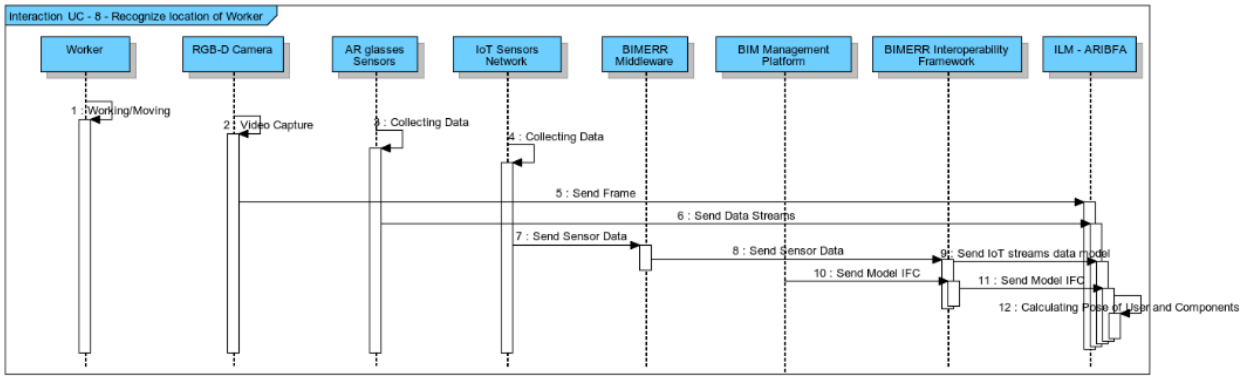

Figure 17: UC–08 – Recognize location of worker

On **Figure 18**, the project scheduling and the procedure for completing the provided work tasks using AR glasses is described. The series of actions begin with site manager initiating schedule creation using the Workflow Automation Tools of PWMA. The module requests and accepts Model IFC, from BIM Management Platform through BIF, to match each work task with the corresponding location. In addition, it assigns specific responsibilities to each worker, it matches tasks with the location of interest and assigns each workflow of tasks to a specific crew. On the other hand, the process of providing guidance to workers is triggered by the use of smart glasses inside the renovation site. The On-site

Guidance Tool accepts the coordinates and orientation of the worker from the Indoor Localization Module and transmits it to Workflow Automation Tools to extract the list of tasks that coincide with the calculated location. Subsequently, tasks are displayed to workers in form of notifications. For each assigned task, the On-site Guidance Tool provides relevant information that also displays it to AR glasses. Moreover, it displays virtual model mapping to the physical space using BIM 3D Model Registration and Tracking to provide guidance to workers. The worker can request, at any time, information for every component. This is accomplished with the help of AR Annotation & Context Aware-Visualization Module, which displays the context of each selected component. When the worker reports that the task is finished, he/she can optionally fill out a checklist to verify that the work has been completed in accordance with the specifications. The checklist is provided by the On-site Guidance Tool.

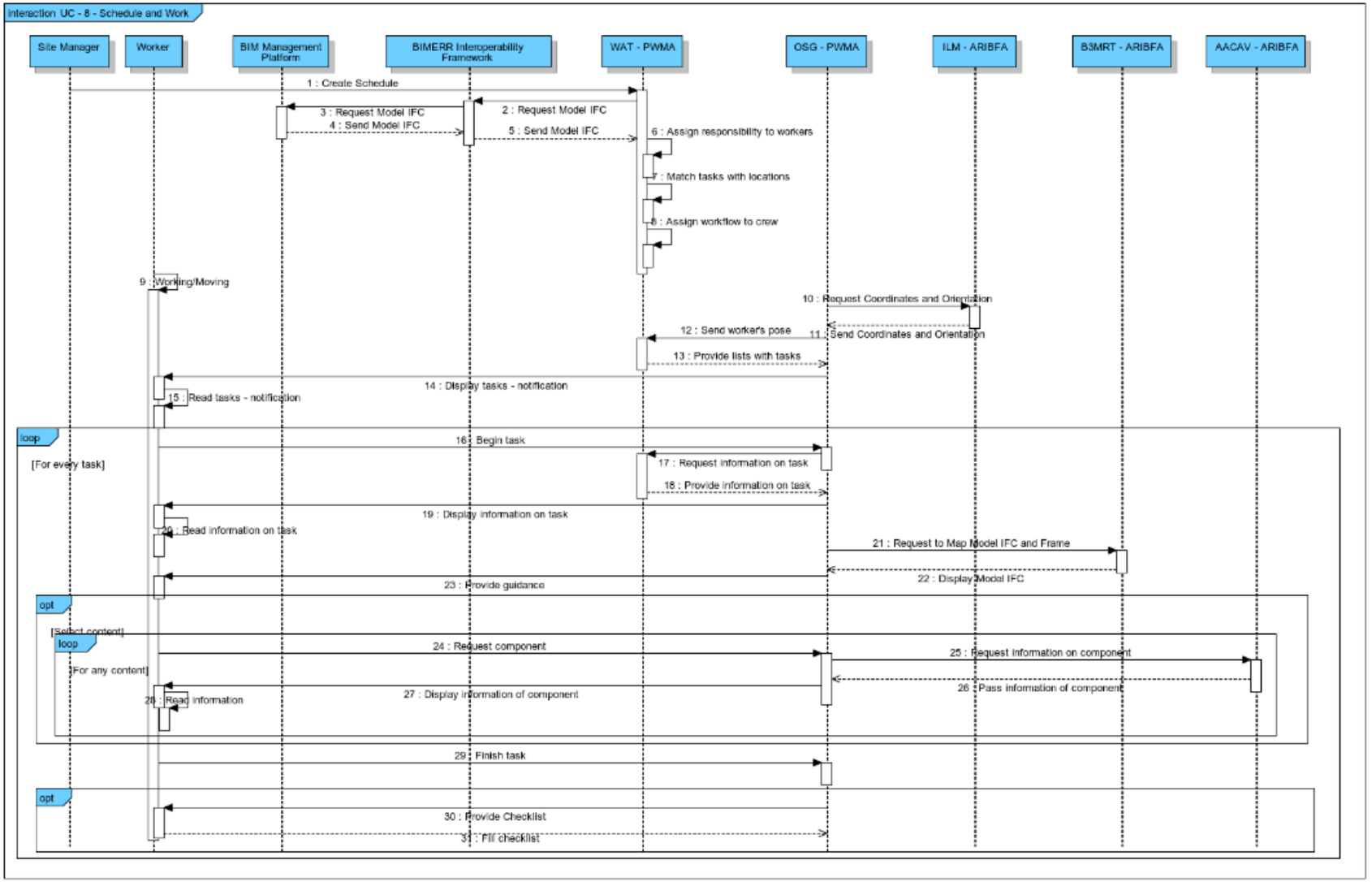

Figure 18: UC–08 – Schedule and Work

3.2.9 *UC-09: Continuous monitoring and updates of renovation activity schedules (based on reporting from the workforce and monitoring of process execution) towards effective devising and avoidance of delays (bi-directional communication through ambient interfaces*

UC-09 involves the role of foreman who at the end of the work day reports back to management the percentage of work completion along with the reason for non-completion, and the role of site manager who uses his/her AR equipment and *follows* the construction works progress that is displayed on BIM model as he/she walks through the site.

The workflow prepared by site manager is assigned to a specific crew. Workers receive notification on everyday basis about the assigned tasks to them. The scheduled workflow is displayed on the **AR** on-site guidance application. The application runs on **smart glasses**, which are worn by worker/foreman. The head-mounted device will recognize semi-automatically or automatically, the worker's location of the construction project and it will provide worker with a list of scheduled tasks with respective workflows created by the site manager.

Using the AR application (workflow automation and on-site guidance application) the worker will receive a context-aware information in real-time and will be able to display job instructions, information on materials, drawings, BIM model, etc. The worker is able to select contents, which are superimposed on real world in AR. Displayed contents are correlated to BIM model and pre-defined locations of the construction project.

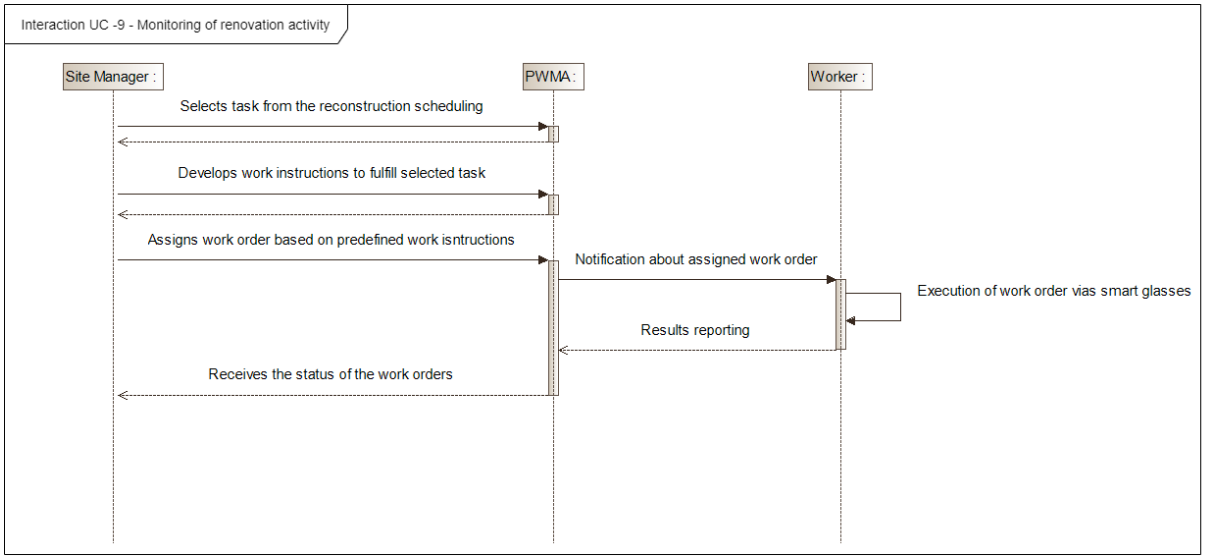

Figure 19: UC–09 – Assignment and monitoring of work orders

3.2.10 *UC-10: Continuous reporting from workforce and occupants for changes performed over the initial renovation design (location-based on a BIM representation) and automated update of the BIM model (as-built documentation)*

UC-10 involves the user groups of worker, occupant and site manager. When, during daily on-site activities, workers notice small design errors, they can report via the ARIBFA application the issue back to management along with the proposed changes that they need to perform. Site manager (or/and project manager) approve the proposed modification which is then automatically reflected to the BIM model, otherwise the issue is re-directed back to the architect (renovation designer). In the same context, the occupants, during a visit to the site, can use the BICA application running at their smart phones to report issues regarding compliance with the original plans. Again, the site manager is the one to decide whether or not there is indeed such an issue that needs to be resolved; in that case he/she creates an issue to the task workflow that coordinates the related to the issue construction activities.

Figure 20 presents the way a design change issue is handled. Specifically, the process begins with the notification of site manager of a reported design change. Site manager reads the notification and requests the issue to locate it in the IFC model. The model is requested from BIM Management Platform via BIF and it is displayed in the On-site Guidance Tool of PWMA. Site manager verifies the notification and decides whether it must be resolved or ignored. In the latter case, he/she marks the issue as ignored through On-site Guidance Tool, then the task is considered complete and its status is passed down to Workflow Automation Tool. IFC Model is updated and sent to BIM Management Platform through BIF. In case the site manager decides to resolve the issue, an instance is created, which is then sent to Workflow Automation Tool to update the workflow. Subsequently, notifications are sent to Foreman to resolve the issue with the corresponding crew. With the completion of the task, Foreman marks the issue as resolved via On-site Guidance Tool to Workflow Automation Tool. The workflow is once again updated and the updated model is sent to BIM Management Platform through BIF.

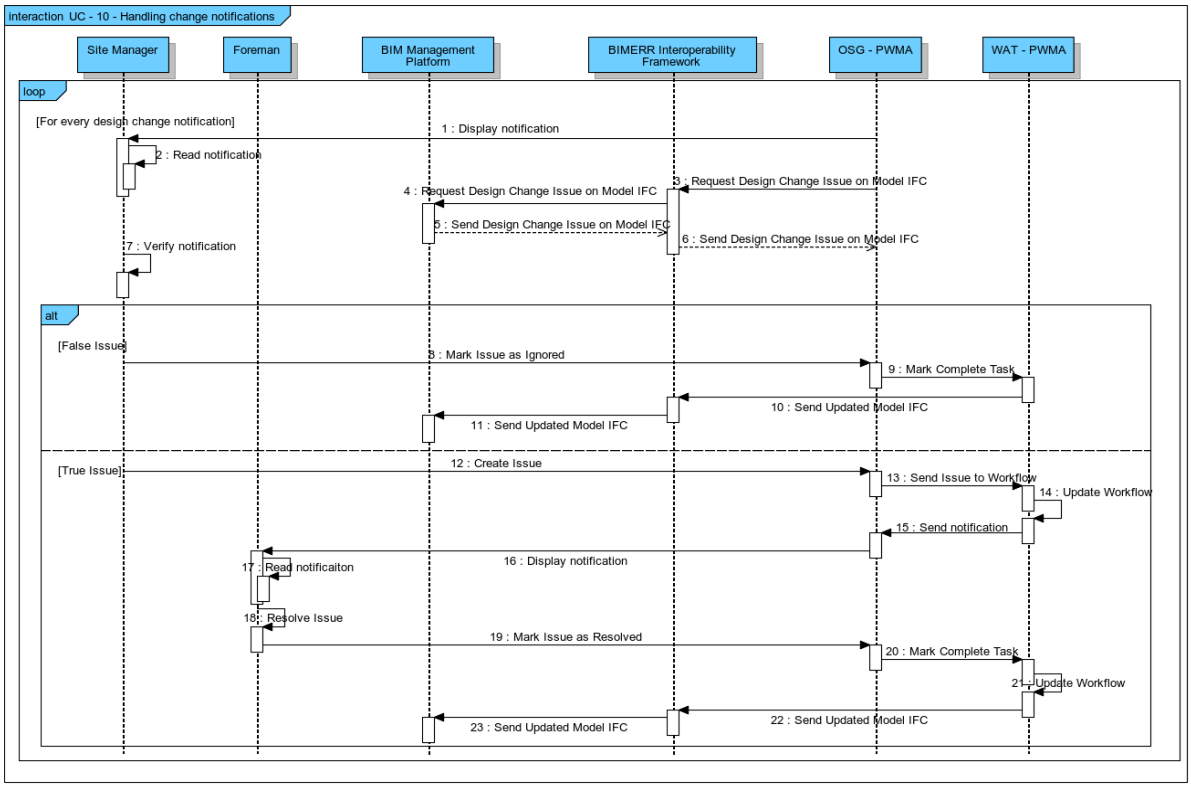

Figure 20: UC–10 – Handling Change Notifications

In **Figure 21** below, the actions needed for workers and building occupants to report a design change or issue are shown. Both workers and building occupants can report a change or issue at any time. In the case of workers, the process begins with content selection through PWMA's On-site Guidance Tool. The tool requests a note and photo, which passes them to the Workflow Automation Tools with the purpose of creating a report with the suggested changes. The Workflow Automation Tools create the report and attach it to the model. The updated model is sent to BIM Management Platform through BIF. On the other hand, when building occupants want to provide feedback, the process begins with reporting a design change issue to BICA. In turn, BICA requests and accepts the BIM Model from BIM Management Platform through BIF. Subsequently, it requests from building occupants to provide the location, where the issue is located as well as relevant information. After receiving the necessary inputs, BICA updates the model and sends it to BIM Management Platform while simultaneously providing notifications to workers using the On-site Guidance Tool.

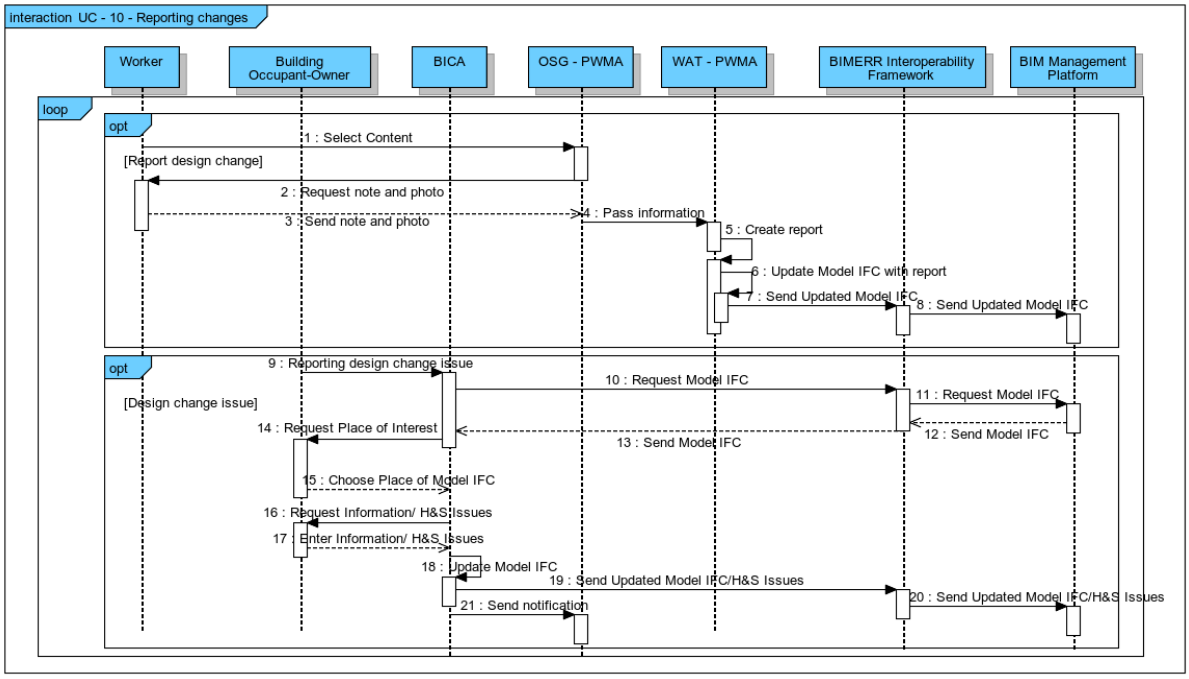

Figure 21: UC–10 – Reporting Changes

3.2.11 UC-11: Identification of threats and dangers and provision of alerts to workforce and occupants through BIM-based apps and UIs

Workers, through the ARIBFA app, receive H&S notifications i) that are attached to the workflow of the task that is assigned to them, ii) that are displayed when the worker is repositioned inside the building (e.g. changes floor) and iii) before their day-shift. The Site manager, who can also receive H&S issues, prepares H&S instructions for the respective construction activities (e.g. scaffolding assembly) and attaches them to the relevant workflows so they can be available to working crews assigned the tasks. Owners that wish to visit the construction site, use BICA app on their phones to get informed about current H&S instructions or safety risks.

Figure 22 shows how the stakeholders are informed about Health and Safety issues. The process is initialized with the creation of Health & Safety report from the site manager using the On-site Guidance Tool. The report is then attached to workflow and to IFC Model through Workflow Automation Tools. The updated model is sent to BIM Management Platform through BIF and the workflow is updated according to the content of the report. When the report becomes available, workers are informed of its content through the On-site Guidance Tool, which extracts it from the BIM Management Platform via BIF and displays it before the workers begin their tasks. In the same way, the Health and Safety instructions are displayed on workers during each task. Foreman reads the Health and Safety instructions through the On-site Guidance Tool, while building occupants and owner read the Health and Safety instructions, through BICA.

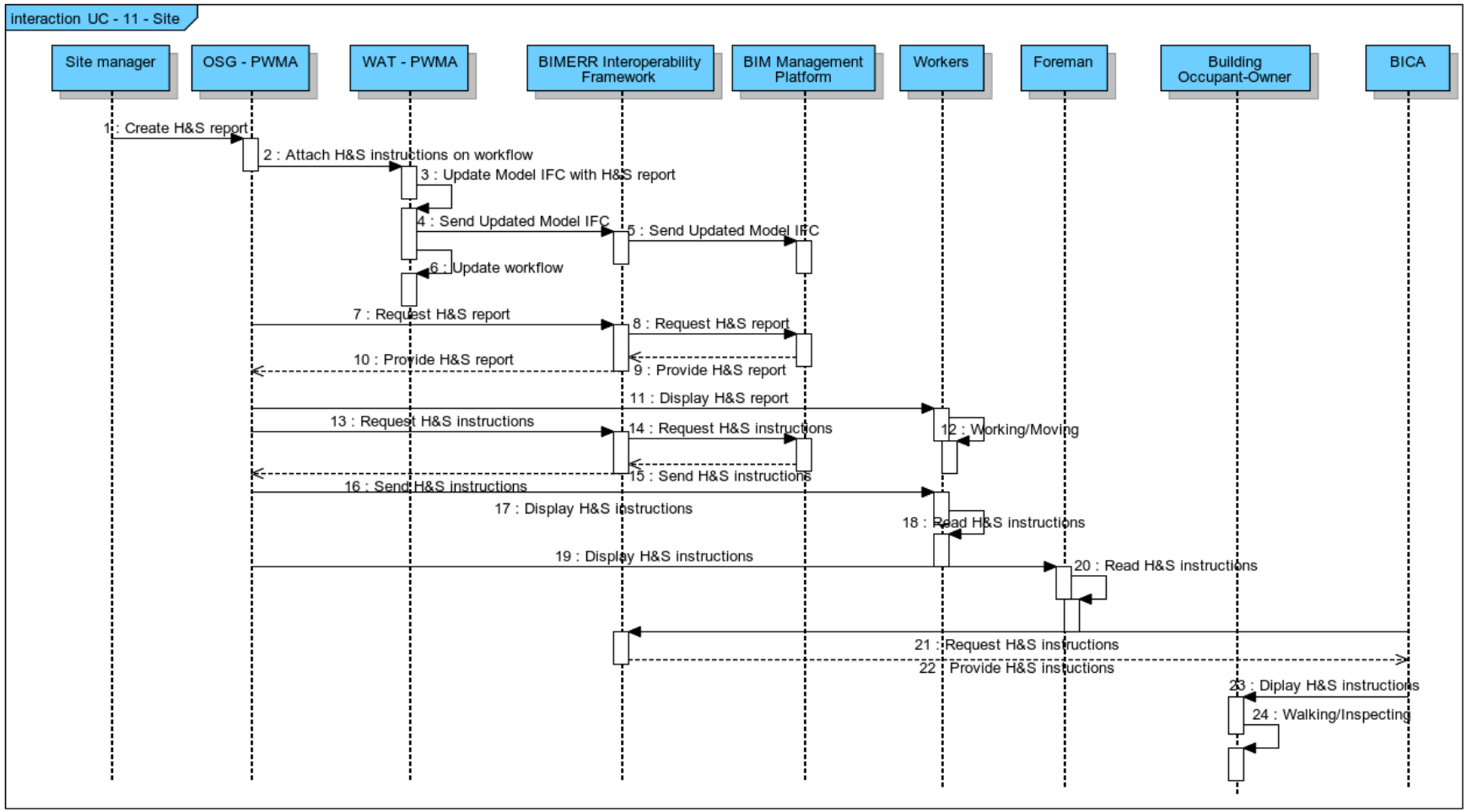

Figure 22: UC – 11 – Site Health & Safety

3.2.12 UC-12: Continuous reporting from workforce and occupants for dangers and threats (location-based on a BIM representation) and automated update of the BIM model

Workers, through the ARIBFA app, create H&S issues that are automatically highlighted in the BIM model. The Site manager, who can also create H&S issues, automatically creates periodically H&S reports using the history log of registered issues and their status. The status of H&S issues is changed by the H&S manager of the construction site. Owners that wish to visit the construction site, use BICA app on their phones to create H&S issues during their visit.

The actions related to reporting Health & Safety issues are presented in Figure 23. The process can be repeated any time the worker or building occupant locates any issue. In case a worker discovers a Health & Safety issue, he/she reports it through the On-site Guidance Tool, which then requests information from the worker about the issue. Afterwards, the issue is sent to Workflow Automation Tools, which incorporate the issue to IFC Model, send the updated IFC model to BIM Management Platform via BIF and lastly, send notifications to stakeholders using the On-site Guidance Tool. In the case a building occupant or the owner of the site discovers a Health & Safety issue, he/she reports it through the BICA application. In turn, BICA requests the IFC Model from BIM Management Platform, so the user can choose the location of the issue. Moreover, it requests related information from the user and after receiving them, it also updates the model. The updated model is sent to BIM Management Platform through BIF and a notification is sent to the users via the On-site Guidance Tool.

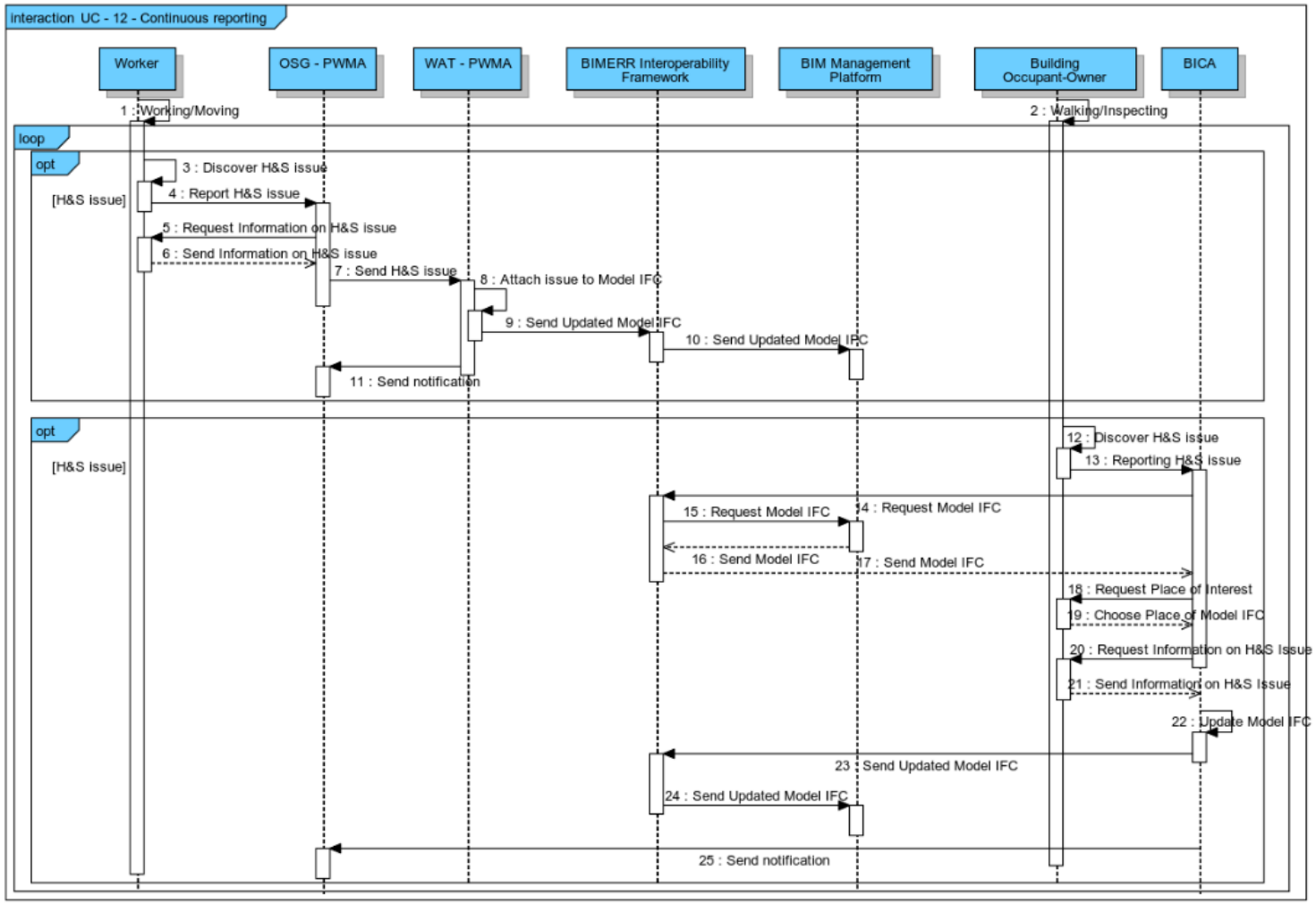

Figure 23: UC–12: Continuous Reporting

Figure 24 shows the way the Health & Safety notifications are handled. At first, the On-site Guidance Tool notifies H&S manager of an issue that arose. H&S Manager reads the notification and provides instructions to Workflow Automation Tools to solve the issue, using the On-site Guidance Tool. In between, the On-site Guidance Tool requests the IFC Model from BIM Management Platform, so the H&S manager can locate the issue. After the provision of instructions, the workflow is updated and the instructions are sent to the Foreman through the On-site Guidance Tool. He/she reads the notifications, makes the proper actions to resolve the issue and reports the solution. Then, H&S manager displays the solution using the On-site Guidance Tool and marks the issue as resolved. The Workflow Automation Tools are also informed of the resolved issue, so they update the workflow and send the updated model to BIM Management Platform. Finally, a notification is sent to the site manager for the H&S issue and its status. In turn, he/she creates a H&S report, which is sent at Workflow Automation Tools. These tools request older H&S issues in order to construct automatically a complete H&S report, which is later attached to Model IFC. Lastly, the updated model is sent to BIM Management Platform.

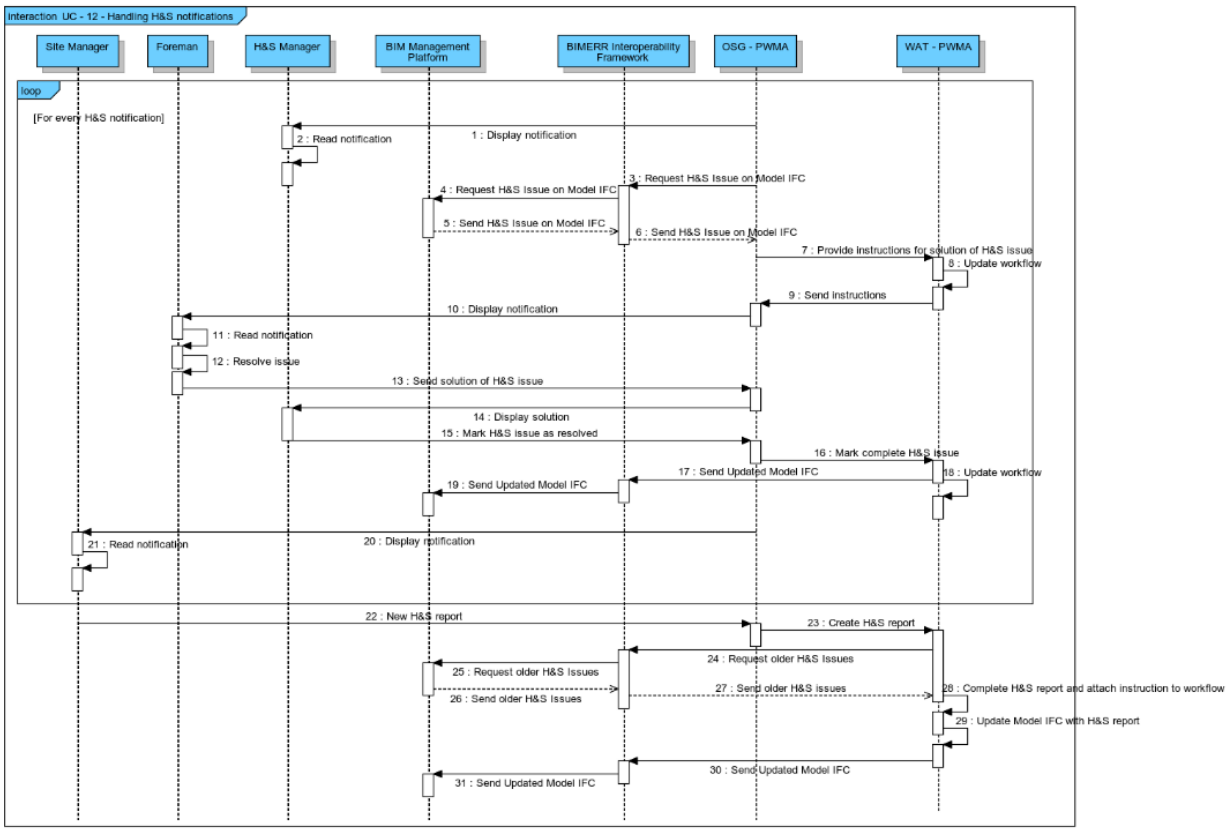

Figure 24: UC–12: Handling H&S Notifications

3.2.13 *UC–13: Perform back-to-back simulations of alternative renovation scenarios to evaluate and select the best energy-performing renovation scenario*

UC-13 to UC-16 refer to the RenoDSS and its components' usage for evaluating the baseline energy performance of the building that is going to be renovated and analyzing the impact of candidate renovation measures' combinations on it. Estimation and analysis are translated to calculation of numerous metrics, that each use case defines, performing simulations based on widely accepted methods that achieve a trade off between "accuracy" and "computational complexity". Although four different uses cases of RenoDSS have emerged, their difference relies on the calculated metrics (KPIs) and the respectively invoked RenoDSS components that each requires. Hence, note here that the sequence diagram that is introduced by Figure 24 and described below applies to all RenoDSS use cases.

According to Figure 24, each stakeholder's credentials that are provided through the RenoDSS UI login functionality correspond to a list of renovation project IDs. Hence, whenever a RenoDSS user logs-in, a list of project IDs pops-up and the user selects the project of interest. Upon that selection, a request for Energy Network Data is sent to the RenoDSS Data Management module to be forwarded to the Urban-planning component. The Urban-planning component replies to that request by sending the Energy Network Data in CityCML format. Afterwards, the user selects the baseline evaluation that is translated to a relevant request for the RenoDSS Data Management module, which in turn communicates with the BIF to receive the as-is IFC, obXML (the occupant behavior model that has been populated by PRUBS) and EPW (weather data file for the projects location) files. Having received them, they are forwarded to the Building Energy Performance Estimation (BEPE) component to proceed with the energy & thermal comfort KPIs calculation; additional building envelop characteristics that are required by other components are also populated by the BEPE simulation (the sequence diagram of the BEPE component is further analyzed below). When the baseline simulation is completed, both the energy & thermal comfort KPI and the additional building envelop characteristics are sent to the RenoDSS Data Management module to be later displayed to the GUI. At this stage the renovation measures selection page is activated, where the user is asked to set targets and select candidate renovation measures types from a predefined list that pops-up. After the selection of measures, the user requests for the candidate renovation measures evaluation. Here, the RenoDSS Data Management module proceeds with generation of a set of candidate renovation scenarios (combinations of renovation measures), while for each candidate scenario, it sends requests for Energy, LCC/LCA and Urban-planning and relevant data models to the proper RenoDSS components (BEBE, LCC/LCA and Urban-planning, respectively) in parallel. Finally, KPIs for each scenario are collected by the RenoDSS Data Management module to be sent the displayed to the GUI.

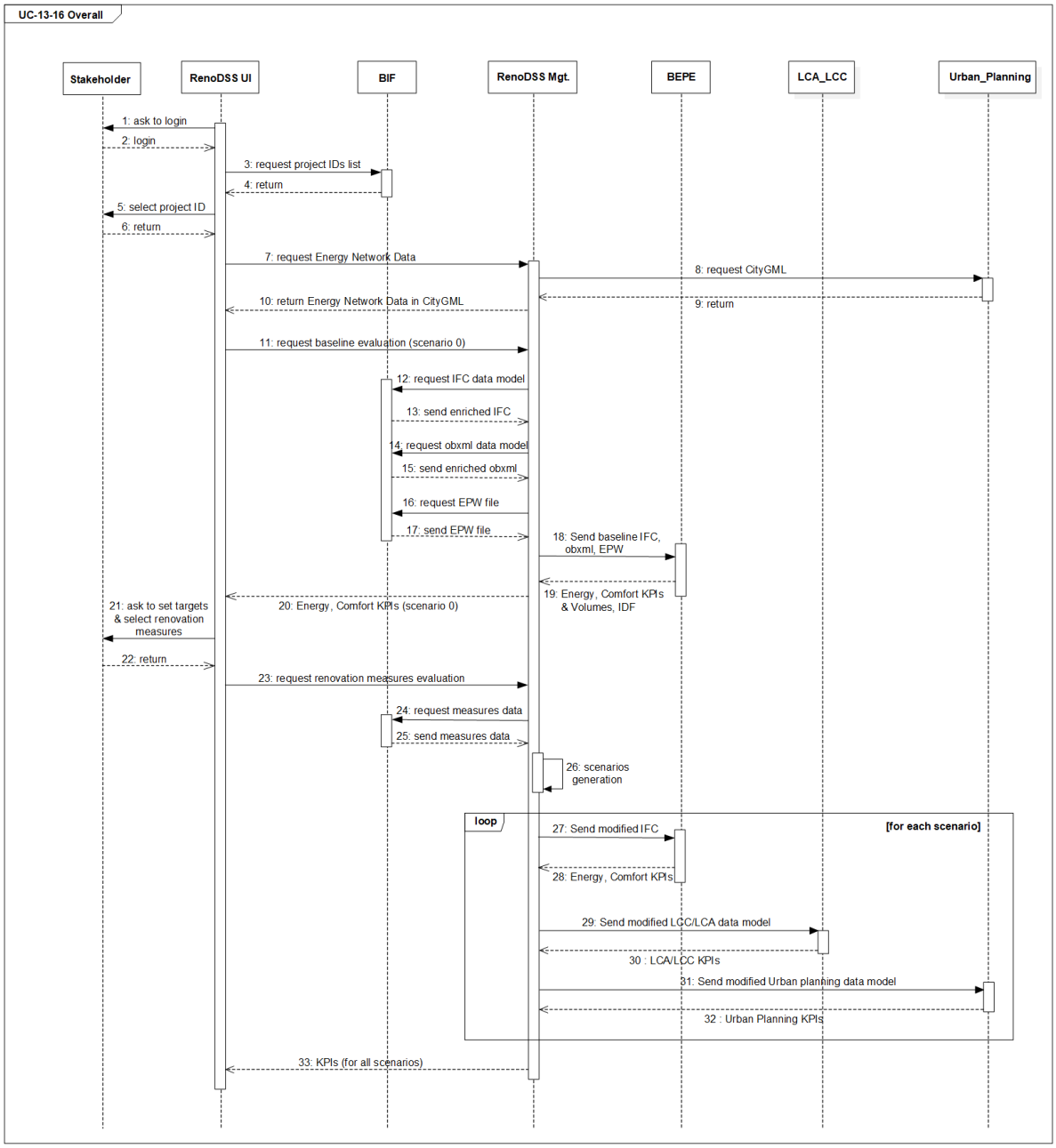

Figure 25: UC–13 to UC–16: RenoDSS – Estimating Baseline and Renovation Measures Performance - overall

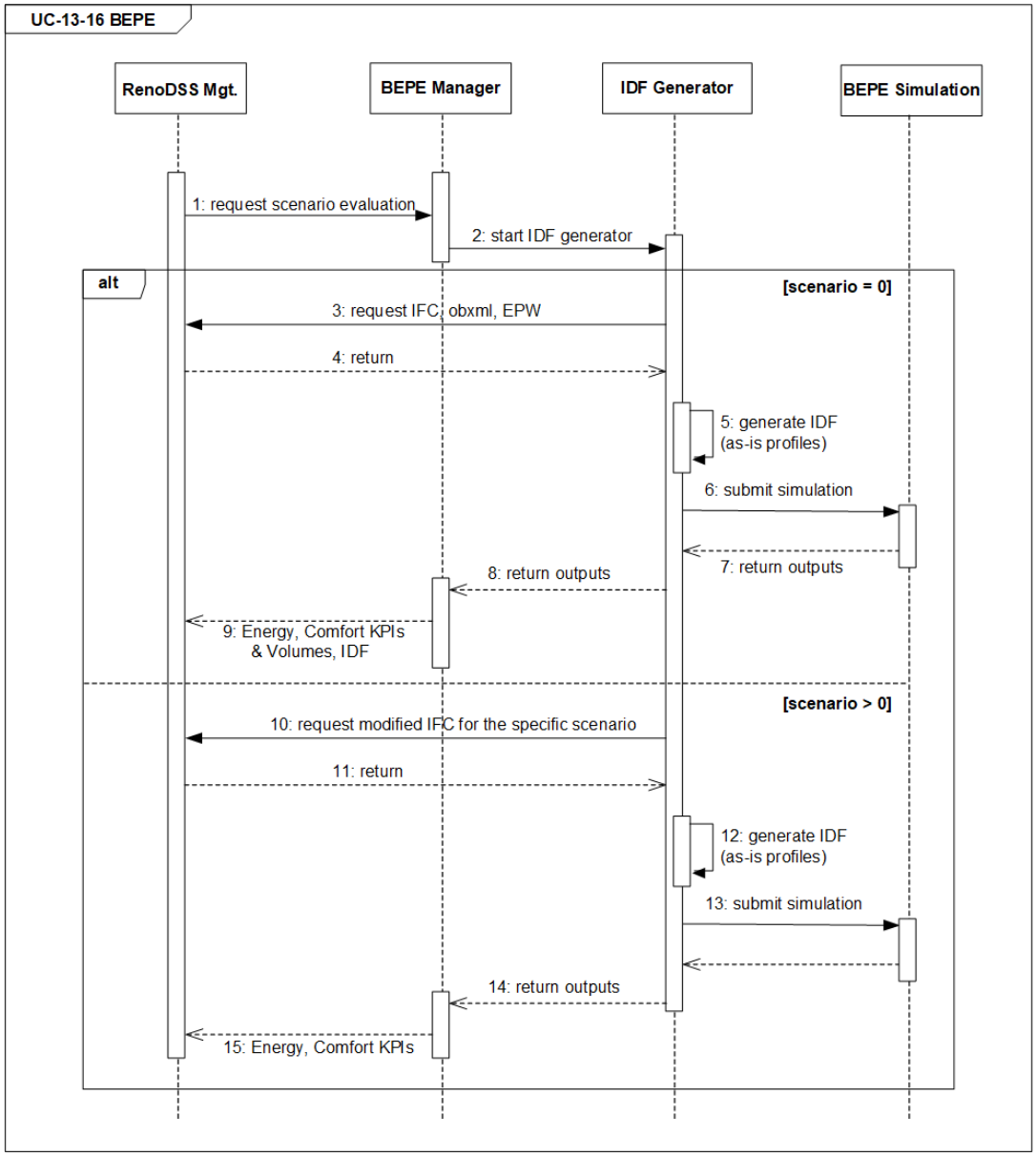

Figure 26: UC–13 to UC-16: Invoking BEPE and its subcomponents – Energy KPIs calculation process

Analyzing the energy KPIs calculation process, whenever the BEPE Manager receives a scenario evaluation, in terms of energy KPIs calculation, request from the RenoDSS data Management module, the IDF Generator module is triggered. We assume that each scenario has a unique, while the scenario with id value equals to 0 corresponds to the baseline. Considering this assumption, when the baseline evaluation is requested, a process of 6 steps is initiated (steps 3 to 9 of Figure 25): (1) the IDF generator sends a request for the relevant IFC, obXML and EPW files to the RenoDSS Data Management module; (2) retrieving the aforementioned from the RenoDSS Data Management module, (3) IDF generator is processing the content of the IFC file to generate the Input Data File of EnergyPlus simulation engine, while the co-simulation with the obXML, to take into account actual schedules based on data-driven occupant behavior models, is being established; then, the input data requirements for an EnergyPlus

simulation are met, and the IDF Generator submits a simulation request to the BEPE simulation module; when the simulation is completed, outputs/report files are populated and sent back to the IDF Generator to be forwarded to the BEPE Manager; finally, the ouputs/report files are processed within the BEPE Manager to populate a Json file with the KPIs that are sent to the RenoDSS Data Management module as the result of the baseline evaluation request.

An almost identical process is followed to handle requests of candidate renovation scenarios evaluation. The main difference occurs in the files requested and processed by the BEPE modules: since renovation measures affect and modify objects of the IFC file only, there is no need to resend the obXML and EPW files.

3.2.14 UC–14: Energy performance assessment to be elevated at a life-cycle perspective including relevant LCA-LCC metrics

In UC-14, the architect (renovation designer) uses again the RenoDSS application but now he/she examines the LCA-LCC aspects of the different renovation designs. To obtain the LCA-LCC KPIs for each renovation scenario, the RenoDSS Management module sends the modified LCA-LCC data model to the LCA-LCC module. The data model includes the quantity (e.g., m^3 or kg) and relevant LCA-LCC properties of the materials and components which are used in the renovation scenario. Relevant LCA-LCC properties were fetched from the building material and component database at the renovation scenario generation.

3.2.15 UC–15: Energy performance simulations to assess not only energy metrics, but also accurately evaluate occupants' comfort and indoor air quality

UC-15 is focused on the occupants' satisfaction and well-being after the renovation, so the renovation designer tries to optimize his/her proposal with respect to occupants comfort and hygienic requirements considering occupants comfort profiles regarding temperature, humidity, etc. The RenoDSS management module generates potential renovation scenarios, modifies the baseline IFC file and sends the modified IFC to the Building Energy Performance Estimation (BEPE) module. BEPE calculates comfort KPIs and returns them to the RenoDSS management module, which returns it to the RenoDSS UI for displaying it to the user.

3.2.16 UC–16: Assessment of energy performance to also address the district aspect and enable the consideration of interactions between buildings, but also between buildings and district systems in a holistic assessment framework incorporated in urban planning applications

Finally, UC-16 is about the renovated building performance as part of large-scale energy efficiency strategies applied at district level and its contribution to the realization of urban development's

strategies. To obtain the urban planning KPIs for each renovation scenario, the RenoDSS Management module sends the modified urban planning data model to the urban planning module. The data model includes energy production and consumption profiles of the given building (in the context of the given renovation scenario) and the surrounding buildings. The profiles for the given building are calculated by BEPE, the profiles of the surrounding buildings are provided by the renovation designer.

4. DETAILED DESCRIPTIONS OF COMPONENTS

Having presented in the previous chapter the architecture of the BIMERR, in this section we focus on presenting each component separately. Specifically, a detailed description of every component is structured using a predefined template that is presented in ANNEX V. The component template is focused on clarifying in greater detail the connections between the components, while providing information about each one's utilities. In particular, the input and output parameters must be completed with details of their format and data type, while the origin and the destination of each parameter must be stated. In this way, it is possible to spot the inconsistencies between the inputs and outputs of the components and it is easier to define the data flow. Moreover, part of the template is focused entirely on the needed sensors, gateways or infrastructure, to know in advance what kind of data will be available on each component.The main components that are analyzed are BIMERR Interoperability Framework (BIF), Middleware, Renovation Support Tools and Digital Building Model Creation Tools. Each one, except the middleware, is composed of multiple sub-components.

4.1 BIMERR INTEROPERABILITY FRAMEWORK

The BIMERR Interoperability Framework is based on the BIMERR ontology and the BIMERR data model in order to address the semantic and syntactic interoperability challenges that the data exchanges between the different BIMERR applications and tools entail. BIF's task is to understand, correlate the semantics of various data models through ontological linking and mapping techniques and to send the requested data models to the applications after first instantiating and populating them with the requested information using semantic search and reasoning capabilities. It contains four sub-components, the Building Information Query Builder, which manages information queries from the application, Building Semantic Modelling that performs semantic modelling and annotation of various data models, Building Information Collection & Enrichment, which has the task of populating the data models from different sources based on semantic links and lastly, Building Information Secure Provisioning that delivers the populated models to the requested application or tool in the appropriate manner.

4.1.1 Building Semantic Modelling

The core subcomponents of the Building Semantic Modelling component are:

The **Ontology Manager Framework**, a collaborative environment suite to support several ontology management activities, including the documentation, evaluation, versioning and publishing of the BIMERR ontology. The OMF documentation and visualisation tool extracts the ontology metadata and generates the documentation from relevant ontology metadata properties in the form of HTML pages. The OMF evaluation tool consists of: A) a common pitfall detector and B) an ontology verification module that will check whether the proposed ontological requirements are satisfied by the

ontology. The OMF versioning tool is based on a git-based system to store the history (current and previous versions) of an ontology. The OMF publishing tool helps to publish an ontology according to best practices (i.e., content negotiation, permanent URI) so that the ontology is available both in human oriented and machine-readable formats under a unique URI. Additionally, the OMF also contains a basic ontology-to-model converter that can be used to obtain the JSON serialisation of an ontology to be shared with the Model Lifecycle Manager to align the ontology and BIMERR data model.

Model Mapper that performs semi-automated mapping of the underlying data model of the data to be exchanged in BIF, to the BIMERR data model. In case the user has uploaded a data sample, the Model Mapper derives the underlying schema from the sample, estimates the mapping of the different concepts to the BIMERR data model with a varying confidence level, allows the user to define mapping reconciliations and transformation rules, and updates the configuration file (that is applied to the data whenever exchanged through the BIF) accordingly.

Model Lifecycle Manager, that is responsible for the evolution of the BIMERR data model and keeping the stored models and ontology aligned. In collaboration with the OMF, it checks regularly for new and obsolete terms in the state-of-the art data models and updates the BIMERR concepts. Furthermore, it allows the users to navigate to the different concepts of the BIMERR data model and understand their definition, as well as to propose new concepts, providing the related justification. Whenever a user's request for a new concept is accepted, this subcomponent coordinates with the Ontology Manager the update of the BIMERR data model and ontology, respectively.

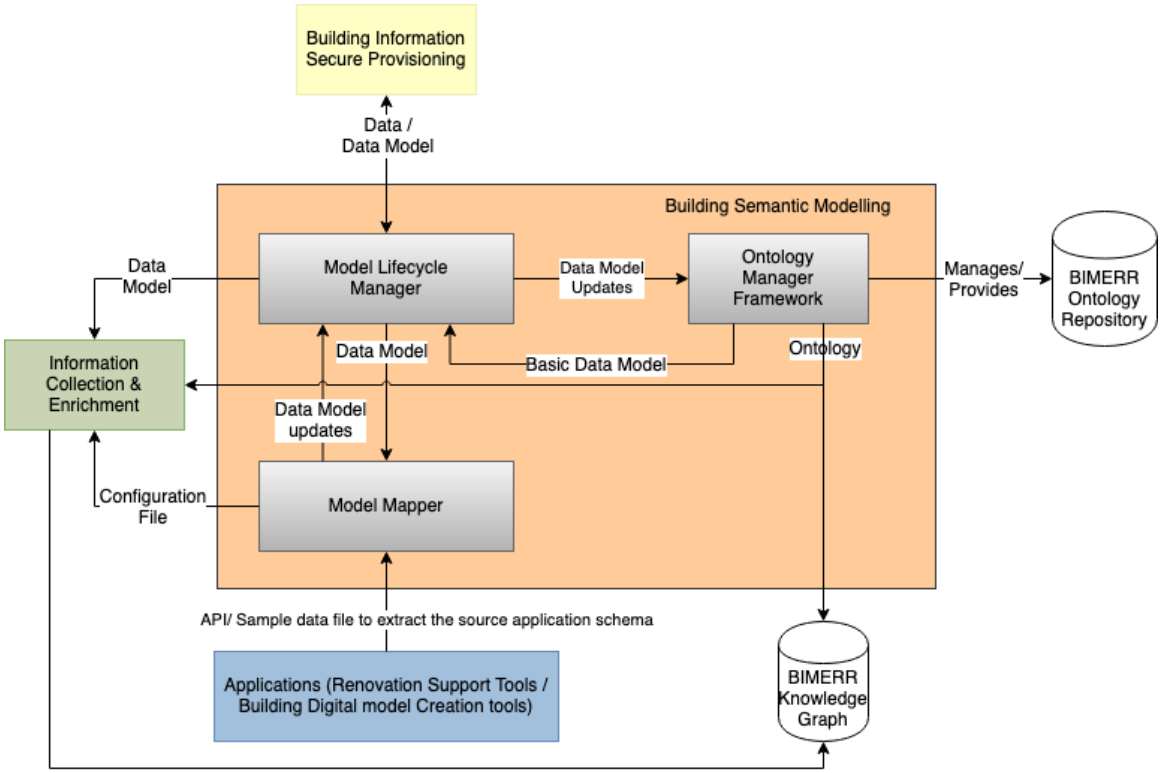

Figure 27: Building Semantic Modelling Architecture

Name of New Component/Service:	*Building Semantic Modelling*
Type:	*Component*
Functionality:	This component is responsible for the definition and maintenance of the BIMERR ontology and data model and their proper synchronization. In particular, this component handles the mapping, alignment and linking of various existing building data models / ontologies under the BIMMER data model / ontology. The user is able to retrieve and view models, either ones that are manually created, semi-automatically calculated or the JSON serialization of BIMERR ontology and adapt them manually through a friendly drag-n-drop BIF UI. The user can also upload a sample of the data that are to be exchanged through the BIF, on the Building Semantic Modelling component and derive the underlying data model. The Building Semantic Modelling component semi-automatically calculates the mapping from the (created) source data model to the BIMERR data model and requests from the user to make updates and corrections whenever needed. The user can make recommendations about potential complementary model concepts, and can also highlight the desired links between models (at class and property level), and mappings to ontologies, as well as any applicable unit transformations that need to take place, considering the baseline units of each concept in the BIMERR data model. After the mapping and the optional linking step, the mapping configuration is stored in the *Master Controller* subcomponent of the Information Collection & Enrichment component, that is responsible to provide it both "locally" to the applications and to the API/Wrappers of the Middleware while the enriched source data models that have been created can be transformed to the chosen format and finally be stored in the BIF storage and published publicly or privately. The component is also responsible for the evolution of the BIMERR data model / ontology (adding new concepts, updating existing concepts, etc.) and for ensuring that the existing mapping configurations remain valid (to the extent it is possible), through an ongoing *Semantic Model Lifecycle Management* process.
Input Connections & Interfaces: From which components it receives input	The *Building Semantic Modelling* component is responsible for: managing the BIMERR ontology and data model; generating the corresponding documentation; reporting the evaluation of the ontology and retrieving data models from various sources. Previously published models and mapping configurations are stored in the BIF storage and can be retrieved from there, if the user is authorised. The *Building Semantic Modelling* component communicates with the *Information Collection & Enrichment* component to be kept up-to-date and enrich the BIMERR data model / ontology with new concepts whenever dictated by the data submitted through the applications. External data models are retrieved from the Linked Open Data Cloud, Linked Data Vocabularies, Open Data Repositories, through LOD Connectors and APIs/ Wrappers. Data exchanges between the BIF and the other BIMERR components and tools are direct, while exchanges with legacy applications and sensors happen through the wrapper/APIs of the Middleware that are responsible to perform mappings and transformations on the data based on the mapping configuration file.
Output Connections & Interfaces: To which components it sends the results	The BIMERR data model and ontology produced and stored by the *Building Semantic Modelling* component can be queried by other BIMERR applications or by a user. In the case that the user queries an ontology, she will have the option to receive the JSON serialization of the corresponding ontology. These queries for data models are served through the *Building Information Secure Provisioning* component, which retrieves the models from the BIF storage and extracts the requested model. The mapping configurations are stored in the BIF storage and sent to the Middleware with the help of the Building Information Collection & Enrichment component and all the related BIMERR applications and legacy systems, where they are populated with data from various sources. As already mentioned, data exchanges between the BIF and the other BIMERR components/digital building model creation tools are direct, while exchanges with legacy applications and sensors happen through the wrapper/APIs of the Middleware.
Relevant Use Cases	*UC-01, UC-02, UC-04, UC-07, UC-11*
Functional Requirements	*BMRR-5-9, BMRR-11, BMRR-12, BMRR-14, BMRR-15-18, BMRR-22, BMRR-25-28, BMRR-30, BMRR-35, BMRR-36, BMRR-47-48, BMRR-55-57, BMRR-66-67, BMRR-69-71, BMRR-75, BMRR-81, BMRR-83-85, BMRR-88, BMRR-90, BMRR-92, BMRR-109-110*

Non-Functional Requirements	*BMRR-1-4, BMRR-20, BMRR-21, BMRR-38, BMRR-39, BMRR-40-42, BMRR-43, BMRR-87, BMRR-91*				
Input Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
User's BIM-related Data Model	The source data model with which a BIMERR application or the stakeholder's legacy system complies.	Text or Binary	IFCXML, STEP	N/A	BIM model directly uploaded on BIF or extracted from sample building data
User's BIM-related Data Sample	Sample data for a construction site in case a model is not available / can not be extracted from a BIMERR application or the stakeholder's legacy system.	Text	XML, JSON, CSV, TSV	N/A	Access to BIM Data Sample
Output Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Mapping Configuration	The applicable mapping and transformation rules from the user's source data model to the BIMERR model to be applied in the APIs / Wrappers prior to exchanging data with the BIMERR BIM.	Text	JSON	N/A	Required by the Middleware Required by the Building Information Collection& Enrichment component and all apps and legacy systems that are to be connected through the BIMERR BIF.
Enriched BIM-related data model / ontology	The enriched BIMERR data model and ontology that underpin the BIMERR activities.	Text	JSON, OWL	N/A	Required by the BIM Management Platform Required by the Building Information Secure Provisioning component in order to define the data access policies and extract the requested data model
Software Requirements/Development Language	Python				
Hardware Requirements	-				
Communications	RESTful APIs				
Status of the development of the component	Partially developed				

Table 1: Building Semantic Modelling Detailed Specifications

4.1.2 *Building Information Collection & Enrichment*

The core subcomponents of the Building Information Collection & Enrichment component are:

- Data Ingester & Fetcher: It ingests data from BIMERR applications, sensors, external legacy systems and data uploaded directly by stakeholders, after they have been transformed in the Middleware according to the mapping configuration file.
- Data Handler: The ingested data is processed as required prior to being used for the population of the BIMERR data model. This processing could imply validation and linking, as required.
- (Big) Data Storage: The processed data is stored in a NoSQL data storage modality, that allows the management of large datasets.
- (Big) Data Indexing: The stored data is indexed to facilitate faster search performance.
- Master Controller: It sends the current mapping configuration file that is applicable for a BIMERR-compliant application to the Middleware, whenever requested.
- Knowledge Graph Generator (KGG): It is responsible for generating knowledge graphs or the semantic representation of existing open data originating either from external data sources or from BIMERR BIF data store, through data translation allowing semantic querying over the translated data.

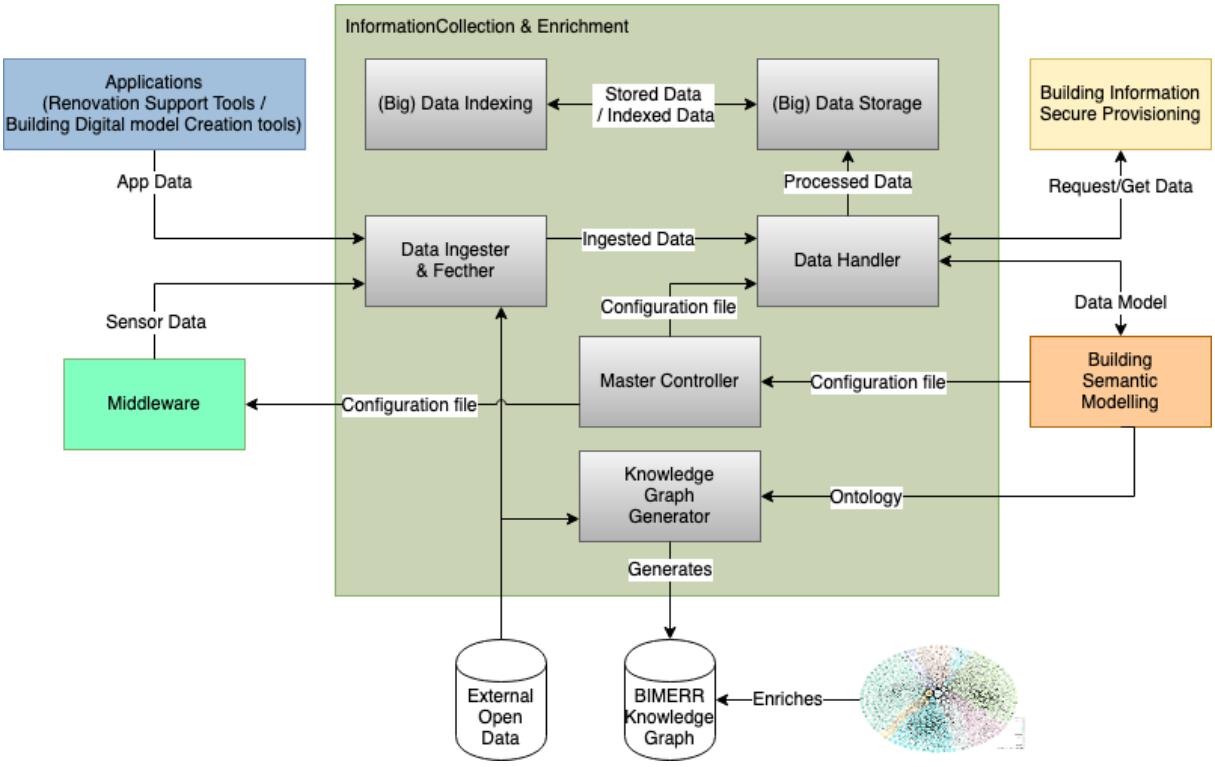

Figure 28: Building Information Collection & Enrichment Architecture

Name of New Component/Service:	*Building Information Collection & Enrichment*
Type:	Component
Functionality:	The *Building Information Collection & Enrichment* component is responsible for the instantiation of the BIMERR-derived BIM models and their population with data from the BIMERR building model creation tools (i.e. BIMERR applications and / or legacy systems). Such BIM-related data are ingested through APIs/wrappers provided by the *Middleware*, according to the mapping instructions produced by the *Building Semantic Modelling* component, and are then stored and indexed in BIF storage. These data and models are accessible by the *Building Information Secure Provisioning* component in order to grant access to other BIMERR applications or AEC stakeholders that submit queries through the *Building Information Query Builder.*
Input Connections & Interfaces: From which components it receives input	The *Building Information Collection & Enrichment* component receives the semantic models and the mapping configurations from the Building Semantic Modelling component. Real-time and batch data are ingested from the digital building model creation tools (scan-to-BIM, ARIBFA, BICA, PRUBS).. Data exchanges between the BIF and the other BIMERR components/digital building model creation tools are direct, while exchanges with legacy applications and sensors happen through the wrapper/APIs of the *Middleware*.
Output Connections & Interfaces: To which components it sends the results	Populated models and linked data produced from the *Building Information Collection & Enrichment* component, are stored in BIF storage, which is accessible by the *Building Information Secure Provisioning* component, in order to forward them to other BIMERR applications and stakeholders, while ensuring the enforcement of appropriate access policies.
Relevant Use Cases	*UC-01, UC-02, UC-07*
Functional Requirements	*BMRR-4, BMRR-5-9, BMRR-10, BMRR-11, BMRR-12, BMRR-13, BMRR-14, BMRR-15-18, BMRR-25-28, BMRR-30, BMRR-33, BMRR-34, BMRR-37, BMRR-47-48, BMRR-51-53, BMRR-55-57, BMRR-69-71, BMRR-75, BMRR-81-85, BMRR-88-90, BMRR-92, BMRR-97-100, BMRR-108*
Non-Functional Requirements	*BMRR-32, BMRR-39, BMRR-40-42, BMRR-86*

Input Parameters

Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
BIM-related Data	BIM-related Data for a construction site as extracted from a BIMERR application or the stakeholder's legacy system.	Text, Image - tbd	IFC, XML, JSON, CSV, TSV - tbd	N/A	BIMERR Applications, External Open/Linked Open Data Sources, Legacy Systems, Access to BIM Data Sample

Output Parameters

Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***

No outputs are provided by the specific component as the *Building Information Secure Provisioning* component is responsible for exposing them to the appropriate apps / stakeholders.	
Software Requirements/Development Language	Python for all sub-components apart from the Knowledge Graph Generator, Java or Scala or Node for the Knowledge Graph Generator
Hardware Requirements	-
Communications	RESTful APIs
Status of the development of the component	Building on existing prototype

Table 2: Building Information Collection & Enrichment Detailed Specifications

4.1.3 Building Information Query Builder

The core sub-components of the Building Information Query Builder component are:

- **Data Query Builder**: It provides a UI for the user to define the parameters of the data she needs. These parameters are used to build the actual data query, which is sent to the Query Handler to be handled.
- **Model Query Builder**: It provides a UI for the user to define the parameters of the model she needs or any pre-processing on the data. These parameters are used to build the actual data model query, which is sent to the Query Handler to be handled.
- **Query Handler**: It transforms and manages the different parts, clauses and filters that constitute a query, which is sent to the Building Information Secure Provisioning component to check the applicable access policies. Each well-formulated query that emerges as a part or the whole initial query is stored for future reuse by each stakeholder / application.

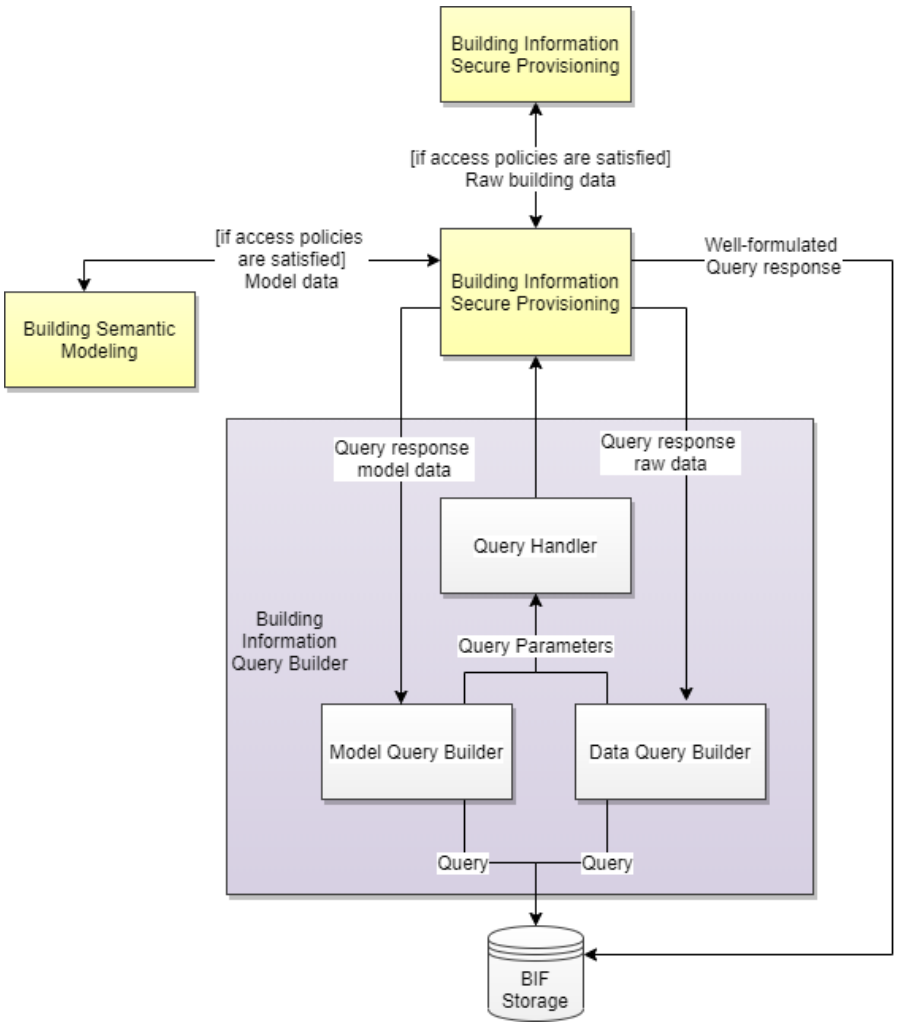

Figure 29: Building Information Query Builder Architecture

Name of New Component/Service:	*Building Information Query Builder*				
Type:	Component				
Functionality:	This component enables the user to request data and models from the BIF, through custom queries. The user can either retrieve an old query that has been stored in BIF, adapt it according to her needs and reuse it, or formulate a new query from scratch through the *Query Builder* UI. The query configuration allows for customisation on multiple levels: data fields, metadata and exact values or value range of field. After the query is built, the *Query Builder* sends the query data to the *Query Handler* that decomposes the query and forwards it to the *Building Information Secure Provisioning* component, which takes over and handles the access control procedures and the formulation of the query response. Once the response is ready, either the raw data of the query response or the well-defined query identifier will be sent to the *Query Builder* from where it can be viewed through the component's UI (for the different stakeholders) or retrieved through its API (for future use by the BIMERR applications).				
Input Connections & Interfaces: From which components it receives input	The user configures the query's parameters through the component's UI.				
Output Connections & Interfaces: To which components it sends the results	The queries that are built in the Query Builder are stored in the BIF storage for future reuse. The *Query Handler* component forwards the query parameters to the *Building Information Secure Provisioning* component, and will receive the raw data of the query response as input from the *Building Information Secure Provisioning* component after the query has been examined, or create a well-formulated query taking into account the data to which an application is authorized to have access.				
Relevant Use Cases	*UC-07*				
Functional Requirements	*BMRR-15-19, BMRR-35-37, BMRR-54-57, BMRR-68-71, BMRR-88-89*				
Non-Functional Requirements					
Input Parameters					
Attribute/ Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Name of concept belonging to the model	Any entity or attribute that is encountered in the BIMERR Data Model	String	UTF	N/A	UI or supporting tools interface
Filters	The upper level filters that the user applies to the query	String	UTF	depends upon specific filter	UI or supporting tools interface
Output Parameters					

Attribute/ Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Well-formulated query	A well-formulated query that requests for BIM-related data to which an application is entitled to have access	Text	JSON	N/A	UI or supporting tools interface BIF API
Raw query results	*Any raw data included in the query response*	*Text*	*JSON*	*N/A*	UI or supporting tools interface BIF API
Software Requirements/ Development Language	Python				
Hardware Requirements	-				
Communications					
Status of the development of the component	Will be developed as extension/upgrade of existing tool				

Table 3: Building Information Query Builder Detailed Specifications

4.1.4 Building Information Secure Provisioning

The Building Information Secure Provisioning Tool returns the requested data from the BIF and provides data protection, confidentiality and integrity. In order to proceed with the design and the definition of the Building Information Secure Provisioning Tool, the following requirements of the BIMERR system must be taken under consideration: a) the potential users (data providers and data consumers) of the BIMERR framework, as well as their datasets, can be registered to (or removed from) to the BIMERR platform any time, requiring a dynamic mechanism of controlling data access and being agnostic to the underlying datasets respecting the relevant access policies of each party, b) the BIMERR platform must handle the access policies applied by each party and respond to any level of complexity they might by defined, c) address the need of interoperability of the BIF and provide the requested data to the format that is supported by the relevant data consumer.

In order to respond to the aforementioned requirements the component implements a data access control mechanism using Attribute-Based Access Control (ABAC) policies, based on the XACML standard which allow the data providers to protect and share their data sets, even when they do not have any prior knowledge of the potential individual data consumers in the system. A proper separation of concerns between policy specification and policy enforcement shall be effectively pursued, while arbitrary attributes in policies will be dynamically enforced. In general, all XACML policies are expressed through: a) A Policy that refers to single access control expressed through a set of Rules, or b) A PolicySet, which acts as a container that can hold other Policies or PolicySets, as well as references to policies found in remote locations.

The core subcomponents of the Building Information Security Provisioning tool are:

- **Access Policy Management**: It provides a policy administration point and is responsible for validating an access request against the specified policies. The component provides an API and a user interface for the definition and the management of the policies that need to be applied to a specific dataset.
- **Policy Enforcement Business Logic**: Issues native requests for accessing the data and receives responses for accessing the dataset. It also receives and forwards the final access response to the requestor. If access is permitted, then the subcomponent permits access to the resource; otherwise, it denies access.
- **Access Request Transformation Handler**: It transforms the native access request to the internal format and reconstructs the request by extending it with additional attributes provided necessary for the validation of the relevant access policies rules.
- **Attributes Handler**: It collects the requested additional attributes which are needed in order to validate an access policy. These attributes include the attributes of the subjects, resource, action, environment. The subject represents any user or organization that has been uniquely

identified and authenticated. The resource refers to the dataset, the action consists of the operations to be performed on the resource (eg. read-only, write, download etc.) while the environment refers to the current state of the system's environment, the current session of a user etc.

The reference architecture of the component is shown below:

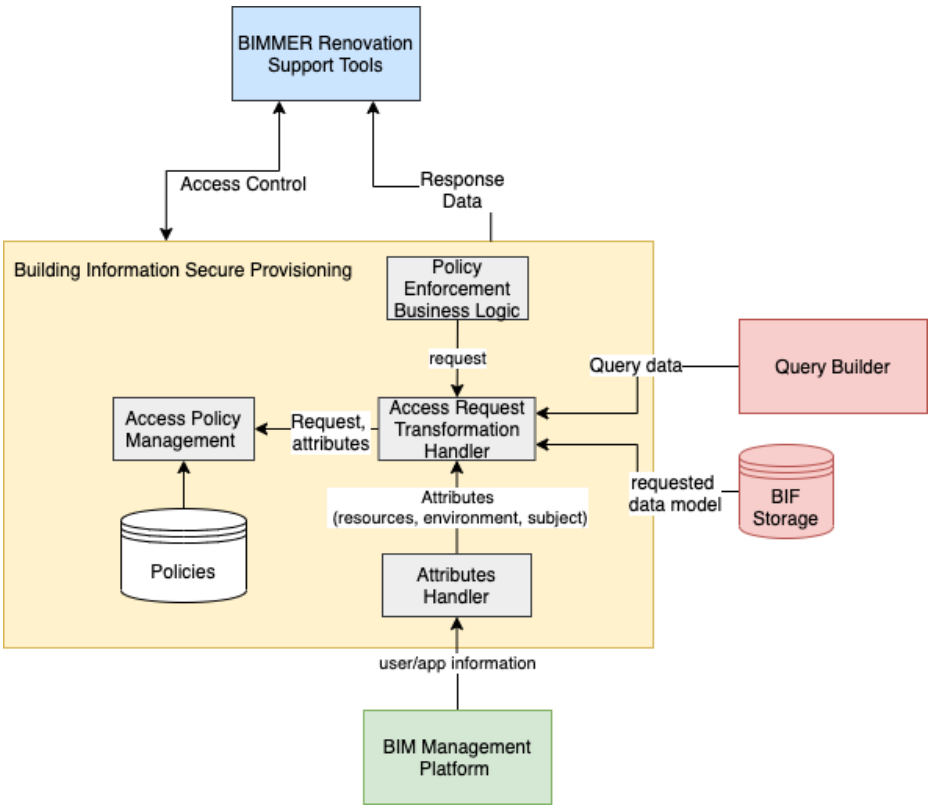

Figure 30: BISP Architecture

Name of New Component/Service:	*Building Information Security Provisioning Tool*				
Type:	*Component*				
Functionality:	*This component provides a mechanism to: (a) define the access policies supported by the BIMMER Platform, (b) enforce the access policies by translating them to specific access requests, (c) returns access controll (allow/not allow) on the various BIMMER data, based on a set of environment attributes (eg. BIMMER user role, organization user role, organization etc.)*				
***Input Connections & Interfaces:* From which components it receives input**	*Policy Interface: an interface or API to manage the policies that are stored in the repository by a specific BIMMER actor.* *Context interface: an interface or API to manage the various environment attributes, subjects, requests etc. repository by a specific BIMERR actor.*				
***Output Connections & Interfaces:* To which components it sends the results**	*BIMMER Building Information Query Builder*				
Relevant Use Cases	*UC-01, UC-02, UC-04, UC-07, UC-11*				
Functional Requirements	*BMRR-5-9, BMRR-11, BMRR-12, BMRR-14, BMRR-15-18, BMRR-22, BMRR-25-28, BMRR-30, BMRR-35, BMRR-36, BMRR-47-48, BMRR-55-57, BMRR-66-67, BMRR-69-71, BMRR-75, BMRR-81, BMRR-83-85, BMRR-88, BMRR-90, BMRR-92, BMRR-109-110*				
Non-Functional Requirements	*BMRR-1-4, BMRR-20, BMRR-21, BMRR-38, BMRR-39, BMRR-40-42, BMRR-43, BMRR-87, BMRR-91*				
Input Parameters					
Attribute/ Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Access policies	*The access policies of the BIMMER data sources*	*String*	*json*	*Controled list (tbd)*	*UI or exposed API*
Data Access requests	*The application/tool specific access requests to BIMERR data sources*	*String*	*json*	*Controled list (tbd)*	*UI or exposed API*
Environment attributes	*The various attributes from the resource to be accessed, environment (e.g. time), subjects, and so forth, which are needed for the evaluation of the access policy*	*String*	*json*	*Controled list (tbd)*	*UI or exposed API*
Output Parameters					
Attribute/ Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Access control permission (allow/not allow)	*The response (allow/not allow) on the access request*	*String*	*json*	*Controled list (tbd)*	*UI or exposed API*

Software Requirements/ Development Language	*Spring Boot web application (JPA, MySQL)* *Drools* *XACML* *REST*
Hardware Requirements	*Virtual Machine with at least 2GB of RAM and 10 GB Storage.*
Communications	
Status of the development of the component	*Will be developed as extension/upgrade of existing tool*

Table 4: Building Information Security Provisioning Tool Detailed Specifications

4.2 BIMERR MIDDLEWARE

BIMERR middleware provides the services to facilitate the communication between BIMERR applications and external legacy applications or sensors. The middleware is designed based on multiple microservices deployed both at the cloud and the edge locations with the intention of effective usage of the resources and ensuring the security of the infrastructure and privacy of the user data. The BIMERR middleware uses various generic components, mainly from the open source IoT platform Linksmart (https://linksmart.eu/).

Different components of the middleware can be combined to interact with each other to achieve a common goal. For example, for integrating IoT devices to the BIMERR framework, device abstractor is used. The data collected by the device abstractor and their corresponding metadata is stored in registry and data storage service. Data processor performs several aggregation and complex processing tasks to prepare the sensor data. Gateway security provides access management for accessing the services running in the edge. OTA Software update & monitoring tool performs the monitoring and updating of the running services in the edge.

BIMERR Middleware is also used to connect legacy components such as weather forecasts to the BIMERR system. In this scenario data processing, registry & data storage are the required components. In addition, OPA update & service Monitoring can be used for monitoring the service functionality if the legacy systems are to be integrated in the edge. Gateway security is also an additional component to be used if needed.

Service Registry is a catalog of available services in a deployment. Other services can use this registry to locate the required services. This can be useful for integration of both IoT and legacy applications.

4.2.1 Service Registry

The BIMERR system operates on multiple interconnected networks consisting of numerous web services. Particularly, the services which are exposed as part of the middleware are standalone components, often unaware of other services configurations and dynamic endpoints. Thus, it is necessary to provide a registry maintaining meta information about all the services. Each service will be responsible for submitting the required meta information (incl. endpoints, API specs, public key) of itself to the registry such that other services can retrieve them. The BIMERR service registry is will be implemented on top of the open-source LinkSmart Service Catalog (https://docs.linksmart.eu/display/SC).
The Service Catalog describes the services available in the network and exposes a JSON-based MQTT and RESTful HTTP APIs. It contains entries of everything that is meant to be discovered or interacted with by applications and other services.

Name of New Component/Service:	*Service Registry*				
Type:	*Software Component*				
Functionality:	The Service Registry is an entry point for web services in the BIMERR Middleware. Its functionality mainly covers the discovery of available services by means of RESTful APIs.				
***Input Connections & Interfaces:* From which components it receives input**	*Internal middleware services*				
***Output Connections & Interfaces:* To which components it sends the results**	*Internal middleware services*				
Relevant Use Cases	*UC-03, UC-07*				
Functional Requirements	• The component must maintain a registry of services • The component must provide a data model capable of describing all meta data required to discover BIMERR middleware services • The component must expose RESTful methods to perform CRUD operations on service objects				
Non-Functional Requirements	• The component must offer a consistent and reliable registry of services				
Input Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Service registration document	Document describing the service	*Object*	*JSON*	*OpenAPI specs: https://docs.linksmart.eu/display/SC/Service+Catalog+API*	*Internal middleware services and services exposed by the middleware*
Output Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Service registration document	Document describing the service	*Object*	*JSON*	*OpenAPI specs: https://docs.linksmart.eu/display/SC/Service+Catalog+API*	*All BIMERR components*
Software Requirements/Development Language	*The software is being developed in Go, released for multiple operating systems (windows, linux, darwin) and also packaged in Docker images*				
Hardware Requirements	*Hardware architecture: AMD64, ARM32, ARM64*				

Communications	*TCP/IP*
Status of the development of the component	*Partially developed*

Table 5: Service Registry Detailed Specifications

4.2.2 OTA Software Update & Monitoring

There will be an instance of the BIMERR middleware in every renovation site, integrating local services with other BIMERR components. These instances will be deployed on gateway devices with restricted connectivity and limited interfaces. The increase in the number of middleware instances and internal services is followed by additional complexity involved in the software provisioning. The OTA Software Update and Monitoring component provides the necessary tooling and abstraction to simplify software provisioning in remote gateways. Concretely, the component provides a usable interface to the software deployer to perform bulk software update operations and monitor the progress and runtime activities of the components.

Name of New Component/Service:	*OTA Software Update & Monitoring*
Type:	*Software Component*
Functionality:	*Bulk software updates, debugging and runtime monitoring of software in remote gateway devices.*
***Input Connections & Interfaces:* From which components it receives input**	*All middleware components*
***Output Connections & Interfaces:* To which components it sends the results**	*All middleware components*
Relevant Use Cases	*UC-03, UC-07*
Functional Requirements	• The component must maintain a list of target devices • The component must allow updating the non-system software on devices • The component must provide metrics about the update status • The component must expose update and runtime logs for debugging purposes

Non-Functional Requirements	• The component must provide secure APIs for all expected operations • The component must be aware of local computing resources during the update to avoid runtime issues • The component must offer an intuitive interface to simplify bulky and remote operations • The component should have minimal computing footprints on devices

Input Parameters

Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Software package	*Package to be deployed on the device*	*Object*	*JSON*	*N/A*	*User*
Update instructions	*Scripts and configurations for the update*	*Object*	*JSON*	*OpenAPI specs: https://app.swaggerhub.com/apis/farshidtz8/deployment-tool/0.9.0*	*User*

Output Parameters

Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Update logs	*Log output of the updates*	*Object*	*JSON*	*OpenAPI specs: https://app.swaggerhub.com/apis/farshidtz8/deployment-tool/0.9.0*	*User*
Devices	*List of devices*	*Object*	*JSON*	*OpenAPI specs: https://app.swaggerhub.com/apis/farshidtz8/deployment-tool/0.9.0*	User

Software Requirements/Development Language	*The software is being developed in Go, supporting multiple operating systems (linux, darwin) platforms and also packaged in Docker images*
Hardware Requirements	*Hardware architecture: AMD64, ARM32, ARM64*
Communications	*TCP/IP*
Status of the development of the component	*Partially developed*

Table 6: OTA Software Update & Monitoring Detailed Specifications

4.2.3 Gateway Security

Gateway security module provides a single point of entry into the IoT autonomous system (IoT AS) consisting of connected devices and services and their messaging infrastructure. In the context of BIMERR, an autonomous system would be either in cloud or edge. This provides an exposed interface which would be a single-entry point for all the services exposing HTTP, MQTT and WebSockets. Authentication and authorization of the external clients happens with the help of an Identity provider placed as part of BIF. This is partially developed as Linksmart Border Gateway (https://docs.linksmart.eu/display/BGW).

Name of New Component/Service:	*Gateway security*
Type:	*Software Component*
Functionality:	▪ *Proxy for all services and devices present in an IoT Autonomous system* ▪ *Authentication and authorization for HTTP, MQTT and WeSocket requests*
Input Connections & Interfaces: From which components it receives input	▪ *BIF* ▪ *All other BIMERR components using border gateway for proxying*
Output Connections & Interfaces: To which components it sends the results	▪ *BIF* ▪ *All other BIMERR components using border gateway for proxying*
Relevant Use Cases	*UC-03, UC-07*
Functional Requirements	▪ *TLS offloading at the edge of the protected anonymous system for HTTPS, TLS encrypted MWTT, TLS encrypted WebSocket* ▪ *Authentication and authorization for HTTP, MQTT and WebSocket requests* ▪ *HTTP request forwarding to internal services according to configured location definitions* ▪ *Address translation of HTTP requests*
Non-Functional Requirements	▪ *Support edge devices and hence lightweight* ▪ *Support for well-known openID providers*

Input Parameters					
Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Incoming access requests	▪ Incoming HTTP requests ▪ MQTT subscription or publication requests for a specific topic ▪ WebSocket connection requests	*any*	*any*	*NA*	*clients accesing the services*
Authorization rules	Set of rules for allowing or disallowing certain methods	Object	JSON	This API is described in the Open API specification https://docs.linksmart.eu/display/BGW/Border+Gateway+Auth+Service+OpenAPI+documentation	administrative tools
Output Parameters					
Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Authorization response	*response stating whether the client has access to the service or not*	*Object*	*JSON*	*NA*	*clients accessing the services*
Software Requirements/Development Language		*The software is being developed in Go, supporting multiple operating systems (linux, darwin) platforms and also packaged in Docker images*			
Hardware Requirements		*Hardware architecture: AMD64, ARM32, ARM64*			
Communications		*TCP/IP*			
Status of the development of the component		*Partially developed*			

Table 7: Gateway Security Detailed Specifications

4.2.4 Data Processor

Data Processor is responsible for stream based or batch-based transformation, annotation and aggregation of the data arriving from multiple sources. This component uses different statistical and machine learning functions for extracting different insights from the raw, aggregated or fused data to get actionable insights from the data. The data processors can be deployed at multiple stages of the network to produce insights at different levels ranging from the site location to the BIMERR cloud. The processors are deployed as micro-services and can be triggered conditionally or periodically

Name of New Component/Service:	*Data Processor*
Type:	*Software Component*
Functionality:	▪ Transformation of the data to a required format/scale ▪ Annotation of the data ▪ Data fusion ▪ Data aggregation ▪ Data filtering ▪ Machine learning and prediction ▪ Triggering of events whenever certain conditions are met by the input data
Input Connections & Interfaces: ***From which components it receives input***	▪ Registry and Storage service ▪ Device abstractor ▪ PRUBS (through BIF)
Output Connections & Interfaces: ***To which components it sends the results***	▪ Registry and Storage service ▪ PRUBS (through BIF)
Relevant Use Cases	UC-03, UC-07
Functional Requirements	• Data Processor must support transformation of the data to a required format/scale • Data Processor must support annotation of the data • Data Processor must support data fusion • Data Processor must support data aggregation • Data Processor must support data filtering • Data Processor must support machine learning and prediction • Data Processor must support triggering of events whenever certain conditions are met by the input data

Non-Functional Requirements				▪ Data Processor must be easy to deploy ▪ Data Processor must provide usable APIs or interface ▪ Data Processor must have lower latency ▪ Data Processor may support multi tenancy with access control	
Input Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Time series data	*Input data streams which are indexed with time.* *This can be sensor measurement, event or output from other data processors*	*Object, number, string, boolean*	*JSON*	*changes with input data type*	Registry and Data Storage service Data processors Device abstractor PRUBS
Output Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Time series data	*Output data streams which are indexed with time*	*Object, number, string, boolean*	*JSON*	*Changes based on input data type*	Registry and Data Storage service PRUBS Data processors
Machine learning models	*models derived after training*	*Object*	*PMML*	*-*	*Data Processor*
Software Requirements/Development Language				*Mainly in Python*	
Hardware Requirements				*Hardware architecture: AMD64, ARM32, ARM64*	
Communications				TCP/IP	
Status of the development of the component				*to be developed from scratch*	

Table 8: Data Processor Detailed Specifications

4.2.5 Registry and Data Storage

Registry and Data Storage services are the microservices responsible for storage and orchestration of sensor measurements data across the edge (building location) and BIMERR cloud. The storage takes care of time series data and is designed to run on low powered and single-board computers. Metadata related to the series will be stored in the registry which shall act as the directory of available data sources. The data store provides MQTT or HTTP based APIs to external services and devices. The Sensor Measurement Lists (SenML) specified in RFC 8428 is used as the data format for storage and retrieval. The storage shall automatically synchronize across the cloud and the edge devices to ensure availability. By using the edge storage, it reduces the latency of communication between the edge and the cloud. On top of it, the Storage service ensures that private data does not leave the user premises. Aggregated information is sent to the cloud either in real-time or on request. The component is partially developed as part of Linksmart historical datastore (https://docs.linksmart.eu/display/HDS).

Name of New Component/Service:	Registry and data storage
Type:	*Software Component*
Functionality:	▪ *Time-series data storage and retrieval* ▪ Registry of data sources (sensors or processing services) ▪ Aggregation and retention of data ▪ Targetting low power and single-board computers
Input Connections & Interfaces: From which components it receives input	▪ *Sensors* ▪ *Legacy applications* ▪ *Data processors* ▪ *BIMERR Interoperability Framework*
Output Connections & Interfaces: To which components it sends the results	• *BIMERR Interoperability Framework*
Relevant Use Cases	*UC-03, UC-07*
Functional Requirements	▪ The service must provide provisions to CREATE, UPDATE, DELETE and READ (CRUD) new registry entries ▪ The service must provide provisions to CREATE and READ time-series measurements ▪ The service may be able to automatically delete/migrate/compress the data in order to reduce the storage requirements with time

Non-Functional Requirements	▪ The service must ensure *availability* by keeping sufficient replications ▪ The service must ensure *privacy* by protecting the user data and by supporting privacy-preserving techniques ▪ The service must respond to the requests from clients as soon as possible

Input Parameters

Attribute/Para-meter	*Short Description*	*Data Type*	*Data Format*	*Value Range & Frequency*	*Data Received From*
Registry entry	*Metadata related to the time series datastream*	*JSON Object*	*JSON*	*Shall follow Open API specification currently specified in https://docs.linksmart.eu/display/HDS/OpenAPI+Documentation*	*Device abstraction service Data Processors Legacy applications BIF Information Collection & enrichment*
Time series data	*actual data to be stored*	*JSON object*	*JSON*	*Shall follow Open API specification currently specified in https://docs.linksmart.eu/display/HDS/OpenAPI+Documentation*	*Device abstraction service Data Processors BIF Information Collection & enrichment*

Output Parameters

Attribute/Para-meter	*Short Description*	*Data Type*	*Data Format*	*Value Range & Frequency*	*Data Sent To*
Registry entry	*Metadata related to the datastream*	*JSON Object*	*JSON*	*Shall follow Open API specification currently specified in https://docs.linksmart.eu/display/HDS/OpenAPI+Documentation*	*BIF Information Collection & enrichment*
Time Series data	*actual data to be stored*	*JSON Object*	*JSON*	*Shall follow Open API specification currently specified in https://docs.linksmart.eu/display/HDS/OpenAPI+Documentation*	*BIF Information Collection & enrichment*

Software Requirements/Development Language	*The software is being developed in Go, released for multiple architectures and packaged in Docker images*

Hardware Requirements	*Hardware architecture: AMD64, ARM32, ARM64*
Communications	*TCP/IP*
Status of the development of the component	*Partially developed*

Table 9: Registry and Data Storage Detailed Specifications

4.2.6 Device Abstraction

Device abstractor offers simple integration to various IoT devices by abstracting the low-level access protocol and a TCP/IP network. In general, the low-level access protocols shall be translated to BIMMERR compatible formats and vice versa. The gateway also exposes APIs to the other services in order to read the sensor measurements and for actuation purposes. This solution is partially implemented as part of Linksmart Device Gateway (https://docs.linksmart.eu/display/DGW).

Name of New Component/Service:	*Device abstraction*
Type:	*Software Component*
Functionality:	▪ The abstraction of IoT devices to support BIMERR supported protocols and data formats ▪ Running locally: mostly attached to the sensing devices or gateways ▪ Exposure of device capabilities and recorded measurements as service endpoints
Input Connections & Interfaces: ***From which components it receives input***	▪ Sensors
Output Connections & Interfaces: ***To which components it sends the results***	▪ PRUBS (through BIF) ▪ Registry & Data storage
Relevant Use Cases	UC-03
Functional Requirements	▪ Provide pluggable device support ▪ Expose APIs of devices/resources via BIMERR standardized APIs and protocols (HTTP/REST, MQTT, etc) ▪ Must register the devices automatically ▪ Natively compiled for major platforms and architectures ▪ No modification/re-compilation of the service for a newly added device

<table>
<tr><td colspan="3"><u>Non-Functional Requirements</u></td><td colspan="4">▪ User-friendly configuration
▪ Lightweight processing requirements
▪ Authentication and authourization for exposed APIs</td></tr>
<tr><td colspan="7"><u>Input Parameters</u></td></tr>
<tr><td colspan="2">Attribute/Parameter</td><td>Short Description</td><td>Data Type</td><td>Data Format</td><td>Value Range & Frequency</td><td>Data Received From</td></tr>
<tr><td colspan="2">Sensor measurements</td><td>Sensor measurements in the form of standard inputs (stdin)</td><td>string, number (float or double), blob, boolean</td><td>Configurable</td><td>configurable</td><td>sensors</td></tr>
<tr><td colspan="7"><u>Output Parameters</u></td></tr>
<tr><td>Attribute/Para-meter</td><td colspan="2">Short Description</td><td>Data Type</td><td>Data Format</td><td>Value Range & Frequency</td><td>Data Sent To</td></tr>
<tr><td>Device Registration</td><td colspan="2">Control message for registering the device in Registry and Storage service</td><td>JSON object specifying the properties of the newly conected device</td><td>JSON</td><td>-</td><td>▪ Registry & Data storage</td></tr>
<tr><td>Sensor measurements</td><td>Sensor measurements in the form of standard inputs (stdin)</td><td>string, number (float or double), blob, boolean</td><td>Configurable</td><td>configurable</td><td>sensors</td><td>▪ PRUBS (through BIF)
▪ Registry and Data Storage service</td></tr>
<tr><td colspan="3">Software Requirements/Development Language</td><td colspan="4">The software is being developed in Go, released for multiple architectures</td></tr>
<tr><td colspan="3">Hardware Requirements</td><td colspan="4">Hardware architecture: AMD64, ARM32, ARM64</td></tr>
<tr><td colspan="3">Communications</td><td colspan="4">TCP/IP</td></tr>
<tr><td colspan="3">Status of the development of the component</td><td colspan="4">Partially developed</td></tr>
</table>

Table 10: Data Abstraction Detailed Specifications

4.3 RENOVATION SUPPORT TOOLS

The BIMERR renovation support tools include the BIMERR Renovation Decision Support System (RenoDSS) and the Process & Workflow Modelling and Automation toolkit (PWMA). Renovation Support Tools allow designers and project managers to explore alternative renovation scenarios and provides solutions to enhance the renovation process. Specifically, it consists of two major sub-components: (1) the RenoDSS: Renovation Decision Support System and; (2) the Process & Workflow Modelling and Automation toolkit (PWMA). The former contains the Building Energy Performance Estimation module, the Life Cycle Cost/Life Cycle Assessment module and the Urban Planning module, while the latter contains the Innovative Business Process Modelling (IBPM) and the Workflow automation tools and on-site guidance. Scope of RenoDSS and its sub-components is to evaluate the performance of candidate renovation measures by computing specific economic, energy and life-cycle management KPIs, while, the PWMA and its sub-components aim to optimize the renovation process by modelling the process and the workflow, including information exchange between the stakeholders, enabling the workflow management to be adaptable to changes, providing an Augmented Reality application for on-site guidance of relevant stakeholders and by developing an application for building residents to be notified about specific parts of the renovation.

4.3.1 RenoDSS: Renovation Decision Support System

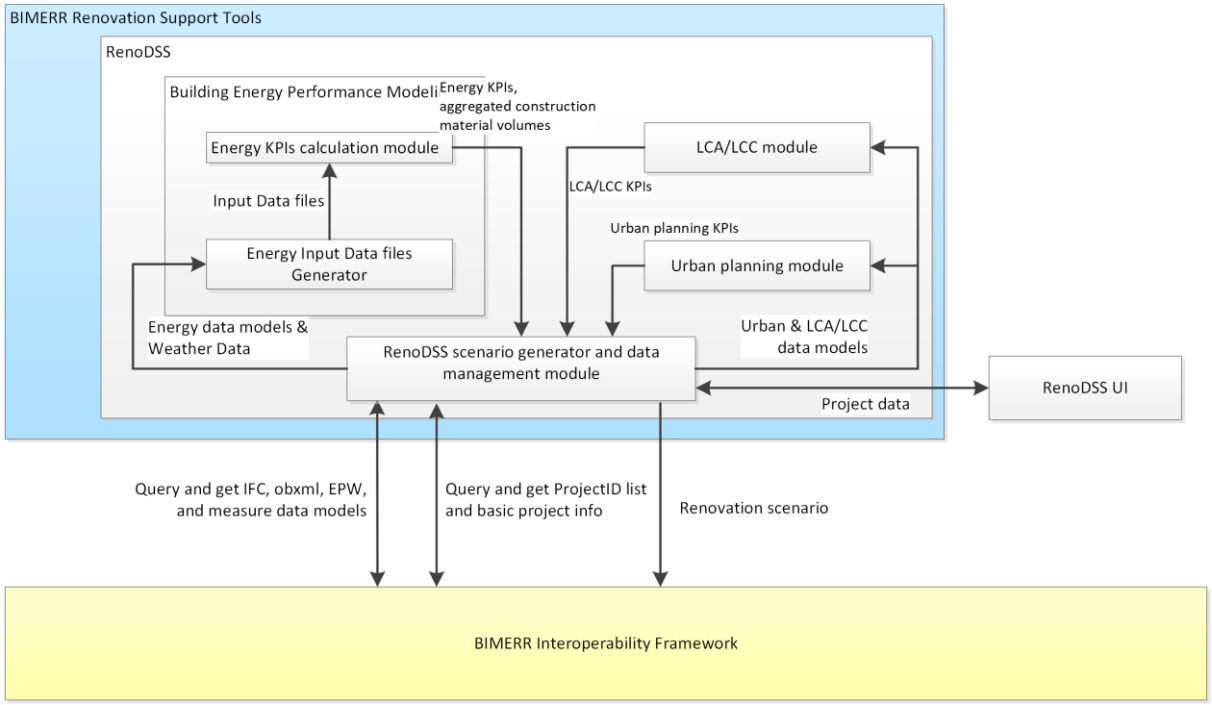

Figure 31: RenoDSS Architecture

RenoDSS supports the user at identifying renovation scenarios based on relevant energy, sustainability, and economic KPIs. RenoDSS consists of the following modules: RenoDSS scenario generator and data management module, building energy performance estimation module, LCA/LCC module, urban planning module, and RenoDSS UI.

4.3.1.1 RENODSS SCENARIO GENERATOR AND DATA MANAGEMENT MODULE

Based on the RenoDSS data models retrieved from the BIMERR Interoperability Framework (BIF), this module 1) creates renovation scenarios, 2) creates (for each renovation scenario) the energy data model and weather data as required by the building energy performance estimation module, 3) creates (for each renovation scenario) the urban planning data model as required by the urban planning module, 4) creates (for each renovation scenario) the LCA/LCC data model as required by the LCA/LCC module, and 5) sends calculated KPIs, building configuration, Scenario ID, and Project ID to the BIF project repository.

Name of New Component/Service:	RenoDSS scenario generator and data management module
Type:	Component
Functionality:	Based on the RenoDSS data model retrieved from the BIMERR Interoperability Framework (BIF) this module: • Creates renovation scenarios • Creates the energy data model and weather data as required by the building energy performance estimation module • Creates the urban planning data model as required by the urban planning module • Creates the LCA/LCC data model as required by the LCA/LCC module • Sends calculated KPIs, building configuration, Scenario ID, and Project ID to the BIF project repository
Input Connections & Interfaces: From which components it receives input	This component queries the BIF via an API call and expects the baseline (as-is) building RenoDSS data models and corresponding weather data. The output of all RenoDSS modules (KPIs, aggregated construction material volumes) is received as input.
Output Connections & Interfaces: To which components it sends the results	This component sends its output to the building energy performance estimation module (energy data model and weather data), the LCA/LCC module (LCA/LCC data model), and the urban planning module (urban planning data model). Calculated KPIs, building configuration, Scenario ID, and Project ID are sent to BIF to be stored in the Project Repository.
Relevant Use Cases	*UC-03, UC-04, UC-13, UC-14, UC-15, UC-16*

Functional Requirements	• The module must be able to ○ retrieve a trigger (from the RenoDSS UI) that it should load a certain data model, generate renovation scenarios, and trigger the remaining RenoDSS modules ○ generate renovation scenarios which are technically feasible and are compatible to the user's requirements with regard to its desired renovation measures ○ quit the generation of renovation scenarios if the process takes too long, because of too many combinations ○ create for each renovation scenario an energy data model according to the requirements of the energy performance estimation module ○ provide weather data to the energy performance module in the specified format ○ create for each renovation scenario an urban planning model according to the requirements of the urban planning module ○ create for each renovation scenario a LCA/LCC data model according to the requirements of the LCA/LCC module ○ store KPIs which have been calculated by the energy performance, urban planning, and LCA/LCC module ○ store the aggregated construction material volumes from the energy performance estimation module and provide them to the LCA/LCC module ○ transmits calculated KPIs, building configuration, scenario ID, and project ID for each renovation scenario and the baseline scenario to the BIF
Non-Functional Requirements	• Reliability: the module has to fetch error messages of the remaining RenoDSS modules and report them to the RenoDSS UI • Response time: calculating all KPIs for too many renovation scenarios can lead to long response times. Therefore, the run time for each renovation scenario should be kept as short as possible. • Accuracy: the RenoDSS data model retrieved from BIF, has to include all necessary data for generating energy, urban planning, and LCA/LCC data models. If not, an appropriate error message has to be shown to the user. • Computational capacity: the computational capacity of the module must be sufficient to generate the required number of renovation scenarios

Input Parameters

Attribute/Parameter	Short Description	Data Type	Data Format	Value Range & Frequency	Data Received From
ProjectID	Project ID	GUID	-	N/A	RenoDSS UI
Energy KPIs	-	JSON objects	JSON	per renovation scenario	Building energy performance estimation module

Aggregated construction material volumes	-	JSON objects	JSON	per renovation scenario	Building energy performance estimation module
Urban planning KPIs	Urban planning KPIs	JSON objects	JSON	per renovation scenario	Urban planning module
Urban planning energy network data	Energy network data in CityGML compatible format	CityGML data structure	XML	per project ID	Urban planning module
LCA/LCC KPIs	-	JSON objects	JSON	per renovation scenario	LCA/LCC module
Output Parameters					
Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Sent To**
Building configuration	Building configuration, i.e., renovation scenarios created by the RenoDSS scenario generator	Complex type	IFC4 (XML)	For each renovation scenario	BIF Project Repository
Calculated KPIs	KPIs calculated by building energy performance estimation, LCA/LCC, and urban planning module	JSON objects	JSON	For each renovation scenario	BIF Project Repository
Energy data model	Containing all data to compute energy KPIs	IFC data structure	XML	For each renovation scenario	Building energy performance estimation module
Weather data	Containing relevant weather data to compute energy KPIs	EPW data structure (CSV)	EPW	For each renovation scenario	Building energy performance estimation module
Urban planning data model - Part 1	Containing all data to compute urban planning KPIs	JSON objects	JSON	per renovation scenario	Urban planning module

Urban planning data model - Part 2	Energy network data	Complex type	XML	per project	Urban planning module
LCA/LCC data model	Containing all data to compute LCA/LCC KPIs	JSON objects	JSON	For each renovation scenario	LCA/LCC module
Software Requirements/Development Language			Java		
Hardware Requirements			Scenario generator might require special hardware, depending on its implementation.		
Communications			-		
Status of the development of the component			To be developed from scratch.		

Table 11: RenoDSS scenario generator and data management module Detailed Specifications

4.3.1.2 BUILDING ENERGY PERFORMANCE ESTIMATION MODULE

Based on the energy data model and weather data retrieved from the RenoDSS scenario generator and data management module this component 1) creates energy input data files for the energy KPI calculation module, 2) calculates energy KPIs, and 3) aggregates construction material volumes for further usage in LCA/LCC module. 2) and 3) are sent to the RenoDSS scenario generator and data management module.

Name of New Component/Service:	*Building energy performance estimation module*
Type:	*Component*
Functionality:	*Based on the energy data model and weather data retrieved from the RenoDSS scenario generator and data management module this component:* • *Creates energy input data files for the energy KPI calculation module* • *Calculates energy KPIs* • *Aggregates construction material volumes for further usage in LCA/LCC module*
***Input Connections & Interfaces:* From which components it receives input**	*This component receives the energy data model and weather data as input from the RenoDSS scenario generator and data management module.*

***Output Connections & Interfaces:* To which components it sends the results**	• *Energy KPIs are sent to the RenoDSS scenario generator and data management module.* • *Aggregated construction material volumes are sent to the RenoDSS scenario generator and data management module.*
Relevant Use Cases	*UC-03, UC-04, UC-13, UC-14, UC-15, UC-16*
Functional Requirements	• *The BEPE module must be able to retrieve a notification/trigger message (e.g. from RenoDSS) that the data model for the baseline or a specific renovation scenario meets the BEPE module input data requirements and has been stored in the data repository* • *The BEPE module must be able to retrieve these data and apply a transformation process to populate the input data file of EnergyPlus* • *Given the input data file of EnergyPlus and the EPW of the building's location, the BEPE module must be able to invoke the EnergyPlus execution, output of which will be the energy KPIs.* • *When the simulation run has been finished, the BEPE module must be able to generate a JSON file as an output message (to be listened by the RenoDSS) that contains the energy KPIs values for the specific renovation scenario.* • *The BEPE module must be able to aggregate construction material volumes*
Non-Functional Requirements	• *Reliability: the module must have a mechanism to report errors when required information is missing, leading to crash of EnergyPlus.* • *Response time: increased building complexity leads to increased simulation runtime; however, the module must respond as fast as possible by proper simulation specific parameters selection.* • *Accuracy: although acceptable levels of accuracy should be a non-functional requirement, it depends on the input data's level of detail; hence, acceptable accuracy cannot be defined here.* • *Computational capacity: the module must have enough computational capacity to face the simulation tasks.*

Input Parameters

Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Weather data file	*A file that contains hourly representative values of climate conditions for a typical meteorological year, such as temperature, solar radiation, wind direction, etc. for the building's location.*	*Complex type*	*EPW*	*<see bigladdersoftware.com/epw-data-dictionary>*	*RenoDSS scenario generator and data management module*

Energy data model	*Containing all data to compute energy KPIs*	*IFC4 data structure*	*XML*	*Value range: N/A* *Frequency: For each renovation scenario*	
Subset of data types that should be captured by the Energy data model					
Building Geometry	*A detailed geometrical repsentation of the building in IFC data format, containing the 2nd level space boundaries topology (IfcRelSpaceBoundary2ndLevel).*	*IfcRelSpaceBoundary2ndLevel*	*IFC4 (XML)*	*Value range: N/A* *Frequency: For each renovation scenario*	*RenoDSS scenario generator and data management module*
Building materials	*The baseline construction (e.g. IfcMaterialLayerSet) of each building element, its materials (e.g. IfcMaterialLayer) and their thermal properties (for opaque materials: thermal conductivity, density, specific heat and thermal absorptance; for transparent materials: u-factor and solar heat gain coefficient) provided by the buildings IFC data.*	*IfcMaterialLayerSet, IfcMaterialLayer and float for thermal conductivity in (W/mK), density in (kg/m³), specific heat in (J/kg K) and thermal absorptance (fraction)*			
HVAC systems	*Energy specifications of the Heating Venting and Air Conditioning System installed on the buidling*	*Complex type – it depends on the system under investigation*			
Internal gains as they defined by Occupancy and usage profiles (schedules)	*These profiles are generated by the PRUBS module and reveal the energy usage patterns of users within a building, also strongly correlated to their comfort profiles*	*Complex type (equation-based occupant behaviour models)*	*obXML or IFC4*		
Output Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***

Energy KPIs	-	*JSON objects*	*JSON*	*N/A*	*RenoDSS scenario generator and data management module*
Aggregated construction material volumes	-	*JSON objects*	*JSON*	*N/A*	*RenoDSS scenario generator and data management module*
Software Requirements/Development Language		*Java*			
Hardware Requirements		*Not yet available*			
Communications		-			
Status of the development of the component		*To be developed from scratch.*			

Table 12: Building energy performance estimation module Detailed Specifications

Note here that, although there is a huge gap between EnergyPlus requirements and what IFC4 can capture, an attempt to store all the data in IFC would be preferred. Simulation of a wide-range of systems is supported in EnergyPlus, each with numerous/different parameters' requirements. Based on the pilots sites, our intention is to specify a subset of HVAC systems that will be supported within BIMERR.

4.3.1.3 LIFE CYCLE COST/LIFE CYCLE ASSESSMENT MODULE

Based on the LCA/LCC data model retrieved from the RenoDSS scenario generator and data management module this component calculates LCA/LCC KPIs and sends them back to the RenoDSS scenario generator and data management module. The LCA/LCC KPIs are calculated per renovation scenario based on the 1) aggregated construction material volumes obtained from the energy performance estimation module, and 2) LCA/LCC data for each of these costruction materials obtained from the RenoDSS data model. 1) and 2) are included in the LCA/LCC data model which is provided by the RenoDSS scenario generator and data management module as ipnut to the LCA/LCC module.

Name of New Component/Service:	LCC/LCA module
Type:	Component
Functionality:	Based on the LCA/LCC data model retrieved from the RenoDSS scenario generator and data management module this component: • Calculates LCA/LCC KPIs per renovation scenario based on the aggregated construction material volumes and LCA/LCC data for each of these costruction materials
Input Connections & Interfaces: From which components it receives input	This component receives the LCA/LCC data model from the RenoDSS scenario generator and data management module.
Output Connections & Interfaces: To which components it sends the results	LCA/LCC KPIs are sent to the RenoDSS scenario generator and data management module.
Relevant Use Cases	*UC-03, UC-04, UC-13,U C-14, UC-15, UC-16*
Functional Requirements	• The module must be able to ○ retrieve a trigger (from the RenoDSS scenario generator and data management module) that it should load a certain LCA/LCC data model ○ calculate LCA/LCC KPIs (according to the chosen calculation method) for which the aggregated construction material volumes and LCA/LCC base data are provided by the LCA/LCC data model ○ transmit the calculated LCA/LCC KPIs to the RenoDSS scenario generator and data management module
Non-Functional Requirements	• Reliability: in case of an error the module has to pass the error messages to the RenoDSS scenario generator and data management module • Response time: the computation run time should be kept under one second • Accuracy: all KPIs have to be calculated with regard to the chosen LCA/LCC calculation method. If necessary input data is missing the process has to be terminated with an error message indicating the missing input data. • Computational capacity: the computational capacity of the module must be sufficient to calculate the KPIs in the required run time

Input Parameters

Attribute/Para-meter	Short Description	Data Type	Data Format	Value Range & Frequency	Data Received From

LCA/LCC data model	Containing all data to compute LCA/LCC KPIs (energy KPIs, aggregated construction material volumes, cost data, etc.)	JSON objects	JSON	per renovation scenario	RenoDSS scenario generator and data management module
Output Parameters					
Attribute/Para-meter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Sent To**
LCA/LCC KPIs	LCA/LCC KPIs	JSON objects	JSON	per renovation scenario	RenoDSS scenario generator and data management module

Software Requirements/Development Language	Java
Hardware Requirements	no special hardware requirements
Communications	-
Status of the development of the component	To be developed from scratch.

Table 13: Life Cycle Cost/Life Cycle Assessment module Detailed Specifications

4.3.1.4 URBAN PLANNING MODULE

Based on the urban planning data model retrieved from the RenoDSS scenario generator and data management module this component 1) calculates urban planning KPIs and sends them to the RenoDSS scenario generator and data management module, and 2) provides the RenoDSS UI via the RenoDSS data management module with building and district network visualization information (CityGML format).

Name of New Component/Service:	Urban planning module
Type:	Component
Functionality:	Based on the urban planning data model retrieved from the RenoDSS scenario generator and data management module this component: • Calculates urban planning KPIs • Provides the RenoDSS UI via the RenoDSS data management module with building and district network visualization information

Input Connections & Interfaces: From which components it receives input	This component receives the urban planning data model from the RenoDSS scenario generator and data management module.
Output Connections & Interfaces: To which components it sends the results	Urban planning KPIs are sent to the RenoDSS scenario generator and data management module
Relevant Use Cases	*UC-03, UC-04, UC-13, UC-14, UC-15, UC-16*
Functional Requirements	• The module must be able to ○ retrieve a trigger (from the RenoDSS scenario generator and data management module) that it should load a certain urban planning data model ○ calculate urban planning KPIs for which the necessary input data is provided by the urban planning data model ○ transmit the calculated urban planning KPIs to the RenoDSS scenario generator and data management module ○ convert energy network data which is provided in the urban planning data model to a CityGML compatible format ○ transmit the CityGML energy network representation to the RenoDSS scenario generator and data management module
Non-Functional Requirements	• Reliability: in case of an error the module has to pass the error messages to the RenoDSS scenario generator and data management module • Response time: the computation run time should be reasonable with respect to the complexity of the provided energy network model • Accuracy: all KPIs have to be calculated with regard to the chosen urban planning calculation method. If necessary input data is missing the process has to be terminated with an error message indicating the missing input data. • Computational capacity: the computational capacity of the module must be sufficient to calculate the KPIs and convert the energy network in a reasonable run time

Input Parameters

Attribute/Para-meter	Short Description	Data Type	Data Format	Value Range & Frequency	Data Received From
Urban planning data model - Part 1	Containing all data to compute urban planning KPIs	JSON objects	JSON	per renovation scenario	RenoDSS scenario generator and data management module

Urban planning data model - Part 2	Energy network data	Complex type	XML	per project	RenoDSS scenario generator and data management module
Output Parameters					
Attribute/Para-meter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Sent To**
Urban planning KPIs	Urban planning KPIs	JSON objects	JSON	per renovation scenario	RenoDSS scenario generator and data management module
Urban planning energy network data	Energy network data in CityGML compatible format	CityGML data structure	XML	per project	RenoDSS scenario generator and data management module
Software Requirements/Development Language			Java		
Hardware Requirements			no special hardware requirements		
Communications			-		
Status of the development of the component			To be developed from scratch.		

Table 14: Urban planning module Detailed Specifications

4.3.1.5 RENODSS UI

The user interacts with RenoDSS UI to access the functionality of the energy performance estimation, LCA/LCC, and urban planning module. RenoDSS UI communicates with the BIF project repository to store and load relevant information such as building information, KPIs, target KPIs, renovation measures, energy network data and visualization information. The RenoDSS UI triggers the RenoDSS scenario generator and data management module for renovation scenario generation and KPI calculation. The RenoDSS UI receives energy network visulization information from the RenoDSS scenario generator and data management module.

Name of New Component/Service:	RenoDSS UI
Type:	Component

Functionality:	• Authorize user • List projects to which the user is authorized • Trigger RenoDSS modules to calculate scenario0 KPIs (status quo) • Display project details • Visualize building, energy networks (optional) on map • Define concrete renovation measures (combinations of products or product classes) in admin view • Set desired renovation measures • Set Target KPIs • Display calculated renovation scenarios including KPIs and building configuration
Input Connections & Interfaces: From which components it receives input	• BIF (project repository) • RenoDSS scenario generator and data management module
Output Connections & Interfaces: To which components it sends the results	• BIF (project repository) • RenoDSS scenario generator and data management module
Relevant Use Cases	*UC-03, UC-04, UC-13, UC-14, UC-15, UC-16*

Functional Requirements	• The module must be able to
	  ○ Authorize users
	  ○ List projects for which the user is authorized
	  ○ Trigger RenoDSS modules to calculate scenario0 KPIs (status quo)
	  ○ Display project details
	  ○ Visualize building, energy networks (optional) on map (necessary data obtained from BIF and RenoDSS scenario generator and data management module)
	  ○ Define concrete renovation measures (combinations of products or product classes) in admin view
	  ○ Set desired renovation measures
	  ○ Set Target KPIs
	  ○ Display calculated renovation scenarios including KPIs and building configuration
	  ○ Store calculated renovation scenarios including KPIs and building configuration in BIF project repository

Non-Functional Requirements	• Intuitive and minimal user interface • Support for multiple languages • Response time: below one second, if longer than 5 seconds a notification has to be sent to the user with the option to terminate the current process (e.g., the renovation scenario generation)

Input Parameters					
Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Received From**
ProjectID list	List of Project IDs	JSON objects	JSON	per user session	BIF
Project details	Project details	JSON objects	JSON	per project	BIF on the basis of Project ID
Output Parameters					
Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Sent To**
Target KPIs	Energy, LCA/LCC, and urban planning target KPIs	JSON objects	JSON	per renovation scenario in context of Project ID	BIF (project repository)
Renovation measures	Potential renovation measures set by the user	JSON objects	JSON	per renovation scenario in context of Project ID	BIF (project repository)
Software Requirements/Development Language			Java		
Hardware Requirements			no special hardware requirements		
Communications			-		
Status of the development of the component			To be developed from scratch.		

Table 15: RenoDSS UI Detailed Specifications

4.3.2 Process & Workflow Modelling and Automation toolkit (PWMA)

The domain expert interacts with the PWMA Toolkit via a designer component – providing graphical design, analysis, simulation and transformation capabilities - where the renovation process and data exchange is specified. Pre-defined “renovation process templates” such as: Improvement of Facade Outside, Improvement of Façade Inside, Improvement of Roof Outside, Improvement of Roof Inside, Exchange of Windows etc.; are designed in co-creative modelling workshops. Those templates describe the most likely way of performing parts of the renovation process but are still too abstract as they do not

consider the concrete context of a particular project. This includes for example different types of facades, different alternatives on the roof improvements, the necessity of re-arranging a electric cables etc.. Hence, for the analysis and simulation of a concrete renovation project, the templates are exported from an open data space, imported into the modelling environment and then re-designed to fit the purpose of the concrete project. This is performed by typical modelling features. Once the renovation process instance is re-designed for a concrete project, the experts provide time and costs estimations. This is performed via CSV files – e.g. using Excel – and import time and costs into the process model. Now the designed process becomes a full fletched model, as time, costs, probabilities, rules and other context-specific elements are entered. This phase supports the making of an offer.

In case the offer is expected, the domain-expert aligns the process model with the project task plan. The transformation engine – an XML file-based rule engine – is used to transform processes into project tasks as well as project task outcomes into process model information. Import, export and transformation – this is performed via Graph-Re-Writing in form of an external service, or in form of a script language within the modelling environment – enables the process model to be on the same level of detail as the project plan.

This process model can now be continuously simulated to assess how time and costs evolve in future. For the simulation we use our open source Discrete Event Simulation service that requires a petri-net and the corresponding time and costs parameters to execute the simulation. The time and cost estimation valuable knowledge that is provided by the domain experts, hence the modelling, the knowledge editing and the simulation environment needs to consider the continues improvement of knowledge. Hence the simulation is re-implemented to become a Knowledge Based Discrete Event Simulation, the knowledge editing considers the different estimations and weights as well as accesses historical data, and the modelling tool needs to integrate the expressed knowledge in form of weights, estimations, mathematical formulas or heuristics in addition to the process model. This enables a continues – currently we consider a weekly simulation in accordance to the construction site visits – simulation and hence an adaptive prediction.

In order to enable a learning, a monitoring dashboard is provided that connects to current and historical data and enables the conceptually composition of data towards Key Performance Indicator (KPI). The modelling environment provides in addition to process modelling also the KPI modelling as well as data structure and data access information. The corresponding modelling language is a configuration of the modelling environment; hence the modelling language does not affect the architecture. In order to interpret the data and KPI services an intermediate Microservice Framework called OLIVE is used to mediate between the modelling tool and the data layer. The relevant OLIVE Microservice components are connectors that enable the access to a process mining tool, to the process log or to the BIF. Those connectors extend the current collection of about 30 connectors to different platforms. The next step is the interpretation of the data according the KPI and data model,

whereas semantic enrichment is provided by the data model and the calculation of the data towards the KPI is specified. Available model-access services realized in AdoScript and encapsulated in the Microservice Framework OLIVE access the model and provide the information which data streams to be merged and how to calculate the result of the different data streams. The dashboard user interface displays the KPIs in combination with the process and hence display the actual and past figures compared with the simulated figures. Based on this continues comparison, the domain experts can learn and adapt their estimations accordingly. This reflection is considered as the improvement environment. As a summary:

- The renovation process, KI and data access modelling takes place in manual matter. Process analysis and simulation can be executed by the domain expert by entering the necessary knowledge.
- The renovation process is exported to an execution component which decomposes the process into executable tasks, manages the event bus, and provides data from workflow execution with the goal to guide and assist complex renovation projects.
- Monitoring and adaptation take place as part of the execution component.
- Monitor Dashboard combines the process, KPI and data access models and provides a KPI dashboard that conceptually merges different data source.
- The comparison between simulated and actual process behaviour used in the improvement component that stores and compares the different expert input and enables the derivation of knowledge based on historical comparison for future estimations using analysis tools like process mining or social media for collective intelligence.
- A Knowledge Base and an AI innovation shop/market place has a supporting role for the PWMA Toolkit. Details can be found in D6.1, also on the expected Technology readiness level of the components some of which exceed the expectations from the DoA.

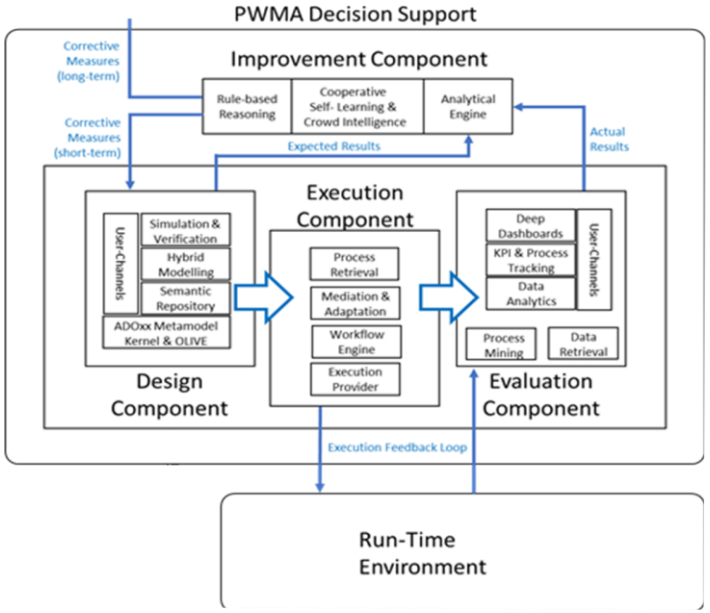

Figure 32: Component Overview of the PWMA Toolkit enabling Knowledge-based Decision Support

4.3.2.1 INNOVATIVE BUSINESS PROCESS MODELLING (IBPM)

Name of New Component/Service:	PWMA – Design Component
Type:	Component
Functionality:	• User management; creation, versioning, modification, and deletion of models and model elements; repository queries; model import and export; and report generation. • Human-computer interfaces for the BIMERR domain-specific modelling method • Verification and simulation capabilities • Information transfer to the Execution Component

Input Connections & Interfaces: From which components it receives input				• Interface for humans to model the renovation process • APIs for other components	
Output Connections & Interfaces: To which components it sends the results				• BPMN DI extended export to the Execution Component	
Relevant Use Cases				*UC-05, UC-06, UC-07, UC-08*	
Functional Requirements				The design component must perform • User authentication • Model management • Formal model verification • Knowledge-based simulation of the renovation process modelled by the users for decision support • Model export of the renovation process in a format that can be interpreted by the Execution Component	
Non-Functional Requirements				• Reusability of reference processes • Intuitive user interface for modelling, formal verification, and simulation • Ability of the underlying modelling method to capture the renovation process	
Output Parameters					
Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Sent To**
Renovation Process	Process that needs to be executed	BPMN-DI	BPMN-DI	After approval of the modelled renovation process	PWMA – Execution Component
Expected renovation process behavior	From renovation process simulation results	API	API	After export of the renovation process	PWMA – Improvement Component
Software Requirements/Development Language				Multi-language	
Hardware Requirements				Standard PC and Webserver	
Communications				Network communication	
Status of the development of the component				Based on ADOxx	

Table 16: PWMA - Design component Detailed Specifications

Name of New Component/Service:	PWMA – Evaluation component
Type:	Component
Functionality:	• Data collection from heterogeneous sources • Data abstraction, semantic lifting, and knowledge discovery • Visualization for decision preparation • Fault detection
Input Connections & Interfaces: **From which components it receives input**	• Interoperability Framework
Output Connections & Interfaces: **To which components it sends the results**	• Improvement Component
Relevant Use Cases	*UC-07, UC-09, UC-10*
Functional Requirements	The evaluation component must perform • Analysis of data need specification • Gathering data from interoperability framework • Data aggregation and visualization • Link data to renovation processes • Data measurements
Non-Functional Requirements	• Useful data operations to visualize problems • Traceable data provision

Input Parameters are specified by the user and are gathered from the interoperability framework

Output Parameters

Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Sent To**
Actual renovation process behavior	Aggregated data from renovation process execution	API	API	Periodically based on user setting	PWMA – Improvement Component

Software Requirements/Development Language	Multi-language
Hardware Requirements	Standard PC and Webserver
Communications	Network communication

Status of the development of the component	Based on ADOxx and OLIVE

Table 17: PWMA - Evaluation component Detailed Specifications

Name of New Component/Service:		PWMA – Improvement component			
Type:		Component			
Functionality:		• Expected results from renovation process design and simulation are compared to actual results from renovation process execution • Differences are analyzed using collaborative intelligence. • The analysis results are fed into a rule engine to issue short-term and long-term changes for the renovation process design.			
Input Connections & Interfaces: From which components it receives input		• Design component • Evaluation Component			
Output Connections & Interfaces: To which components it sends the results		• Design Component			
Relevant Use Cases		• UC-09, UC-10			
Functional Requirements		The improvement component must • Imports simulation results and the aggregated data coming from renovation process execution • Analyze differences in the data based on collective intelligence • Issues corrective measures			
Non-Functional Requirements					
Input Parameters					
Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Received From**
Expected renovation process behavior	From renovation process simulation results	API	API	After export of the renovation process	Design Component
Actual renovation process behavior	Aggregated data from renovation process execution	API	API	Periodically based on user setting	Evaluation Component
Software Requirements/Development Language		Multi-language			

Hardware Requirements	Standard PC and Webserver
Communications	Network communication
Status of the development of the component	Based on ADOxx and OLIVE

Table 18: PWMA - Improvement component Detailed Specifications

4.3.2.2 WORKFLOW AUTOMATION TOOLS AND ON-SITE GUIDANCE

Name of New Component/Service:	PWMA – execution component
Type:	Component
Functionality:	• Receive the full workflow from the Design component • Simplify the workflow to atomized actions, lowering probability of outer influence • Follow the status of simple actions and orchestrate their execution • Report back the results and issues to the Evaluation component • The Runtime environment provides information to other components via notifications
Input Connections & Interfaces: From which components it receives input	• PWMA – Design component
Output Connections & Interfaces: To which components it sends the results	• PWMA – Run-Time environment • PWMA – Evaluation component
Relevant Use Cases	*UC-05, UC-06, UC-07, UC-08, UC-09, UC-10, UC-11, UC-12*

Functional Requirements	• The module must be able to
	  ○ Receive the full workflow from the Design component
	  ○ Simplify the workflow to atomized actions, lowering probability of outer influence
	  ○ Follow the status of simple actions
	  ○ Operate with additional events
	  ○ Orchestrate the execution of simple actions
	  ○ Report back the results and issues to the Evaluation component
	  ○ Provide information to other components via notifications

Non-Functional Requirements	• Intuitive and minimal user interface • Support for multiple languages

Input Parameters					
Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Received From**
Renovation Wokflow	ID of the Work Order need to be done by workers	BPMN-DI	BPMN-DI	After creation of the renovation workflow and after every changes on it	PWMA – Design component
Sub-processes status	Status of the sub-processes	API	API	After execution of sub-processes	Executors of sub processes - material management system; ARIBFA, BICA, ...
Output Parameters					
Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Sent To**
Renovation Workflow status	Status of the renovation workflow	BPMN-DI	BPMN-DI	After change on status of the workflows components	PWMA – Evaluation component
Sub-processes	Atomized actions of the workflow	BPMN-DI	BPMN-DI	Before a sub-process need to be executed	Executors of sub processes - material management system; ARIBFA, BICA, ...
Software Requirements/Development Language				*Programming language: JAVA*	
Hardware Requirements				Standard linux based web server	
Communications				Network communication	
Status of the development of the component				Based on the open-source jBPM	

Table 19: PWMA - Execution component Detailed Specifications

4.3.2.3 ON-SITE RENOVATION SUPPORT TOOL

The On-Site Renovation support for workers will be provided via smart glasses. The activities to be provided by workers will be defined by technologists in advance. Once the work process template is prepared, it needs to be locked against additional changes. The technologist approves the defined work process and is responsible for workers safety as well as for the correct definition of the processes provided by the workers.

Typically, a work process is a sequence of actions grouped by steps. Steps are connected to locations. Every action can generate several ending events. Each action can have one or more starting event, which need to be fulfilled to start the execution of the action. The technologist can attach to the work process template additional resources, which will help the worker to execute the work on-site.

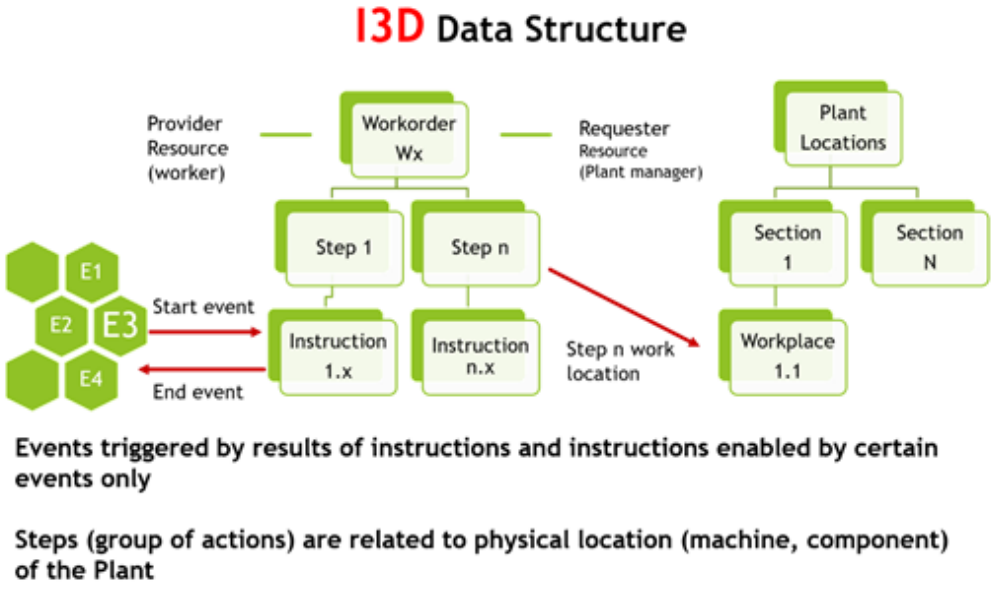

Figure 33: I3D Data Structure

The work process templates prepared by the technologist will be used by operator to issue work orders to be executed by selected workers at defined specific time and with support of the selected smart glasses. The operator can monitor the status of execution of the work orders and can generate reports from the completed work orders.

The worker will see for every step, where he needs to provide the work. For every action, the worker will see exact instructions, what to do and, what is the time dedicated to executing the action and provide the work. The execution of every action will start a counter, which will measure the effectivity of the worker and will indicate, if execution of some actions took longer than planned. On top of it, the worker will produce real-time evidence about the provided work by pictures and video-recordings created during the execution of actions.

All the collected information, including the produced multimedia content will be attached to the work order and will be accessible via work order report.

The execution status of the actions, steps and whole work orders will be available via API, which will be the connecting point between the PWMA and the "On-Site Renovation Worker Support tool". The PWMA will automatically change the status of the work orders, and in case of need, will re-schedule the already issued work orders.

Name of New Component/Service:	On-Site Renovation Worker Support tool
Type:	Component
Functionality	• Web based Tool to define work instructions to be executed • Web based Tool to assign work instructions to selected workers • Smart-glasses based tool to notify workers about new assigned work orders • Smart-glasses based app to guide the workers trough the work instructions/ work orders • Smart-glasses based app providing instant reporting option during the work order execution. • Integrated Remote-Assistance
Input Connections & Interfaces: From which components it receives input	• PWMA • IoT
Output Connections & Interfaces: To which components it sends the results	• PWMA
Relevant Use Cases	*UC-07, UC-09, UC-10, UC-11*

Functional Requirements	• The module must be able to
	  ○ Authorize users
	  ○ Create and manage work flows (work order templates)
	  ○ Create and manage work orders
	  ○ Notify workers about new work orders
	  ○ Guide the workers trough the work instructions
	  ○ Allow instant reporting
	  ○ Allow for workers to receive remote advice

Non-Functional Requirements	• Intuitive and minimal user interface • Support for multiple languages
Input Parameters	

Attribute/Parameter	Short Description	Data Type	Data Format	Value Range & Frequency	Data Received From
Work order ID	ID of the Work Order need to be done by workers	JSON objects	JSON	per work order	PWMA
Output Parameters					
Attribute/Parameter	**Short Description**	**Data Type**	**Data Format**	**Value Range & Frequency**	**Data Sent To**
Work order status	Status and results of the executed/non-executed work instructions	JSON objects	JSON	per work order	PWMA
Software Requirements/Development Language		*Programming language: C#, Unity 3D, PHP, AngularJS*			
Hardware Requirements		Standard linux based web server Android based devices (mobile phone, tablet, smart glasses)			
Communications		WiFi			
Status of the development of the component		Based on the existing I3D toolset			

Table 20: On-site Renovation Worker Support Tool Detailed Specifications

4.4 DIGITAL BUILDING MODEL CREATION TOOLS

The Digital Building Model Creation Tools consist of Scan-to-BIM, Augmented Reality enabled In-situ Building Feature Annotation (ARIBFA), Profiling Resident Usage of Building Systems (PRUBS), Building Information Collection Application (BICA) and Legacy Systems. Scan-to-BIM's goal is to capture a 3D scan of the renovation and create the corresponding digital building model. ARIBFA consists of BIM 3D Model Registration and Tracking Module, Indoor Localization Module, AR Annotation & Context Aware-Visualization Module and Marker-less Feature Recognition Module, providing recognition and registration of features in a building, while displaying information to the user through the HMD-AR glasses. PRUBS objective is to extract residents' profiles based on the use of the building and its systems. Lastly, BICA enables residents to provide feedback on the renovation by appending information, either notes or photos, to the digital building model.

4.4.1 Scan-to-BIM

This module is responsible for the generation of a semantically-rich 3D BIM model in IFC format. Inputs to the scan-to-BIM process are point clouds (i.e. lists of unconnected 3D points) and images. These are obtained by means of diverse reality capture technologies, such as laser scanners and RGB cameras, and are not linked to any other module in the system. Both point clouds and images are stored in files according to the E57 open standard. The outputs of the tool are BIM models, including structural (i.e. primary) and MEP elements (i.e. secondary) that are relevant to energy refurbishment processes, and are generated following the IFC4 specification. These models are sent to the BIM Management Platform through the Building Interoperability Framework (BIF).

Name of New Component/Service:	*Scan-to-BIM*
Type:	*Software and Process*
Functionality:	*This component takes as input reality capture data (3D point clouds, with colour and possibly other data) in E57 format (and other if necessary) and outputs a semantically-rich model (i.e. BIM) in IFC format.*
***Input Connections & Interfaces:* From which components it receives input**	*Input comes from Reality Capture technology used on site. This data is not linked to any other module/component.*
***Output Connections & Interfaces:* To which components it sends the results**	*Output goes to BIM Management Platform through the Building Interoperability Framework (BIF)*

Relevant Use Cases			*UC-01*		
Functional Requirements			*The solution delivers a BIM model of a facility from reality capture data (3D coloured point clouds and images). The BIM model must contain geometric as well as semantic information from primary (i.e. structure) and secondary components with particular relevance to the energy refurbishment process.*		
Non-Functional Requirements			***Interoperability:*** *The solution must be able to handle input in E57 format and output its model in IFC format.* ***Efficiency:*** *The solution should be faster than conducting the process completely manually. For this, the solution should include a state-of-the-art (semi-)automated algorithm, but shall also provide a solution to manually correct and enhance the final model.* ***Portability:*** *The solution should work on Windows, and at least provide guarantees it can work on other platforms (e.g. MacOS).*		
Input Parameters					
Attribute/ Parameter		***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
PointCloud		*List or array*	*E57 (ascii+binary)*	*N/A*	*Terrestrial Laser Scanner (TLS) or Photogrammetric (PG) reality capture systems.*
Images		*Image (2D array of integer)*	*E57 (ascii+binary), PNG*	*N/A*	*TLS and/or PG reality capture systems.*
Output Parameters					
Attribute/ Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Model	*The semantic 3D model of the facility containing the topology, main components and ideally secondary components of relevance to energy refurbishment.*	*(very) complex (IFC file)*	*IFC*	*N/A*	*BIM Management Platform through the Building Interoperability Framework (BIF)*
Software Requirements / Development Language		*C# and C++ development languages, and using a number of existing libraries (e.g., xBIM, PCL, Qt)*			
Hardware Requirements		*Modern computer with 8 -12GB RAM, at least, and ideally with a dedicated graphics card.*			
Communications		*None*			

Status of the development of the component	*To be developed from scratch (more or less)*

Table 21: Scan-to-BIM Detailed Specifications

4.4.2 Augmented Reality enabled In-situ Building Feature Annotation (ARIBFA)

The ARIBFA application is in charge of the software that will run on the smart glasses and provides a deep learning solution to recognize and register components and other features present in a building to enable the (semi)automatically annotation of building characteristics on a digital building model. It is composed of four sub-components. Each sub-component has its own functionality, but may accept and provide inputs from and to another sub-component. The sub-components are BIM 3D Model Registration and Tracking Module, Indoor Localization Module, AR Annotation & Context Aware-Visualization Module and Markerless Component/Feature Recognition Module. The component as a whole accepts as input the BIM model in IFC format, information related to building materials and components and IoT streams, while it outputs the coordinates and orientation of the user to BIF.

Name of New Component/Service:	*Augmented Reality enabled In-situ Building Feature Annotation (ARIBFA) using smart glasses*
Type:	*Component*
Functionality:	*This component recognizes and registers features present in a building, using AR glasses, to enable a building surveyor wearing the glasses to walk through a building and (semi)automatically annotate building characteristics on a digital building model (enhanced BIM).*
***Input Connections & Interfaces:* From which components it receives input**	*This module receives input from the RGB-D camera and from the sensors installed on the AR glasses. It also receives as input data streams from the sensors network on the site, which are stored on the Data Store of the BIMERR Middleware. Moreover, it accepts building component information, mostly images, from BIMERR Interoperability Framework. Additionally, ARIBFA obtains as input the BIM 3D model from BIM Management Platform through BIMERR Interoperability Framework.*
Output Connections & Interfaces: To which components it sends the results	*Output goes to Work-flow automation tools and on-site guidance application of PWMA through BIMERR Interoperability Framework.*
Relevant Use Cases	*UC-02 ,UC-08, UC-09, UC-10, UC-11, UC-12*

Functional Requirements	• *ARIBFA must be able to recognize building components.* • *ARIBFA must be able to map the BIM 3D model to the site.* • *ARIBFA must be able to track every component, that has been registered.* • *ARIBFA must be able to determine user's position and orientation.* • *ARIBFA must be able to locate every recognized characteristic of the building.* • *ARIBFA must provide information for every mapped component of the building.* • *ARIBFA must be able to update information data of every component.* • *ARIBFA must be able to register and annotate building components, that have not been recognized or registered.*
Non-Functional Requirements	• *ARIBFA must provide a friendly user interface.* • *ARIBFA must be able to connect anytime to WiFi.* • *ARIBFA must be able to extract information from BIM 3D model.* • *ARIBFA must support multiple languages.* • *ARIBFA must have a menu to discern its different functionalities.* • *ARIBFA must be able to receive data from sensors network, cameras, AR glasses' sensors and BIMERR Interoperability Framework.*

Input Parameters

Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Images	*Images, captured by the camera, are being used as input to the deep learning recognition model. It is also used to determine the location of user and that of the components as well as to achieve registration and tracking. They are being used as input to the Marker-less Feature Recognition Module, to the Indoor Localization Module and to the BIM 3D Model Registration and Tracking Module, which are subcomponents of ARIBFA.*	*Image (3D array of integer)*	*PNG*	*0-255 for RGB* *0-2048 (if 11 bits are being used) for Depth* *30 or 60 or 80 fps*	*RGB-D camera*
IoT streams data models	*The IoT sensors and meters installed at the pre-renovation building communicate through signals, which are used to deploy triangulation techniques to determine the user's location. These signals are also used to provide information regarding the indoor building conditions and electrical equipment function related to the comfort preferences and energy usage of the occupants. They are being used as input to the Indoor Localization Module and to the AR Annotation and Context Aware-Visualization Module, which are subcomponents of ARIBFA.*	*Complex type*	*JSON*	*Varying - Some are event driven and some are timeseries*	*BIMERR Middleware*

Model	*The semantic 3D model of the facility containing the topology, main components and ideally secondary components of relevance to energy refurbishment. It is being used as input to the Indoor Localization Module and to the BIM 3D Model Registration and Tracking Module, which are subcomponents of ARIBFA.*	*(very) complex (IFC file)*	*IFC*	*N/A*	*BIM Management Platform*
Data Streams from AR glasses' sensors (IMU, Accelerometer, Gyro, Compass, etc.)	*The outputs of sensors are being used as input to determine user's position and orientation. They are being used as input to the Indoor Localization Module, which is subcomponent of ARIBFA.*	*Complex type*	*JSON*	*Varying - based on sensor type*	*Sensors installed at the AR Glasses*
Building Materials	*The available materials to be used at the renovation process of the building to improve its energy performance (e.g. insulation etc). They are being used as input to the Marker-less Feature Recognition Module, which is subcomponent of ARIBFA.*	*Materials and Components Database*	*N/A*	*N/A*	*BIMERR Interoperability Framework*
Building Components	*Components introduced to the building during the renovation process that can influence the occupants' consumption patterns (e.g. heating and cooling systems, automations etc.). They are being used as input to the Marker-less Feature Recognition Module, which is subcomponent of ARIBFA.*	*Materials and Components Database*	*N/A*	*N/A*	*BIMERR Interoperability Framework*
Output Parameters					
Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Coordinates/ Orientation	*The coordinates of user's position, the user's orientation and the location and pose estimation of each building component. They are being calculated to the Indoor Localization Module, which is subcomponent of ARIBFA.*	*2 vectors of floats*	*JSON*	*$[(-10^5,10^5),(-10^5,10^5),(-10^3,10^3)]$ for position [(-180,180),(-180,180),(-180,180)] for orientation*	*Work-flow automation tools and on-site guidance application of PWMA*
Software Requirements/Development Language	*Programming language: Python, Keras, OpenCV, C#, Unity 3D*				
Hardware Requirements	*Modern computer with 16GB RAM and with a dedicated graphics card. Augmented-Reality Smart Glasses with RGB-D camera and all the necessary sensors.*				
Communications	*Supported communication: To be defined.*				

Status of the development of the component	*To be developed from the scratch.*

Table 22: ARIBFA Detailed Specifications

4.4.2.1 BIM 3D MODEL REGISTRATION AND TRACKING MODULE

This module is responsible for the mapping of BIM 3D Model to the actual physical space, while tracking the mapping along the user's motion. In order to achieve its goal, it receives RGB-D Images, the user's location from Indoor localization module of ARIFA, the semantic 3D model of the renovation site from BIM Management Platform and component models that represents the building components from Marker-less Feature Recognition Module of ARIBFA. It does not produce any output, as the result of this module is displayed on the AR glasses.

Name of New Component/Service:	*BIM 3D Model Registration and Tracking Module of ARIBFA*
Type:	*Component*
Functionality:	*This module maps 3D information, coming from BIM 3D Models, to the actual positions in physical space and it tracks this mapping along the user's motion within a building.*
***Input Connections & Interfaces:* From which components it receives input**	*This module receives input from Marker-less Feature Recognition Module and Indoor Localization Module of ARIBFA. It also receives input from BIM Management Platform through BIMERR Interoperability Framework and from RGB and depth cameras.*
Output Connections & Interfaces: To which components it sends the results	*<None>*
Relevant Use Cases	*UC-02, UC-08, UC-09, UC-10, UC-11, UC-12*
Functional Requirements	• *BIM 3D Model Registration and Tracking Module must be able to map the BIM 3D model to the site.* • *BIM 3D Model Registration and Tracking Module must be able to track every component, that has been registered.*
Non-Functional Requirements	• *BIM 3D Model Registration and Tracking Module must be able to connect with WiFi.*
Input Parameters	

Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Images	*Images, captured by the camera, are being used as input to achieve registration and tracking.*	*Image (3D array of integer)*	*PNG*	*0-255 for RGB 0-2048 (if 11 bits are being used) for Depth 30 or 60 or 80 fps*	*RGB-D camera*
Coordinates/ Orientation	*The coordinates of user's position, the user's orientation and the location and pose estimation of each building component.*	*2 vectors of floats*	*JSON*	*[(-10^5,10^5), (-10^5,10^5), (-10^3,10^3)] for position [(-180,180), (-180,180), (-180,180)] for orientation*	*Indoor Localization Module subcomponent of the ARIBFA*
Model	*The semantic 3D model of the facility containing the topology, main components and ideally secondary components of relevance to energy refurbishment.*	*(very) complex (IFC file)*	*IFC*	*N/A*	*BIM Management Platform (through BIMERR Interoperability Framework)*
Building component models	*Components models that represents the recognized building components, which are contained in the camera view.*	*IFC file*	*IFC*	*N/A*	*Marker-less Feature Recognition Module subcomponent of the ARIBFA*
<u>Output Parameters</u>					
Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Registered 3D Model	*The building modle or a subset of it overlayd on top of the actual building in the correct position and orientation relative to the physical location of the user*	3D model (binary or text representation of 3D polygons)	OBJ, FBX, IFCXML	*N/A*	HMD Glasses/Tablet Screen
Software Requirements/Development Language		*Programming language: C#, Unity 3D*			
Hardware Requirements		*Modern computer with 16GB RAM and with a dedicated graphics card. Augmented-Reality Smart Glasses with RGB-D camera and all the necessary sensors.*			
Communications		*Supported communication: To be defined.*			
Status of the development of the component		*To be developed from the scratch.*			

Table 23: ARIBFA - BIM 3D Model Registration & Tracking Module Detailed Specifications

4.4.2.2 INDOOR LOCALIZATION MODULE

The approach that will be used to address the localization task will be both signal and visual based. Its task is to determine the position of the user on the renovation site. For this reason, the module receives data extracted by the sensors network on the site, which will be in JSON format and will be sent by BIMERR Middleware, by the sensors of AR glasses, both images from RGB-D camera, and data streams in JSON format from IMU, accelerometer etc. Moreover, it receives as input, the semantic BIM 3D model of the renovation site from BIM Management Platform. It calculates and sends as output the user's location.

Name of New Component/Service:				*Indoor Localization Module of ARIBFA*	
Type:				*Component*	
Functionality:				*This module determines the user's positions within a building.*	
Input Connections & Interfaces: ***From which components it receives input***				*This module receives input from RGB and depth cameras mounted on the AR HMDs. It also receives input from data streams from sensors on the site, which are stored on Data Store of BIMERR Middleware, and from the sensors of AR glasses. Moreover, it accepts as input the BIM 3D model from BIM Management Platform through BIMERR Interoperability Framework.*	
Output Connections & Interfaces: ***To which components it sends the results***				*Output goes to BIM 3D Model Registration and Tracking Module and AR Annotation & Context Aware-Visualization Module of ARIBFA. Moreover, results are being sent to Work-flow automation tools and on-site guidance application of PWMA through BIMERR Interoperability Framework.*	
Relevant Use Cases				*UC-02, UC-08, UC-09, UC-10, UC-11, UC-12*	
Functional Requirements				• *Indoor Localization Module must be able to determine user's position.* • *Indoor Localization Module must be able to locate every recognized characteristic of the building.*	
Non-Functional Requirements				• *Module must use sensors network, camera and AR glasses' sensors to find user's position and orientation.*	
Input Parameters					
Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***

Images	*Images, captured by the camera, are being used as input to determine the location of user and that of the components.*	*Image (3D array of integer)*	*PNG*	*0-255 for RGB* *0-2048 (if 11 bits are being used) for Depth* *30 or 60 or 80 fps*	*RGB-D camera*
IoT streams data models	*The IoT sensors and meters installed at the pre-renovation building communicate through signals, which are used to deploy triangulation techniques to determine the user's location.*	*Complex type*	*JSON*	*Varying - Some are event driven and some are timeseries*	*BIMERR Middleware (through BIMERR Interoperability Framework)*
Model	*The semantic 3D model of the facility containing the topology, main components and ideally secondary components of relevance to energy refurbishment.*	*(very) complex (IFC file)*	*IFC*	*N/A*	*BIM Management Platform (through BIMERR Interoperability Framework)*
Data Streams from AR glasses' sensors (IMU, Accelerometer, Gyro, Compass, etc.)	*The outputs of sensors are being used as input to determine user's position and orientation.*	*Complex type*	*JSON*	*Varying - based on sensor type*	*Sensors installed at the AR Glasses*
Output Parameters					
Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Coordinates/ Orientation	*The coordinates of user's position, the user's orientation and the location and pose estimation of each building component.*	*2 vectors of floats*	*JSON*	*[(-10^5,10^5), (-10^5,10^5), (-10^3,10^3)] for position* *[(-180,180), (-180,180), (-180,180)] for orientation*	*BIM 3D Model Registration and Tracking Module and AR Annotation and Context Aware-Visualization Module subcomponents of the ARIBFA. Work-flow automation tools and on-site guidance application of PWMA through BIMERR Interoperability Framework.*
Software Requirements/Development Language				*Programming language: Python, OpenCV, C#, Unity 3D*	
Hardware Requirements				*Modern computer with 16GB RAM and with a dedicated graphics card. Augmented-Reality Smart Glasses with RGB-D camera and all the necessary sensors.*	

Communications	*Supported communication: To be defined.*
Status of the development of the component	*To be developed from the scratch.*

Table 24: ARIBFA – Indoor Localization Module Detailed Specifications

4.4.2.3 AR ANNOTATION & CONTEXT AWARE-VISUALISATION MODULE

This module is responsible for the display of up-to-date context related to every recognized building component and it also shows a user interface to enable the users to interact with the ARIBFA. With the purpose of successfully providing its functionality, it receives as inputs the coordinates and orientation of the user in JSON format from the Indoor Localization Module of ARIBFA, the data extracted by the sensors network on the site, which will also be in JSON format and will be sent by BIMERR Middleware, and lastly the building components models from the Marker-less Feature Recognition Module of ARIBFA that contain the information, which will be displayed on the AR glasses. It send as output, to the BIM 3D Model Registration and Tracking Module, any information data the user has added using the interface.

Name of New Component/Service:	*AR Annotation & Context Aware-Visualisation Module of ARIBFA*
Type:	*Component*
Functionality:	*This module displays information data for every building component, while it also provides a user interface to add complementary information to any mapped characteristic.*
***Input Connections & Interfaces:* From which components it receives input**	*This module receives input from the Indoor Localization Module of ARIBFA and from data streams from sensors on the site, which are stored on Data Store of BIMERR Middleware. It also receives as input the building component models from Marker-less Feature Recognition Module of ARIBFA.*
***Output Connections & Interfaces:* To which components it sends the results**	*Output goes to BIM 3D Model Registration and Tracking Module of ARIBFA, to place the building component in space, that has not been annotated automatically.*
Relevant Use Cases	*UC-02, UC-08, UC-09, UC-10, UC-11, UC-12*

Functional Requirements	• *AR Annotation & Context Aware-Visualisation Module must provide information for every mapped component of the building.* • *AR Annotation & Context Aware-Visualisation Module must be able to update information data of every component.* • *AR Annotation & Context Aware-Visualisation Module must be able to register and annotate building components , that have not been recognized or registered.*
Non-Functional Requirements	• *Module must provide a friendy user interface.* • *Module must be able to connect anytime to WiFi.* • *Module must be able to extract information from BIM 3D Model.* • *Module must support muptiple languages.* • *Module must have a menu to discern its different functionalities.*

Input Parameters

Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Coordinates/ Orientation	*The coordinates of user's position, the user's orientation and the location and pose estimation of each building component.*	*2 vectors of floats*	*JSON*	*[(-10^5,10^5), (-10^5,10^5), (-10^3,10^3)] for position [(-180,180), (-180,180), (-180,180)] for orientation*	*Indoor Localization Module subcomponent of the ARIBFA*
IoT streams data models	*The IoT sensors and meters installed at the building pre-renovation provide information regarding the indoor building conditions, occupancy metrics and electrical equipment function related to the comfort preferences and energy usage of the occupants.*	*Complex type*	*JSON*	*Varying - Some are event driven and some are timeseries*	*BIMERR Middleware (through BIMERR Interoperability Framework)*
Building component models	*Components models that represent the recognized building components, which are contained in the camera view. They also contain information regarding each component.*	*IFC file*	*IFC*	*N/A*	*Marker-less Feature Recognition Module subcomponent of the ARIBFA*

Output Parameters

Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***

Building component models	*Information data of the selected component, which user has added in the annotation process of the component.*	*IFC file*	*IFC*	*N/A*	*BIM 3D Model Registration and Tracking Module subcomponent of the ARIBFA.*
Software Requirements/Development Language		*Programming language: C#, Unity 3D*			
Hardware Requirements		*Modern computer with 16GB RAM and with a dedicated graphics card. Augmented-Reality Smart Glasses with RGB-D camera and all the necessary sensors.*			
Communications		*Supported communication: To be defined.*			
Status of the development of the component		*To be developed from the scratch.*			

Table 25: ARIBFA – AR Annotation & Context Aware-Visualisation Module Detailed Specifications

4.4.2.4 MARKER-LESS FEATURE RECOGNITION MODULE

This module must be able to recognize the different kind of elements that can be found in a renovation site. For the task of recognition, deep learning models will be deployed which will receive as input RGB-D images. The training and evaluation of such models as mentioned, require image data, in this case building materials and components, which are provided by the BIMERR Interoperability Framework. Even though the image recognition model provide a class label as output, in this case the module will match the label with the corresponding building component and will sent it to BIM 3D Model Registration and Tracking Module of ARIBFA.

Name of New Component/Service:	*Marker-less Feature Recognition Module of ARIBFA*
Type:	*Component*
Functionality:	*This module recognizes a variety of elements contained in the building, without using identifying markers.*
***Input Connections & Interfaces:* From which components it receives input**	*This module receives as input RGB and depth images, captured by cameras mounted on the AR HMDs, and building components information, mostly images, from BIMERR Interoperability Framework.*
***Output Connections & Interfaces:* To which components it sends the results**	*The results are being sent to BIM 3D Model Registration and Tracking Module of ARIBFA.*
Relevant Use Cases	*UC-02, UC-08, UC-09, UC-10, UC-11, UC-12*

Functional Requirements		• *Marker-less Feature Recognition Module must be able to recognize building components.*			
Non-Functional Requirements		• *Marker-less Feature Recognition Module must be able to connect to cloud services.*			
Input Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Images	*Images, captured by the camera, are being used as input to the deep learning recognition model.*	*Image (3D array of integer)*	*PNG*	*0-255 for RGB 0-2048 (if 11 bits are being used) for Depth 30 or 60 or 80 fps*	*RGB-D camera*
Building materials	*The available materials to be used at the renovation process of the building to improve its energy performance (e.g. insulation etc).*	*Suggested: EnergyPlus format*	*N/A*	*N/A*	*BIMERR Interoperability Framework*
Building components	*Components introduced to the building during the renovation process that can influence the occupants' consumption patterns (e.g. heating and cooling systems, automations etc.).*	*Suggested: EnergyPlus format*	*N/A*	*N/A*	*BIMERR Interoperability Framework*
Output Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Building component models	*Components models that represent the recognized building components, which are contained in the camera view.*	*IFC file*	*IFC*	*N/A*	*BIM 3D Model Registration and Tracking Module subcomponent of the ARIBFA.*
Software Requirements/Development Language		*Programming language: Python, Keras, OpenCV, C#, Unity 3D*			
Hardware Requirements		*Modern computer with 16GB RAM and with a dedicated graphics card. Augmented-Reality Smart Glasses with RGB-D camera and all the necessary sensors.*			
Communications		*Supported communication: To be defined.*			
Status of the development of the component		*To be developed from the scratch.*			

Table 26: ARIBFA – Marker-less Feature Recognition Module Detailed Specifications

4.4.3 Profiling Resident Usage of Building System (PRUBS)

PRUBS addresses the profiling of how the building and its systems are used by the residents. The information needed to extract preference and usage models is represented as streams and derives from IoT devices installed at the renovation site and from nearby weather stations. The PRUBS component aims at designing Occupant Behaviour models that could act as predictors of occupants presence, needs (in terms of comfort) and actions. In an effort to increase the pre/post-renovation energy consumption prediction's accuracy, these models will be used to enrich the energy data models with relevant information to be later transformed as input to the Building Energy Performance Estimation (BEPE) module.

Name of New Component/Service:	*Profiling Residents Usage of Building System (PRUBS)*
Type:	*Component*
Functionality:	*This component receives an IoT streams data model and populates the PRUBS output data model (obXML)*
***Input Connections & Interfaces:* From which components it receives input**	*This component receives the IoT streams data model from the BIMERR Middleware*
***Output Connections & Interfaces:* To which components it sends the results**	*The Output contains generated Occupant Behaviour models that populate the PRUBS output data model (e.g. obXML) which is sent to BIMERR Interoperability Framework (the Building Operational Data Extraction Agent of the Building Information Collection and Enrichment component)*
Relevant Use Cases	*UC-03, UC-13, UC-15*
Functional Requirements	• *The PRUBS component must be able to retrieve a notification message that the data model (JSON) for a requested time interval has been populated, meets the PRUBS module input data requirements and has been stored in the data repository* • *The PRUBS component must be able to retrieve these data and apply innovative methodologies to generate Occupant Behaviour models/profiles.* • *The PRUBS component must be able to populate the Occupant Behaviour data model and send it to the BIF (Building Operational Data Extraction Agent)*

Non-Functional Requirements	• *Interoperability: the component must be able to read the JASON data model populated by the Middleware and output its model in obXML format.* • *Reliability: the module must have a mechanism to report errors when required information is missing.* • *Response time: the module must respond as fast as possible.* • *Computational capacity: the module must have enough computational capacity to face the Occupant Behaviour models' training tasks.* • *Scalability: new Occupant Behaviour modelling methodologies must be easy to add.*

Input Parameters

Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
IoT streams data model	*A data model populated by event-based data streams from IoT devices installed at the pre-renovation building following a predefined JSON schema*	*Complex type*	*JSON or Sen ML*	*IoT streams data model includes objects of prameters that have different ranges and varying frequencies - some are event driven and some are timeseries*	*BIMERR Middleware*
Subset of the Parameters that are captured by the IoT streams data model					
Zone Air Temperature (°C)	*Indoor Temperature from a specific sensor installed inside the building zone*	*float*	*JSON object*	*Value range: [0, 50] (°C)*	*IoT streams data model*
Zone Air Relative Humidity (%)	*Relative humidity from a specific sensor installed inside the building zone*	*float*		*Value range: [0, 100] (%)*	
Zone Illuminance (Lux)	*Illuminance from a specific sensor installed inside the building zone*	*float*		*Value range: [0, 10000] (lux)*	
Zone Occupant presence	*occupancy inside a building zone based on several motion detections from one or a group of motion sensors*	*boolean*		*Value range: {0,1}*	
Zone Energy Metering Data	*Metering data for power consumption will be collected from smart meters, power meters and smart clamps.*	*float*		*Values range: [0, …] watts*	

HVAC's thermostat setpoint temperature	*Desired temperature for HVAC device configured by the end user*	*float*		*Value range: Unit's dependent – [16, 30] (°C) usually*	
HVAC equipment's mode	*HVAC's Mode configured by the end user*	*string*		*Value range: {Heating, Cooling}*	
HVAC equipment's status	*Activation based on end user's preferences*	*string*		*Value range: {ON, OFF}*	
Zone Artificial Lighting brightness	*Dimming level based on end user's preferences*	*float*		*Value range: [0, 100] (%)*	
Outdoor Dry Bulb Temperature	*The outdoor dry bulb temperature in °C measured from local weather stations*	*float*		*Value range: Weather station's dependent*	
Outdoor Relative Humidity	*The outdoor relative humidity in percent measured from local weather stations*	*float*		*Value range: [0, 100] (%)*	
Wind Speed	*The wind speed in m/sec measured from local weather stations*	*float*		*Value range: [0, 40] (m/sec)*	
Wind Direction	*The Wind Direction in degrees, where the convention is that North = 0.0, East = 90.0, South = 180.0, West = 270.0, measured from local weather stations*	*float*		*Value range: [0, 360] (°)*	
Direct Normal Radiation	*Amount of solar radiation in Wh/m² received directly from the solar disk on a surface perpendicular to the sun's rays*	*float*		*Value range: [0, 1500] (Wh/m²)*	
Output Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***

PRUBS output data model	*A data model populated by the PRUBS module and includes data about the occupant preferences and can be formulated as closed-form equations or as data-series so that they are compatible with EnergyPlus requirements*	*Complex type*	*obXML*	*N/A*	*BIMERR Interoperability Framework (Building Operational Data Extraction Agent of the Building Information Collection)*
Software Requirements/Development Language		*Java*			
Hardware Requirements		*IoT sensors installed at the building. The list of the minimum sensor requirements includes multi-sensors for the monitoring of the indoor environment, occupancy sensors (that might be included in the multisensory), energy meters for the overall energy consumption and energy meters for the heavy loads of the building.*			
Communications		*REST API*			
Status of the development of the component		*Partially developed*			

Table 27: Profiling Residents Usage of Building System (PRUBS) Detailed Specifications

While pre-validation sites (e.g. KRIPIS building owned by CERTH) are fully equipped with IoT devices, sensors networks have to be designed and installed on the validation sites. Previous experimentation with different sensors/gateways has shown that the gateways and sensor specifications may ensure that the system will be running according to PRUBS requirements. These specifications will be provided in detail in D5.7.

4.4.4 BIM Management Platform

The BIM Management Platform is responsible for the storage, management, query into and visualization of the information of a construction (or other building related) project. Data is stored in the open data standard IFC using a model-driven architecture approach. This means that IFC data is stored as objects stored in a database, with special extra features like model checking, versioning, project structures, merging, etc. The main advantage of this approach is the ability to query, merge and filter the BIM-model and generate IFC output (i.e. files) on the fly. Scan-to-BIM is responsible for capturing accurately a 3D scan of the renovation site and creating the corresponding digital building model containing all primary (`structural') components and space geometries, as well as some 'secondary' components (e.g. MEP). The capturing is achieved with reality capture systems, primarily laser scanning and photogrammetry. The resulting digital building model is sent to BIF.

Name of New Component/Service:	*BIM Management Platform*				
Type:	Component				
Functionality:	This component enables IFC BIM Model storage, management, query system and visualization among other functionalities provided as plugins to the system, including IFC model validation, model merging, model comparison, model subset extraction and more according to the requirements of the BIMERR users. It also provides the user authentication and user management services that are then shared with the other BIMERR components				
Input Connections & Interfaces: From which components it receives input	The BIM Management platform receives BIM models generated by the Scan-to-BIM component in IFC format and stores them in its internal database. It also receives updated IFC formatted BIM models from the Interoperability framework once they have been modified with annotations and extra data.				
Output Connections & Interfaces: To which components it sends the results	The BIM Management platform provides IFC models to the Interoperability Framework to propagate to end-user applications				
Relevant Use Cases	*UC-02, UC-07, UC-08, UC-10, UC-11, UC-12*				
Functional Requirements	*BMRR-3, BMRR-7, BMRR-14, BMRR-19, BMRR-43, BMRR-75, BMRR-110*				
Non-Functional Requirements					
Input Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
User Information	User account information	Text	JSON	N/A	
User Role	User role	Text	JSON	*N/A*	
BIM Model	The semantic 3D model of the building including the topology, main components (size, geometry, type, age, etc.) required for defect detection	IFC file, DWG	IFC	N/A	BIM model; Access to BIM Data from the *Building Information Secure Provisioning* component
Output Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***

BIM Model	The semantic 3D model of the building including the topology, main components (size, geometry, type, age, etc.) required for defect detection	IFC file, DWG	IFC	N/A	BIF; ARIBFA; UI or supporting tools interface
Comparison Results	The results in text describing the differences between two IFC models	String	UTF	N/A	UI or supporting tools interface
Validation Results	The results in text reporting on the validity of IFC models	JSON	UTF	N/A	UI or supporting tools interface
Software Requirements/Development Language	Windows/Linux implementation, Java / Java portlet				
Hardware Requirements	PC/Server 16Gb RAM or more, 500Gb Storage or higher				
Communications	REST API				
Status of the development of the component	Based on BIMserver.org				

Table 28: BIM Management Platform Module Detailed Specifications

4.4.5 Building Information Collection Application (BICA)

BICA aims to exploit the resident's information regarding the renovation site as they understand their home performance much better than any professional. It allows residents to provide complementary information, such as notes and photos, to the already recorded building information in the BIM, using the BICA's UI. Specifically, it accepts as input the BIM model in IFC format, photos and notes uploaded by residents and lastly, already existing annotations and markups submitted by residents or other stakeholders. It outputs the new information provided by users, as well as health and safety issues, in case any have been reported.

Name of New Component/Service:	*Building Information Collection Application (BICA)*
Type:	*Application Software*

Functionality:	This component enables the residents provide their feedback on the building and the renovation works, based on their experience on site. The residents will give their input spontaneously on their home indoor/outdoor areas or at the request of the building surveyors/engineers (e.g. with regard to preferred building equipment/appliance usage or future intended usage patterns of rooms). The feedback can come in the form of notes, photos or even markups related to elements of the building's original BIM model, identifying inaccuracies and other issues. BICA will also serve as a bilateral health and safety (H&S) information point: The residents are able to view the H&S instructions, which are issued by the H&S managers. Additionally, they can create new H&S issues, when they spot a possible danger on-building-site and the H&S managers are notified accordingly. Notifications necessary for the above functionalities, will also be supported by BICA.
Input Connections & Interfaces: From which components it receives input	The *BICA* component receives the building's BIM model from the *BIF*, in collaboration with the *Building Semantic Modelling* component (for just the semantic model) and the *Building Information Secure Provisioning* component (for the populated BIM model in accordance with the applicable BIM data access policies). The *BICA* app also receives data from the mobile device's image storage. Other data is submitted by the resident through the *BICA* app.
Output Connections & Interfaces: To which components it sends the results	The BICA component collects input from the residents and forwards it to the other BIMERR components/applications through BIF. The collected data is ingested by the *Building Information Collection & Enrichment* component through the APIs and wrappers of the *BICA* application. Data exchanges between BICA and other BIMERR components happen through the BIF.
Relevant Use Cases	*UC-02, UC-10, UC-11, UC-12*
Functional Requirements	*BMRR-7-9, BMRR-51-53, BMRR-65, BMRR-73-74, BMRR-76, BMRR-80-85*
Non-Functional Requirements	

Input Parameters

Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
Occupant Information	User account information	Text	JSON		*To be decided if it will be received by another BIMERR application or directly created in BICA*
BIM Model	The semantic 3D model of the building including the topology, main components (size, geometry, type, age, etc.) required for defect detection	IFC file, DWG	IFC	N/A	BIM model; Access to BIM Data from the BIF
Photos/ Notes	Photos/Notes to be uploaded by residents spontaneously or after receiving associated notification regarding defect detection or complementary information to BIM elements (e.g. regarding HVAC)	PNG, JPEG, TXT		N/A	Photos from the residents' cameras

Existing Annotations/Markups on Drawings	Annotations/ Markups on Drawings and building digital model already uploaded by residents and other stakeholders	Design Web Format (DWF), PDF		N/A	Drawings for mark-ups either received either through the BIF (Marker-less Feature Recognition Module and Scan-to-BIM) or from the past history of the BICA
Notifications	Notifications and messages regarding H&S issues that the occupants should have in mind	Text	JSON	N/A	Notifications from PWMA component for existing H&S issues.
Output Parameters					
Attribute/Parameter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
Complementary Building Information	Complementary information related to the building location, the different elements in a building (e.g. HVAC elements) and markups made by the residents through the BICA UI. Such data are afterwards forwarded to other BIMERR applications in order to be inspected by the responsible personnel.	Text	JSON	N/A	*Building Information Collection & Enrichment* and any other BIMERR application through the BIF
H&S Issues	The residents can report new H&S issues through the BICA app, which are highlighted in the BIM model.	Text (notes), PNG, JPEG (Photos)	JSON	N/A	*Building Information Collection & Enrichment, PWMA, BIM platform*
Software Requirements/Development Language	Web Application				
Hardware Requirements	This application should be accessible by a multitude of devices to reduce access barriers of residents				
Communications	REST API				
Status of the development of the component	To be developed from scratch				

Table 29: Building Information Collection Application (BICA) Detailed Specifications

5. IMPLEMENTATION, INTEGRATION AND DEPLOYMENT ROADMAPS

In this section, we focus on providing the milestones regarding the implementation, integration and deployment of each component that structures the BIMERR framework.

5.1 BIMERR INTEROPERABILITY FRAMEWORK ROADMAP

The design and implementation of the BIMERR Building Interoperability Framework is carefully planned in two iterations in order to deliver the intended functionalities in an incremental, agile manner, prioritizing the most critical features for the data exchanges and semantic interoperability between the BIMERR applications. The implementation of the BIMERR BIF is also considered as a challenging task as it needs to deliver all intended functionality in a scalable and performant manner while in the beginning, the BIMERR applications that it is intended to interconnect are still at the conception phase.

5.1.1 Building Semantic Modelling Tool

In the early design phase (M8-M12), the typical semantic modelling use cases as well as the definition of the semantic model lifecycle management process (featuring data-to-model mapping and model evolution) will be specified and documented in detail prior to any development activities. In the detailed specification phase (M13—M15), mockups are created and the backlog of functionalities is defined. Since the Building Semantic Modelling Tool is heavily dependent on the BIMERR ontology and data model, as defined in the context of T4.2, initial tests shall be also performed to ensure that their structure is aligned with the different, implicit mapping problems (e.g. unit transformation, timezone conversion, etc.). During the preliminary implementation and integration phase (M15-M18), the proposed mapping generation (from the underlying source schema to the target BIMERR data model) will be based on different techniques (e.g. fuzzy mapping), and shall be complemented by the manual mapping validation based on the BIMERR data model information that shall be provided in an intuitive manner. The mapping configuration file shall be defined per information source along with certain provenance information, and stored. During the final implementation and integration phase (M19-M30), emphasis will be laid on: (a) performance improvements and enhancements (e.g. in the proposed mapping generation), (b) data model evolution management through a suggestions' review and accept/decline mechanism, as well as alignment with the BIMERR ontology, and (c) additional functionalities and usability improvements based on the evaluation feedback that shall be collected in WP9.

5.1.2 Building Information Collection and Enrichment Tool

In the early design phase (M8-M12), the detailed definition of the data collection-related steps ranging from ingestion to pre-processing, indexing and storage of the information provided by the individual BIMERR-compliant applications will be specified and documented in detail prior to any development activities. In the detailed specification phase (M13—M15), mockups are created and the backlog of functionalities is defined. Since the Building Information Collection and Enrichment Tool is tightly related with the Building Semantic Modelling Tool, initial tests shall be also performed to ensure that all necessary information is captured based on an appropriate metadata schema that is also designed in this phase. During the preliminary implementation and integration phase (M15-M18), the core data collection and enrichment technology stack is delivered, allowing for the design and execution of data collection jobs for selected, prioritized data formats, as well as basic CRUD operations over the storage and indexing. The preliminary version of the Master Controller and the Worker to be executed on the BIMERR Middleware based on the configuration file of the collection job, as well as the BIMERR APIs, shall be also delivered. Any additional functionalities required to facilitate information exchange with the Midddleware and the knowledge graph generation, will also be defined in this phase. During the final implementation and integration phase (M19-M30), support for reusable data collection templates and more data formats shall be provided, the data update and sync mechanism will be finalized, a full collection failure management process shall be enabled, the CRUD operations over the storage and indexing shall be expanded, and performance improvements shall be made based on the technical verification and the overall validation activities in WP9.

5.1.3 Building Information Secure Provisioning Tool

The implementation of the Building Information Secure Provisioning Tool requires two phases of action: a) The definition and the preparation of a preliminary set of access policies, based on the defined data sources that are shared among the BIMERR Renovation Support Tools, as well as, other data sources used by the BIMERR solution, and b) the technical development of the XACML-based policy engine. For the successful delivery of the component as part of the 1st version of the Integrated BIMERR Interoperability Framework on M18, the following planning is foreseen: Initially, the preliminary set of access policies needs to be finalized by the end of M13, based on the outcomes of T4.2, while the implementation of the BISP component will start during M13. All subcomponents will be implemented incrementally in an agile approach. Nevertheless, some of the components have slightly higher priority in order to assure the successful delivery of the component. This priority is as following: Access Policy Management (M14), Access Request Transformation Handler (M15), Policy Enforcement Business Logic and Attributes Handler (M16). The implementation of the core part of the BISP is planned to be finished by the end of M16, so as to proceed with the technical integration of the component with the rest BIF components until M18. During that period (M16-M18) the finalization of the subcomponents, as well as, the fine tuning of the parameters of the Attributes Handler and the

Policy Enforcement Business Logic with the rest of the BIF components and the BIMERR Management Platform will take place, as part of the integration tasks.

5.1.4 Building Information Query Builder Tool

As in the case of all BIMERR BIF tools, the Building Information Query Builder will be developed and deployed in 2 implementation phases. Initially, from M11 until M15, the baseline query workflows will be designed, different query examples shall be defined and the core query functionalities for applications and users shall be consolidated. In the 1st release of the Building Information Query Builder on M18, basic search and filtering functionality will be provided for applications based on the users' configuration, translating their searches to valid queries that are available at any time through the BIMERR APIs. Query response and storage will be supported taking into consideration the applicable access policies in collaboration with the Building Information Secure Provisioning Tool. In the 2nd, final release of the Building Information Query Builder on M30, increased expressivity in query definition is expected while new functionalities will be introduced to take into account the users' validation feedback, but also considering certain planned functionalities (such as query history browsing, query scheduling or re-execution to effectively handle errors).

5.2 BIMERR MIDDLEWARE ROADMAP

The BIMERR Middleware consists of several independently developed components. This section first outlines the roadmap for each component and defines three milestones for the release of middleware as a whole. It is important to note that the roadmap covers only key implementation and deployment activities with expected refinements followed until the end of demonstration activities (M40).

The implementation roadmap for individual components is as below:

- Service Registry is built on top of existing open source solutions. There is ongoing work on the adaptation of the code to match middleware service discovery requirements, with stable version expected by M15.
- OTA Software Update & Monitoring is a fork of an open source software being customized to the needs of the project. The first stable version of this component will be available in M16 for on-premise application deployment and simple monitoring. A second version with access control and full monitoring functionalities will be delivered by M24.
- Gateway Security will be realized using state-of-the-art security guidelines. The first version will involve basic access control and integrate with all other middleware components by M16. The second version will be integrated with the central BIMERR identity provider and released by M24.

- Data Processor involves the development of lightweight data handling components. This component will be released in three stages, first with basic functionalities such as data transformation and ingestion (M16) followed by annotation, fusion, aggregation and filtering (M24), and local data analysis (M26).
- Registry & Data Storage is under active development and will ready for beta testing by M15 followed by a stable first release on M16. The first release provides functionalities for time-series storage on gateway devices. A second version is expected by M18 with retention management and full compliance to the selected standard data schemas. The final release on M24 will provide access control along with improvements to the underlying storage layer and integration with the Data Processor.
- Device Abstraction is a combination of components developed from scratch or using existing open source software. As required for data collection from the early validation stages, connectors for integrating sensor drivers and the middleware will be developed for pre-validation sites sensing (M16-M17) and then for validation sites (M18-M20).

The deployment of middleware is based on three milestones:

1. The availability of the initial version of all components for deployment in pre-validation sites (M16).
2. The middleware with improved components and stable functionality for data collection in validation sites and integration with BIF (M18).
3. The fully functional middleware, available for reliable operation and secure integration with relevant BIMERR components (M24).

5.3 RENOVATION SUPPORT TOOLS ROADMAP

5.3.1 RenoDSS: Renovation Decision Support System

The RenoDSS component retrieves information from the Interoperability Framework (BIF), transforms these data to proper simulation input data files and launches respective simulation modules to calculate Energy, Comfort, LCC/LCA KPIs to be communicated back to the BIF and stored to the respective project repository. RenoDSS comprises several modules, e.g. the RenoDSS data management, the Building Energy Performance Estimation (BEPE), the LCA/LCC to name but a few, that exchange information and cooperate to address all its functional requirements. The first version of all these modules will be officially issued on M20 to support the pre-validation deployment and testing activities, while their final version will be delivered on M30 to evaluate their performance in real renovation projects (validation phase). The implementation roadmap for RenoDSS modules will consist of three main phases.

Phase 1 – RenoDSS prototype development (due M18): This phase concerns the development of the RenoDSS component prototype consisting of several components for generation of the simulation input, invocation of the simulation tools, post-processing of the simulation outputs to generate relevant KPIs, and interfaces for communication of the results between the modules and back to the BIF. Initial verification and validation experiments of each module will be conducted in phase 1: supposing that IFC, obXML and EPW files will be available for simplified "shoe-box" test-cases, RenoDSS data management module, the orchestrator of the data exchange between the RenoDSS modules, will be able to communicate with and send data to the BEPE, the LCC/LCA and the Urban Planning modules. Additionally, to experiment with data retrieval, exchange, transformation, execution of simulation tools and KPI computation functionalities that each tool provides, a first version of the aforementioned modules and the User Interfaces for RenoDSS dashboard, building baseline information, KPIs (current and target), renovation measure selection, and scenario viewer are expected to be released. Scope of this phase is to early detect major potential drawbacks that may affect the RenoDSS performance in the pre-validation and validation phases.

Phase 2 – RenoDSS component integration and communication with the BIF (due M24): Based on lessons learned from phase 1 results, additional functionalities that deal with supplementary data transfer requirements for candidate renovation scenarios evaluation will be delivered on M20. During M21-M24, refinements of RenoDSS modules will take place towards delivering the core of the RenoDSS that will be well-integrated with the BIF for proper data exchange and ready to be used for the pre-validation activities on M24 (in accordance with milestone MS3: Delivery of the first version of BIMERR system for deployment and testing at the pre-validation pilot sites).

Phase 3 – RenoDSS component refinement (due M30): Based on verification and validation experiments of RenoDSS performed in relevant environments (pre-validation pilot sites) the RenoDSS modules will be further extended and refined to eventually deliver the second version of the integrated RenoDSS for deployment and use at the real renovation pilot sites (see milestone MS5).

5.3.2 Process & Workflow Modelling and Automation toolkit (PWMA)

The PWMA toolkit will enable to manage the whole process of reconstruction, from modelling trough simulation till the execution. The toolkit will have two versions. The first version is planned to be finished at M19. The second version will be ready until the M30.

First version (M19)

The first step will be to define and implement a concrete, executable workflow based on the stakeholders requirements collected in T3.1 as well as the outcomes of T6.1 in terms of renovation process analysis. This workflow will be modeled and the BPMN model containing the definition of the

process will be used for communication between the definition tool, simulation and the execution tool.

The modeling tool will be created in the ADOxx classic version for this first prototype and will integrate a simulation component for forward looking prediction and a dashboard for backwards looking monitoring. Together they will support the final user during decision stages.

The execution tool will provide User Interface (UI), which will allow for different stakeholders to manage their part of the reconstruction process and which will provide different view on the status of the reconstruction process, including its sub-processes. The project manager will be able to modify the reconstruction process (e.g. rearrange and/or reallocate the upcoming tasks). The execution tool will provide information about the status of the reconstruction process via API.

Workplan (D6.6)

- Basic workflow defined and exported to BPMN model(M14)
- First prototype of dashboard component (M14)
- The basic workflow imported and displayed in the execution tool (M16)
- Adjustability (rearrange and reassign) of the sub-processes (M17)
- Execution of the basic workflow and API provided for accessing the results of execution (M18)
- First prototype of model simulation component (M18)

Second version (M30)

The functionality will be extended to cover the identified needs of the stakeholders. Every sub-process will be distinguished, if it is an automatic process, or need to be executed by person. The User interface of this module will be adjusted to the common BIMERR UI. Integration with the On-site workers support tool will be implemented to monitor the work/process. In the execution tool it will be possible to create/define detailed instructions to selected sub-processes, which will be executed via smart-glasses. In the modelling tool an assessment component will be provided in order to check if the model is meaningful respect to the available data and, based on that data, how much trustable will be a calculated KPIs for supporting the user in the decision making process. The modeling tool will be also finalized and released as web application.

Workplan (D6.7)

- Workflow extended with information related to external processes defined and exported to BPMN model (M22)
- Initial version of the modelling assessment component (M24)
- UI adjusted to BIMERR Standards (M24)

- Integration with on-site workers support tool to define and follow the workers activities (M28)
- Final version of the web modelling tool integrating the assessment component (M28)

5.4 DIGITAL BUILDING MODEL CREATION TOOLS ROADMAP

5.4.1 BIM Management Platform (CERTH)

According to the schedule depicted in the DoA, the first version of the BIM Management Platform is expected on M20. This is expected to be delayed for 2-3 months due to the lead partner's withdrawal from the project and pending a selection of a new partner to take over the leadership of the activities pertaining to the development of the BIM Management Platform. As such, a first prototype that can be used for testing can be expected on M23. The implementation of the BIM Management Platform will be based on the BimServer.org open source platform, hence a major part of the foreseen functionalities of the BIM Management Platform are to be available in the first prototype. Within these functionalities are the following:

- User Management/Authentication
- BIM Model Management/Storage/Versioning
- BIM Model Query System
- BIM Model Comparison
- BIM Model Merging
- BIM Model Validation
- WebGUI/BIM Model Visualisation
- Notification System

The final version of the BIM Management Platform is planned for M30 and is expected to be on track. The functionalities that will be added in the final version include:

- Support for IFC Extensions developed by BIMERR (M20-M24)
- Scan-to-BIM integration to allocate point clouds to IFC model elements (M20-M24)
- BIF Integration (Semantic alignment/Ontology-Model mapping) (M24-M28)
- Query Builder wrapper for BIM Model queries (M24-M26)
- BIM Model duplication/versioning subsystem (in conjunction with BIF) (M24-M28)

The final two months in the roadmap (M28-30) are planned to be used for extensive testing of the BIM Management Platform in the pre-pilot sites using real data and integration with the other interconnected BIMERR components to polish and optimize the operation of the BIM Management Platform

5.4.2 Scan-to-BIM

According to the initial schedule, a first version of this tool is due by M20. The Scan-to-BIM process can be divided in different projects, namely:

- modelling of primary (i.e. structural) building components from point clouds obtained by means of Terrestrial Laser Scanning devices;
- generation of a 2nd Level Boundary Representation of the building layout to support energy assessment purposes;
- augmentation of the structural components with their material characteristics (principally the layers making walls and ceilings) through links to the BIMERR material/component database.
- modelling of secondary (i.e. MEP elements for energy purposes) components by means of images;
- generation of BIM models (including 2nd Level Boundary Representation) to be exported following the IFC standard; and finally,
- development of a Scan+BIM platform, where BIM models and point clouds can be simultaneously visualised, and all processes run (including communication with the BIMERR Interoperability Framework).

Regarding the identification and modelling of primary components, an initial task leading to the segmentation of planar components (i.e. walls, ceilings and floors) will be carried out. The relationships between these planes will be analysed and recorded into adjacency graphs, which will define the boundary representation of every scanned room or space. These graphs will subsequently be used for the modelling of the mentioned structural components, as three-dimensional entities, and potential openings in these volumes, such as doors or windows, will be identified and subtracted from the model. Once structural elements are defined for all the individual spaces, second level boundary information will be generated to be used for energy assessment purposes. A first version of this tool will be ready by the end of M18, while second level boundary information will be added by M20.

Additionally, the Scan-to-BIM software will be able to communicate with the BIMERR material/component database to populate the generated BIM model with information related to the materials used in the construction of the structural building components.

Secondary components are those elements inherent to buildings not being part of their structure. Amongst these, Mechanical, Engineering and Plumbing (MEP) components, especially the ones related to energy (e.g., radiators, HVAC devices), will be subject of this study. The developed Scan-to-BIM tool will be able to identify secondary elements from both planar and 360 pictures obtained through campaigns of digital documentation of buildings. First, regions of pictures containing secondary components will be labelled. These labelled datasets will be used to train a classification model, based

on deep learning techniques, which will help identify MEP devices. This is expected by the end of M18. Finally, information obtained from the classification of identified components will be utilised to include this kind of elements into BIM models. A demo of this tool will be ready by M20.

Once primary and secondary components are identified and modelled, BIM models are subsequently produced, following the IFC (version 4x1) open standard, to be uploaded into the BIMERR Interoperability Framework platform and used by other BIMERR components/services. For the generation of BIM models, we aim to employ the xBIM solution. A first version of this tool will be delivered on M18.

These three projects will be integrated in a Scan+BIM engine, which will be able to render both point clouds and BIM models. This software will be based on the existing Open Infra Platform and will allow basic operations on the BIM models. A demo of this tool will be ready by M18.

Testing and Validation of these modelling tools will be carried out by using different datasets, including the two pilot sites. This will help identify the existing weaknesses and suggest potential functionalities to improve the proposed Scan-to-BIM approach. A demo version of this solution will be delivered on M20, when a preliminary version of the software leading to the modelling of both primary and secondary components will be integrated into the Scan+BIM platform. Potential improvements on the developed software, based on the testing and evaluation of the tools with different datasets, will take place between M20-M30.

5.4.3 Augmented Reality enabled In-situ Building Feature Annotation (ARIBFA)

The development of ARIBFA is a challenging task and it is scheduled to be completed on M20. During M12-M15, the initial goal is to develop a localization, registration and tracking system that would achieve at least benchmark results. At the same time, it is crucial to successfully deploy the developed system on the AR glasses while taking fully advantage of the sensors provided. Simultaneously, it is expected that the required data, BIM Model, building elements dataset and IoT data streams, will be collected, in order to test the functionality of each component that makes up ARIBFA. With the completion of the initial system development and the successful collection of the dataset, preliminary tests would take place to evaluate the functionality of the system. The results of the actions that will be implemented in these months will be the basis for the development of the rest of the ARIBFA system.

In the course of M15-M18, the development of both recognition and AR annotation and context aware-visualisation modules will take place. The development of the recognition module consists of building and training deep learning models and deploying these models to the cloud. Moreover, actions, regarding the communication between the AR glasses and the cloud, will be made towards the recognition of the building components using the AR glasses while the models will be on the cloud.

At the same time, the AR annotation and context aware-visualisation module will be developed and tested using the AR glasses. Over these months the initial localization, registration and tracking system would be slightly improved and tested. By the end of M18, it is expected that all of the modules will be able to provide most of their functionalities.

The last two months, M18-M20, that also mark the completion of the deliverable of BIMERR final architecture will mostly be used to test and evaluate the first version of the completed ARIBFA. Components will be tested both separately and as a whole. Testing's purpose is to discover the weaknesses of the system, as a whole and component-wise, and to evaluate whether the functionalities provided by the APIs, which connect each component with the others, are sufficient for ARIBFA or require further development. In addition, the system will be tested on different uses cases to capture its behavior and set its performance as a benchmark for future versions of ARIBFA. Furthermore, actions will be taken to discover ways that ARIBFA's integration with the rest of the BIMERR Framework will be achieved. By the end of M20, the main objective is to have a complete demo of ARIBFA capable of being integrated into the BIMERR solution. The improvements that need to be made, based on the evaluation of the system, will take place between M20-M30.

5.4.4 Profiling Residents Usage of Building System (PRUBS)

The PRUBS module aims to develop occupant behavior models that simulate the actual building usage patterns through human-centric behavioral profiling of indoor environmental conditions via Internet-of-Things solutions. Hence, prerequisite for the occupant behavior models development is the availability of data provided by the IoT stream data model populated based on sensed data captured by a well-defined wireless sensor network topology. The first version of PRUBS module will be officially issued on M22 to support the pre-validation deployment and testing activities, while their final version will be delivered on M30 to evaluate their performance in real renovation projects (validation phase).

Due M18, three main tasks are foreseen to be delivered:

1. Design of the wireless sensor network topology that will be used to collect data from the pilot sites – the proposed topology must be able to provide information about the indoor temperature at each room; room air relative humidity; room luminance; Room occupant presence; HVAC's thermostat setpoint temperature; HVAC equipment's mode; HVAC equipment's status; Opening elements (exterior operable/not-fixed windows and doors) status (open/closed) and weather conditions.
2. Occupant behavior models development – based on data retrieved from existing test-labs, occupant thermal comfort and presence models are expected to be developed, tested and validated in relevant environments, emphasizing on the comfort preferences of residents from the contextual conditions, the resident actions upon key building loads and other parameters, such as time, day of week, external weather conditions etc.

3. ObXML data model population tool – methods that translate the occupant behavior models to data instances following the obXML schema will be developed. Scope of these methods will be to populate the occupant behavior data model and facilitate the co-simulation between the occupant behavior and the building energy performance simulation following well established FMU based co-simulation interfaces.

During M19-M22, the occupant behavior models and the obXML data population tool delivered on M18 will be refined. Additionally, functionalities for seamless communication and data exchange with the BIMERR Interoperability Framework will be developed. Mechanisms to report errors when required information is missing will be delivered as well. Due M22, a concrete PRUBS module that mainly receives an IoT streams data model, populates the PRUBS output data model (obXML) and send it to the BIF is expected to be delivered.

During M23-M30, based on the PRUBS module performance on the pre-validation pilot sites and the capability of the occupant behavior models to capture the occupants' habits, the PRUBS module will be further extended and refined to finally deliver its second version on M30.

5.4.5 Building Information Collection Application (BICA)

The Building Information Collection Application (BICA) will be designed and delivered in 2 iterations, with a preliminary version expected on M22 and a final version released on M30. During the design phase (M10-M15), the functionalities to be delivered are agreed, the expected data exchanges with other applications through the BIMERR Interoperability Framework (BIF) are consolidated and detailed mockups of the mobile application are designed and discussed in order to check their user friendliness and usability for occupants. During the initial development activities (M16-M22), the first version of the BICA mobile application and backend will be released, allowing for basic functionality such as: (a) annotation and reporting of information in a building apartment (uploading information on specific BIM elements, such as HVAC, providing details on the status and issues faced in the apartment), (b) smart, non-intrusive notifications for health & safety issues (as communicated through the PWMA tool), and (c) residents' registration on specific buildings. In the final development activities (M23-M30), usability improvements, updates and additional functionalities (e.g. more interactive visualization of the building layout) are expected based on the users' feedback.

6. CONCLUSIONS

This document reported on the work carried out within Task 3.5 (System Architecture Design & Elaboration) while also making use of the outcomes of WP2 and the entire WP3 activities with a main focus on the findings of T3.1 (Elicitation of Stakeholder Requirements). It concerned the first version of the definition of the BIMERR architecture while an updated and final version of the architecture is foreseen to be elaborated and delivered at M20.

The architecture was defined following four consecutive steps. In the first one, the main principles and methodology of the systems architecture for BIMERR was defined while in the second step, a top-down view of the entire system architecture was defined where the high level overview of the BIMERR components was designed, in order to provide a definition of BIMERR's main components and their role in the entire system. This was followed by a bottom-up phase, where a number of components and subcomponents, belonging to the set of partners' assets, were identified and described in technical detail along with their corresponding functionalities and interrelations. The components' internal architecture, functionalities, and interaction with other main components was elaborated and presented. The final step was focused on each components role and their interaction within a workflow. In particular, the 16 use cases identified within Task 3.1 were selected to build the related sequence diagrams by considering the identified components that were involved in each use case. This has allowed emphasizing the services each component would provide. In addition, an extensive implementation, integration and deployment roadmap was drafted for each component.

Following this approach, the BIMERR architecture was defined and documented in two different views namely, Structural and Dynamic view while the Implementation and integration of the described components was covered with the inclusion of a roadmap for each one of them for the upcoming period.

The Data exchange and Interoperability between the system components was explored making explicit provisions for Data Security and GDPR compliance including a first draft of the Data Protection Impact Analysis to be updated in the Data Management deliverable and finally, a provisional list of services to be expanded and formalized in the final version of this deliverable was also included to finalize the document.

The next iteration of this deliverable, D3.6, will update the architecture as implementation, testing and pre-pilot integration efforts come into effect with adjustments to certain assumptions made so far with real-world observations, feedback and issues that arise. This version of the deliverable will also go further into the functional description of system services/APIs and data communication protocols as those will have matured after initial development of the system components.

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7. ANNEX I - DATA EXCHANGE AND COMPONENT INTEROPERABILITY

Data Ontologies and Semantic Interoperability. The BIMERR Interoperability Framework (BIF) and Middleware deal with data coming from various sources in the architecture, engineering and construction-related domains. Each of these data sources is designed independently and some important tasks in this context are to ensure the semantic interoperability of this data and to overcome issues with respect to the heterogeneity aspects of these data sources. Some of the issues are related to heterogeneity in terms of terminologies being used (i.e. Person and People) and some related to the languages used (i.e., Person and Persona). By using ontologies (Studer, 1998) to organize the relevant classes and properties, we may be able to benefit from the information encoded in the ontology (i.e., Door and Window are kinds of Building Opening). The BIMERR ontology (developed in T4.2) will be used to overcome the aforementioned issues. The BIMERR ontology will have the following characteristics:

- Formal. The BIMERR ontology will be available in machine-readable formats in different expressivity ranging from a simple RDFS to a more complex one in OWL.
- Modular. The BIMERR ontology consists of the BIMERR ontology core (in which the common classes and properties are defined) and an extension of the core ontology for each of the relevant domains, such as Building, Project Management, Weather, Energy Consumption and Habits.
- Shared. The BIMERR ontology will use/extend the popular and widely accepted data models or ontologies in their corresponding domain, such as IFC in the building domain or EPW in the weather domain so as not to reinvent-the-wheel while at the same time ensuring its uptake. Furthermore, the BIMERR ontology will also be shared and published online so that it can be reuse by others.

7.1 DATA FLOW, NETWORKING AND COMMUNICATION REQUIREMENTS

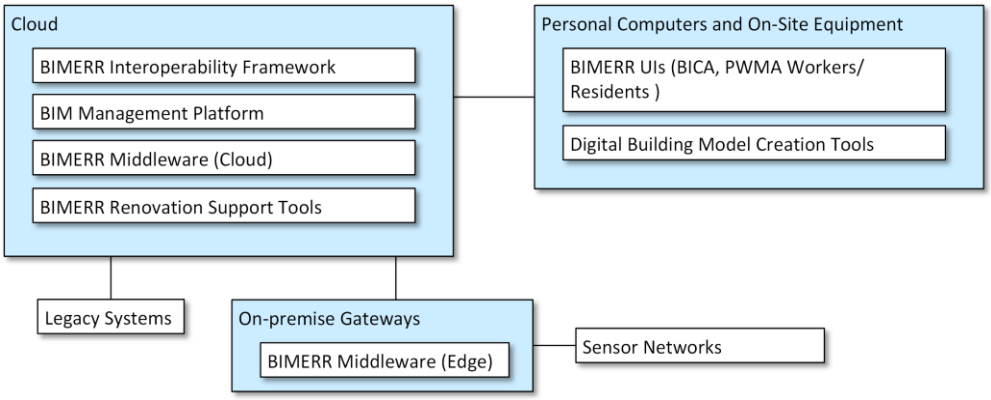


Figure 34: BIMERR Components Communication

BIMERR consists of several subsystems with various different communication requirements. This section describes the high-level communication model from a deployment point of view. The BIMERR subsystems may be divided into three deployment environments:

- Cloud: The current design envisions the deployment of the BIMERR Interoperability Framework along with parts of the Middleware in the cloud. These subsystems provide most BIMERR services in form of cloud APIs exposed over the internet with appropriate access control. These may be treated as the entry point to the BIMERR system. Moreover, such subsystems benefit from high resource availability and reliability of the cloud to store large amounts of data and perform heavy computational tasks depending on the use cases.
- Personal Computers & On-site Equipments: Various BIMERR GUI applications run on end users' personal computers (desktop, workstation, laptop, tablet). Such applications communicate with BIMERR cloud services over the internet to exchange small to very large amounts of data. Moreover, systems such as the localization module and AR devices will operate on-site and communicate with the rest of the system (e.g. over WiFi, 4G/5G).
- On-premise Gateway: BIMERR involves the deployment of embedded devices such as single board computers as gateways to interconnect sensor networks into the rest of the system. Such gateways will be deployed on pilot sites and utilize a wide range of communication protocols for connectivity to sensor networks (e.g. over Zigbee, Z-Wave, Bluetooth LE) and the cloud components (e.g. over Cellular/4G, DSL). The gateways host instantiations of the BIMERR Middleware which enable the operation of the gateway without permanent internet connectivity.

Data Residency

The BIMERR system tends to maintain the data in strategic locations to improve data locality (i.e. the ability to move the computation close to where the actual data resides on the node, instead of moving large data to computation) and privacy. In particular, the system stores large amounts of sensor data on-premise and close to the producer. The profiling data is transferred to cloud and end-user applications only after local aggregation and anonymization. On the other hand, the big data available on external sources is not replicated but rather queried on demand and stored in aggregated form for active BIMERR construction and renovation activities.

Storage Location	Data Type
Cloud	Aggregated and anonymized profiling data, user profiles, project details, construction data, BIM models, ontologies, annotated media and more to be defined in the respective deliverables of each cloud-based component

Personal Computers & On-site Equipment	Authorized, application-specific data from cloud APIs, localization data, 3D scan of buildings
On-premise Gateways	Profiling data, sensor meta data
External sources	Material and component data, weather data

Table 30: Data Storage Specifications

7.2 DATA PROTECTION AND PRIVACY

BIMERR needs to provide data protection and privacy mechanisms on the data that are imported and generated into the platform. These data may include building, usage, organization data as well as personal data included into the created user accounts. Thus, additionally to the access control mechanism implemented by the Building Information Security Provisioning tool, presented in section 5.1.5, the BIMERR platform will also provide data encryption and anonymization and/or pseudonymization of the any potential personal and sensitive data the platform may need to handle. GDPR Provisions and general Impact Analysis regarding Data protection made by BIMERR are provided in ANNEX II

7.2.1 Data Encryption

The purpose of data encryption in BIMERR is to ensure that the data will be securely transmitted from the various legacy systems, applications etc. and external data sources to the BIMERR Platform, and vice versa, without any alterations from unauthorized parties. As part of cryptography, the data encryption/decryption process has been developed to provide security for the senders and receivers to transmit and receive confidential data through an insecure channel. Encryption of data refers to a set of techniques that can be used between two parties to exchange information in a secure and reliable way. This means that data exchanged between them are:

- Encrypted: No other party can make sense of the data unless the other party has possession of the private key needed to decipher the information.
- Signed: The identity of a sender can be verified in a way that the recipient is sure that the sender is who she/he claims to be. Upon receival of the message, the sender cannot deny that the message originated by her/him and cannot claim that the contents of the message were others than those received by the receiver.

7.2.2 Data Anonymization

Apart from encryption, there are cases where the data contain both informational content that needs to be communicated and personal data that need to remain inaccessible. In these cases, techniques that perform data masking on the original data set need to be applied. Performing data masking to these data ensures that only relevant information is transmitted publicly, whereas irrelevant data that contain personal information are hidden. Before proceeding with an analysis of the existing techniques, the definition of the terms pseudonymisation and anonymisation is going to be provided as these are used in most legal documents and especially in the GDPR.

- **Pseudonymisation** means the transformation of data in such a way so that personal data cannot be retrieved without the usage of additional identifiers, not present in the transformed set.
- **Anonymisation** means the transformation of data in such a way so that personal data cannot be retrieved in any way from the transformed set.

Data anonymisation can be performed by a variety of techniques, that are not needed to be performed exclusively (Simplification, 2013). The first step in anonymising the data set is performing removal or encryption of personal identifiable information (PII) (Benitez, 2010); these include information like name, address, id number etc. The mapping to the original data can be maintained in a separate database in case of pseudonymisation or be entirely discarded for anonymisation.

Removal of PII often is not enough for ensuring privacy however, since combinations of other information can still lead to the identification of a person, especially if said combinations occur rarely in the original data set. Combinations of Personal Characteristics data (also called Quasi-identifying attributes), like ethnicity and sex, are typically such combinations. If, for example, a single combination of a certain nationality, sex and marital status appears in a data set, this certain person can be identified by only requiring the extra knowledge that she/he is a member of the data set. Anonymising a set that contains personal characteristics data typically involves one or more of the techniques of data masking, namely a) encryption, b) shuffling, c) substitution, d) variance, e) masking and f) pruning. The degree of anonymisation often depends not only on the efficiency of the transformation themselves, but to the extent that an attacker possesses knowledge of extra datasets containing information of the data subjects. These datasets may be also anonymised, but when combined they could be used to de-identify the subject(s). To handle these cases, a set of privacy models have been suggested; each one attempts to quantify the degree of anonymisation to one or more metrics and transform the data set in a way that target values of the metrics are achieved: k-anonymity (Sweeney, 2002), k-map (Dhanore, 2013), l-diversity (MACHANAVAJJHALA, 2007), t-closeness (Li, 2007), δ-presence (Nergiz, 2007), p-sensitivity (Xiao, 2008). ARX (Prasser, 2014) is a comprehensive open source software for anonymising sensitive personal data. It supports a wide variety of (1) privacy and risk

models, (2) methods for transforming data and (3) methods for analysing the usefulness of output data. Due to the fact that this section focuses on privacy models and ARX supports several combinations of privacy models, some of them are presented in the following subsections.

8. ANNEX II - DATA PROTECTION IMPACT ANALYSIS (DPIA)

Introduction

The Data Protection Impact Analysis in the Smart Grid Environment addresses organizations that manage Smart Grid deployments as well as organizations introducing changes to the existing Smart Grid Architecture platforms, in identifying and assessing the privacy risks of these initiatives. After having identified these risks, the organisations can take adequate measures to reduce them along with their potential impact on the data subject, the risks of non-compliance, the legal actions and the operational risks. Additionally, the organisations can take a competitive advantage by providing trust.

The specification of the BIMERR Data Protection Impact Analysis (DPIA) is a very important task and has to be performed at the early stages of the project. It focuses on identifying existing privacy risks and adapting the overall architecture to meet the requirements defined in the BIMERR data management policy, following the Regulatory Recommendations of the Smart Grid Task Force [X] for Privacy, Data Protection and Cybersecurity. All partners involved with the collection, process and storage of personal data have performed a DPIA.

The DPIA is conducted by the **Data Controller**, who according to the *Article 4* of the GDPR is defined as:

'the natural or legal person, public authority, agency or any other body which alone or jointly with others determines the purposes and means of the processing of personal data'.

According to this definition, for the data collected at the pilot sites, the Data Controllers of BIMERR are the partners that are responsible for the pilot sites, the Pilot Supervisors.

Regarding the partners responsible for further storage or processing of the collected data, they are considered as Data Processors of the raw data and additionally. According to the Article 4 of the GDPR, the **Data Processor** is defined as:

'the natural or legal person, public authority, agency or any other body which processes personal data on behalf of the controller.'

The raw data collected at the pilot sites undergo no processing locally at the Gateway apart from cleansing. Data processing takes place in the dedicated cloud server. As the local cleansing is done automatically and extracts no additional information from the collected data, it is assumed that no physical person applies as Data Processor until the raw data is stored at the cloud server.

The DPIA is a process complementary to the Risk Management Plan included in *D7.1 Quality Management Plan* and is also a risk assessment procedure performed for the specific analysis of the data protection risks. The surveys collected by the partners along and the overall results of the analysis are presented in the following sections.

DPIA Methodology

Step 1: The need for a DPIA

Under the GDPR, a DPIA is mandatory for processing operations that are likely to 'result in a high risk to the rights and freedoms of natural persons'(art.35). These include in particular:

- a 'systematic and extensive' analysis of personal data in the context of automated processing, including profiling, where this has a significant effect on the data subject;
- large-scale processing of 'special categories' of personal data, or of personal data relating to criminal convictions and offences; or
- a systematic monitoring of a publicly accessible area on a large scale.

Benefits for applying the DPIA methodology are:

- preventing costly adjustments in processes or system redesign by mitigating Risks to Privacy and Personal Data;
- facilitating the compliance with the principle of minimization and accuracy of Personal Data (quality of Personal Data);
- raising awareness on Risks to Privacy and Data Protection within the organization; strengthening confidence of consumers, employees and citizens by demonstrating compliance with the GDPR, respect to Privacy and commitment to safeguarding Personal Data protection;

Although a DPIA is not a legal requirement, all project partners involved in collecting, storing and processing data have carried out the process in order to effectively demonstrate that the processing of personal data is compliant with the EU Personal Data legislation.

Step 2: Conducting a DPIA

Definition of the DPIA team

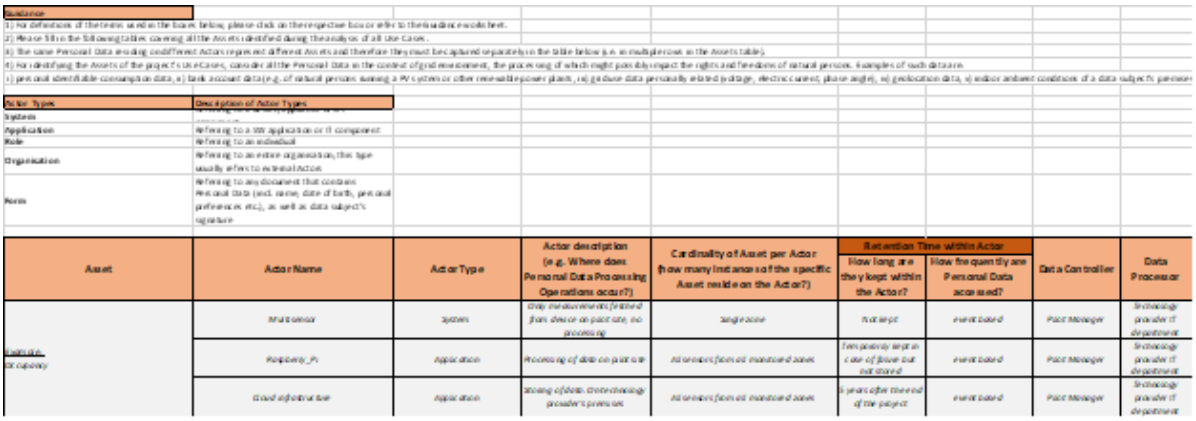
According to the simplified template, adjusted to the Smart Grid Environment specifications, that has been distributed to the involved partners, the first step for conducting a DPIA is to define the responsible team. Several options are provided for each partner to select the one that is better applicable to their organization.

Please indicate who will carry out the Data Protection Impact Assessment (DPIA)	
Available Options:	
1) A dedicated team within the user's organisation, but not the one in charge of the project or application/system which is the target of the DPIA.	
2) A third party providing an external expertise needed for the DPIA.	
3) The person(s) in charge of the application/system which is the target of the DPIA. This might especially apply in the case of SME's with limited resources.	
The DPIA will be carried out by:	1) A dedicated team within the user's organisation, but not the one in charge of the project or application/system which is the target of the DPIA.
When carrying out the DPIA:	
Has a DPO been consulted?	
Have the data subjects of the project been consulted?	Yes
If the DPIA team is different to the team in charge of the project or application/system (option 1):	
Has the project/application/system team been consulted?	Yes

Figure 35: Example of selection of the team conducting the DPIA

Definition of Use Cases, Actors and Assets

After assigning the people responsible for conducting the DPIA, the next step is to define the scope of the analysis and the related Assets. According to this, the term Assets refers to the personal data collected for the current project. All relevant Assets must be listed in detail along with the Actors related to their collection, storage or processing, and the information related to it. In this stage, the Data Controllers and Data processors need to be defined, referring to physical persons or teams responsible for the collection and processing of the listed Assets.



Asset	Actor Name	Actor Type	Actor description (e.g. Where does Personal Data Processing Operations occur?)	Cardinality of Asset per Actor (how many instances of the specific Asset reside on the Actor?)	Retention Time within Actor: How long are they kept within the Actor?	Retention Time within Actor: How frequently are Personal Data accessed?	Data Controller	Data Processor
Energy consumption	Multimeter	System	Only measurements retrieved from device on-premise, no processing	Single asset	Not kept	event based	Pilot Manager	Technology provider IT department
	Raspberry_Pi	Application	Processing of data on-premise	All sensors/devices mentioned above	Temporarily kept in case of failure but not stored	event based	Pilot Manager	Technology provider IT department
	Cloud infrastructure	Application	Storing of data. Cloud technology provider's premises	All sensors/devices mentioned above	5 years after the end of the project	event based	Pilot Manager	Technology provider IT department

Figure 36: Asset description including Actors and other relevant information

The Actor Type refers to the collection, storage and process of the data and can be identified as a device or appliance, a software application or similar IT component (e.g. a cloud server), an individual or an organization.

Identification of possible threats

After defining the related Assets and their relevant information, the possible Threats associated with them, that might trigger unwanted consequences, need to be identified. Additionally, the severity of

this threats and the likelihood of such an event occurring are evaluated in a scale from 1 to 5 (Figure 37).

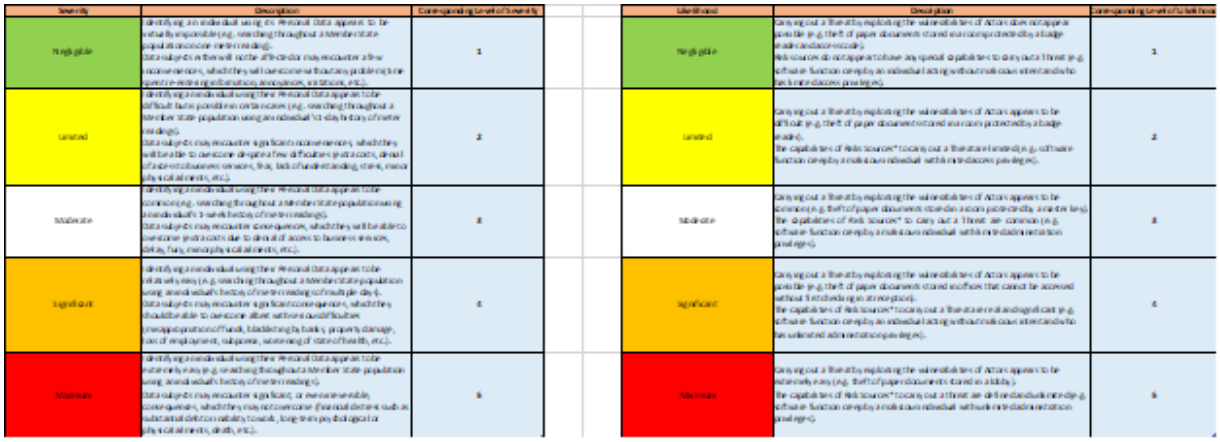
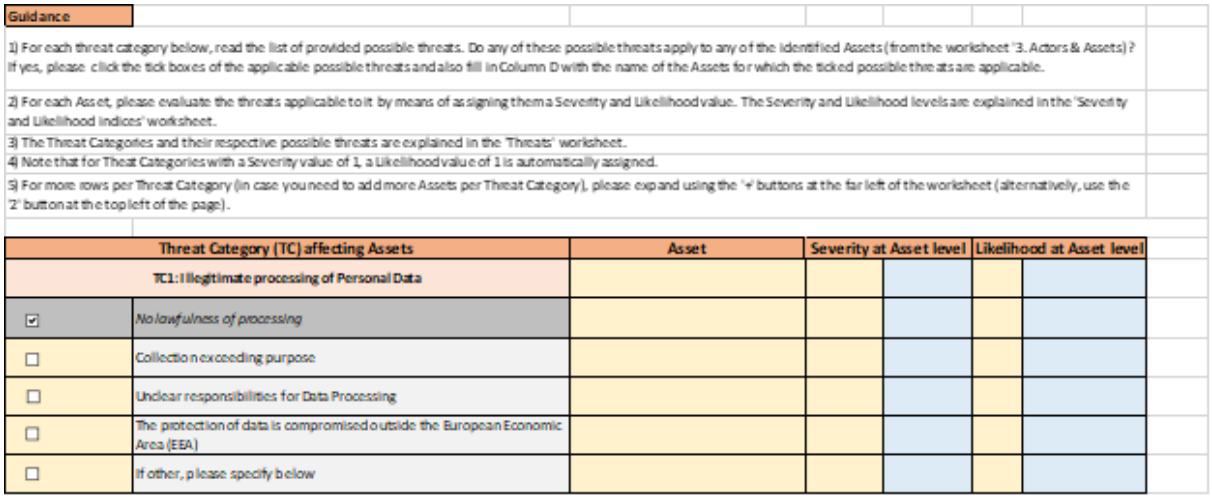


Figure 37: Evaluation scale for Threat Severity and Likelihood evaluation

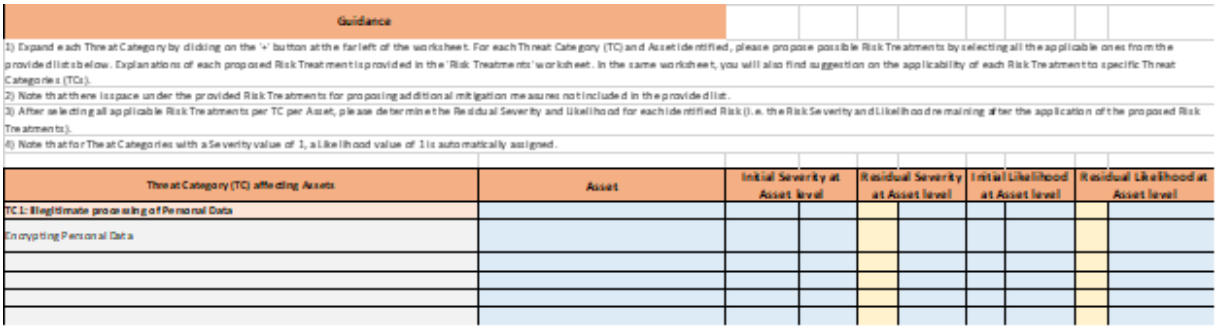


Guidance						
1) For each threat category below, read the list of provided possible threats. Do any of these possible threats apply to any of the identified Assets (from the worksheet '3. Actors & Assets)? If yes, please click the tick boxes of the applicable possible threats and also fill in Column D with the name of the Assets for which the ticked possible threats are applicable.						
2) For each Asset, please evaluate the threats applicable to it by means of assigning them a Severity and Likelihood value. The Severity and Likelihood levels are explained in the 'Severity and Likelihood Indices' worksheet.						
3) The Threat Categories and their respective possible threats are explained in the 'Threats' worksheet.						
4) Note that for Threat Categories with a Severity value of 1, a Likelihood value of 1 is automatically assigned.						
5) For more rows per Threat Category (in case you need to add more Assets per Threat Category), please expand using the '+' buttons at the far left of the worksheet (alternatively, use the '2' button at the top left of the page).						
	Threat Category (TC) affecting Assets		Asset	Severity at Asset level		Likelihood at Asset level	
	TC1: Illegitimate processing of Personal Data						
☑		*No lawfulness of processing*					
☐		Collection exceeding purpose					
☐		Unclear responsibilities for Data Processing					
☐		The protection of data is compromised outside the European Economic Area (EEA)					
☐		If other, please specify below					

Figure 38: Threats related to Assets and their corresponding Severity and Likelihood levels

Risk Treatment and Resolution

At the final stage of the DPIA process, the team conducting the analysis is required to propose actions that can mitigate the possible consequences related to the identified threats and reduce both the threats' severity and likelihood levels. By application of each mitigation measure, the new severity and likelihood levels per Asset are expected to be lower, contributing to the overall score per organization that is presented as the DPIA output.



Guidance
1) Expand each Threat Category by clicking on the '+' button at the far left of the worksheet. For each Threat Category (TC) and Asset identified, please propose possible Risk Treatments by selecting all the applicable ones from the provided list at below. Explanations of each proposed Risk Treatment is provided in the 'Risk Treatments' worksheet. In the same worksheet, you will also find suggestion on the applicability of each Risk Treatment to specific Threat Categories (TCs).
2) Note that there is space under the provided Risk Treatments for proposing additional mitigation measures not included in the provided list.
3) After selecting all applicable Risk Treatments per TC per Asset, please determine the Residual Severity and Likelihood for each identified Risk (i.e. the Risk Severity and Likelihood remaining after the application of the proposed Risk Treatments).
4) Note that for Threat Categories with a Severity value of 1, a Likelihood value of 1 is automatically assigned.

Threat Category (TC) affecting Assets	Asset	Initial Severity at Asset level		Residual Severity at Asset level		Initial Likelihood at Asset level		Residual Likelihood at Asset level	
TC 1: Illegitimate processing of Personal Data									
Encrypting Personal Data									

Figure 39: Mitigation actions and residual Severity and Likelihood levels

Outputs

The DPIA outputs are presented for each organization as a summary of the initial and residual levels of Severity and Likelihood after the implementation of mitigation measures, for each Threat Category, which includes the individual threats per Asset. The associated Threat Categories are; *Illegitimate processing of Personal Data, Inadequate information of the data subject, Violation of the data subject's rights, Compliance violations in the contracts, Personal Data integrity loss, and Damage to individual*. In the following section, the overall results are the visualized using a Risk Quadrant map generated per project partner.

Step 3: Process followed within the project

The DPIA process that will be carried out within the BIMERR project will be guided by MERIT, as the responsible partner for this task. A common template has been distributed to all related project partners along with a guideline document explaining each step of the process.

Each partner will fill out the provided template depending on their role in the project and the final outcomes have been consolidated in cooperation with the MERIT.

8.1 GDPR Compliance Provisioning

The European regulation (EU) 2016/679, the new General Data Protection Regulation (GDPR), is a set of rules defining how individuals, companies and organizations collect, store and process personal data related to individuals in the EU (Anon., n.d.). As a key instrument of the GDPR, the Data Protection Impact Analysis (DPIA) is recommended to enhance the accountability of Data Controllers and demonstrate their compliance with the GDPR. The main purpose of a DPIA is to enable the entities responsible for data collection and processing to identify possible risks for data protection and establish rules, in particular, concerning the amount of collected data and the purpose of processing.

Within the context of Smart Grids and Smart Buildings, the collection of data by responsible operators (Energy Service Companies, Renovation/Construction Companies, Facility Management Providers, Distribution System Operators, Energy Retailers, etc.) is an important element for business operation. It is, therefore, likely that operators are subjects to GDPR obligations and are expected to perform a DPIA. To promote a common methodology for adequate Personal Data processing concerning the Smart Grid operators across the EU Member States, a template has been developed by an editorial team involved in the Smart Grid Task Force (SGTF) (SGTF, 2014), Expert Group 2 (EG2). This template defines the necessary process steps for identifying the risks and consequently the necessary control measures to support the monitoring of Smart Grid applications from the start. According to this template, a list of datasets (however, not limited to the current elements) related to smart grid and smart home activities has been proposed. These datasets are defined as Personal Data and a DPIA should be conducted. Such data would be (SGTF, 2014):

- Consumer registration data such as names & addresses of data subjects etc.
- Energy consumption data such as household consumption, demand information and time stamps that can provide information about the lifestyle and habits of the data subjects
- Energy and provided to the grid in the cases of sustainable energy resources
- Profiles of consumer types that can be used for targeted marketing approaches
- Facility operation profile data (occupancy hours, number of occupants etc.)
- Frequency of transmitted data, if certain thresholds apply
- Billing data and consumer's payment methods

Additional details about the Smart Grid DPIA and how it will be conducted within the scope of BIMERR are provided in Annex I which will be expanded in the Data Management deliverable.

Data Collection and Transfer

During the pilot period of the BIMERR framework, information about participants, their living/working space ambient conditions and their interaction with the electrical devices and provided technology will be collected, transmitted, shared, stored and processed. Additionally, by processing this data, comfort and energy activity profiles of the users will be generated. Although only a limited amount of data is collected within the BIMERR activities, according to the list provided in the previous section many of the datasets collected at the pilot sited should be treated as personal under the definition of the EU Directive 95/46/EC and the regulation (EU) 2016/679.

To comply with these regulations, the BIMERR consortium is required to ensure that all data collected from the pilot users will be kept confidential and anonymized. To this end, it has decided to implement Privacy Enhancing Technologies (PET) (e.g. encryption, pseudonymization) to ensure the confidentiality of the data collected, and minimize breaches. Additional measures concerning the

security from external attacks during the data collection, transmission and storage are included (e.g. secure protocols, authentication) to ensure that the personal data will be also secured during all stages of the project. More specifically, the data security is addressed at two levels; at device level, referring to the transfer of the collected data from the installed meters and sensors to the gateway, and at public network level during the transfer from the gateways to the cloud and the web application (UI) using the internet. In the first case, the communication technologies used by the commercial hardware (i.e. Wi-Fi, Z-wave etc.) include encryption to prevent eavesdropping. In the second case, a number of protection technologies and protocols are applied to prevent external attacks. A detailed technical description of the encryption methods and protocols applied for the transfer of personal data within the project is/will be presented in XXX.

Data Storage and Management

Depending on their role in the project, different partners are involved with transferring or processing of different data including questionnaires, raw data, generated profiles, control signals and KPIs. Depending on their storage location and access level the collected data can be categorized in the following manner:

- **Private:** The characterization *private* refers to the questionnaires and consent forms that have been collected by the utilities that participate in the consortium and as a rule are stored locally at the premises of the corresponding partners. According to the regulations the hard copies must be stored in locked compartments while the digitalized copies are password protected and can be only accessed by authorized personnel.
- **Consortium:** The collected anonymized raw data as well as the data generated by processing the collected values are securely stored in the cloud application of [FiT/ Responsible Partner] and can be made available to project partners upon request. This information is only accessible by members of the consortium for the purposes of the BIMERR project and will not be kept after their purpose has been fulfilled. Additionally, project related documents that have been classified as confidential are uploaded to a dedicated location set up by FiT that is accessible by all project partners that have authorization and can upload/download them directly.
- **Open:** The project results and abstract statistics of the collected and generated data are made available openly in the several ways, the Project web portal, ResearchGate, Zenodo open access repository and Github.

Further processes that may derive from the recent EU legislation will be also taken into account towards the data collection, storage, protection, retention, destruction and confirmation. Detailed information about the BIMERR compliance with the EU regulations and requirements regarding the security of personal data is provided in ANNEX I.

Research in HORIZON 2020

The second step of the proposed framework includes a thorough investigation of the ethical guidelines for research projects in EU. Horizon 2020 must comply with ethical principles and relevant national, EU and international legislation, for example the Charter of Fundamental Rights of the European Union, the European Convention on Human Rights and the European Code of Conduct for Research Integrity. This investigation has revealed the major concerns around data protection and privacy.

Ethics is dealt with extensively in the Horizon 2020 legislation:

1. Horizon 2020 Rules for Participation: Ethics Reviews (Article 14)
2. Horizon 2020 - Regulation of Establishment: Ethical principles (Article 19)

- Model Grant Agreement: Ethics (Article 34)

1. The document "H2020 Programme Guidance How to complete your ethics self-assessment, Version 5.2 12 July 2016" summarizes the main information about the compliance with H2020 Ethic requirements.

Legislation Overview

The BIMERR project has to abide by the European laws and directives as well as the national laws of the countries that are involved in the pilots or in other activities of the project. Beside the directives of the EU, the legislation of the countries where the five pilots of BIMERR are to be established has been taken into consideration. Concisely, the legislation with which the BIMERR framework has to conform includes:

- European Union – Directives 95/46/EC & 2002/58/EC
- DIRECTIVE 2016/680 the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data by competent authorities for the purposes of the prevention, investigation, detection or prosecution of criminal offences or the execution of criminal penalties, and on the free movement of such data, and repealing Council Framework Decision 2008/977/JHA
- REGULATION (EU) 2016/679 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 April 2016 on the protection of natural persons with regard to the p rocessing of personal data and on the free movement of such data, and repealing Directive 95/46/EC
- Greece- Hellenic Data Protection - Protection of Individuals with regard to the Processing of Personal Data - Law 2472/1997
- Spain – Organic Law LORTAD, 5/1992

- Poland- Polish Act -GIODO- December 10, 2014

Below, the general scope of each legislation is summarized.

E.U. legislation for General Data Protection Regulation- EU 2016/679

Data Collection, Storage, Processing and data protection

In April 2016 the GDPR (2016/679) was finally approved by the EU Parliament. The regulation refers to the protection of natural persons with regard to the processing of personal data and on the free movement of such data enforcement date: 25 May 2018 - at which time those organizations in non-compliance will face heavy fines.

It replaces the Data Protection Directive 95/46/EC. The GDPR harmonizes data privacy laws across Europe, protects and empowers all EU citizens' data privacy and reshapes the way organizations across the region approach data privacy.

Towards defining the detailed procedure for data collection, storage, protection, retention and destruction in the project the General Data Protection Regulation (GDPR) - is described below. The GDPR applies generally to processing the personal data of data subjects residing in the Union, regardless of the company's location. It also applies to the processing of personal data by controllers and processors in the EU, regardless of whether the processing takes place in the EU or not. Very important: the GDPR strengthens Data Subjects rights and imposes strong penalties on breaches, dealing with personal data.

The GDPR introduces newly:

- Right to be Forgotten (Article 17)

The "right to be forgotten" entitles the data subject to have the data controller erase his/her personal data, cease further dissemination of the data, and potentially have third parties halt processing of the data. The conditions for erasure, as outlined in article 17 of GDPR, include the data no longer being relevant to original purposes for processing, or a data subjects withdrawing consent.

- Right to data portability (Article 20)

GDPR introduces data portability - the right for a data subject to receive the personal data concerning them, which they have previously provided in a 'commonly use and machine-readable format' and have the right to transmit that data to another controller.

- Privacy by Design (Article 23)

Privacy by design is part of a legal requirement with the GDPR. At its core, privacy by design calls for the inclusion of data protection from the onset of the designing of systems, rather than an addition. Article 23 calls for controllers to hold and process only the data necessary for the completion of its duties (data minimization), as well as limiting the access to personal data to those needing to act out the processing.

- Penalties (Chapter 8)

Under GDPR, organizations in breach of GDPR can be fined up to 4% of annual global turnover or €20 Million (whichever is greater). This is the maximum fine that can be imposed for the most serious infringements e.g. not having sufficient customer consent to process data or violating the core of Privacy by Design concepts. There is a tiered approach to fines e.g. a company can be fined 2% for not having their records in order (article 28), not notifying the supervising authority and data subject about a breach or not conducting impact assessment. It is important to note that these rules apply to both controllers and processors -- meaning 'clouds' will not be exempt from GDPR enforcement.

- Data Protection Officers

Currently, controllers are required to notify their data processing activities with local DPAs. Under GDPR it will not be necessary to submit notifications / registrations to each local DPA of data processing activities, nor will it be a requirement to notify / obtain approval for transfers based on the Model Contract Clauses (MCCs). Instead, there will be internal record keeping requirements, as further explained below, and DPO appointment will be mandatory only for those controllers and processors whose core activities consist of processing operations which require regular and systematic monitoring of data subjects on a large scale or of special categories of data or data relating to criminal convictions and offences. Importantly, the DPO:

- Must be appointed on the basis of professional qualities and, in particular, expert knowledge on data protection law and practices

- May be a staff member or an external service provider

- Contact details must be provided to the relevant DPA

- Must be provided with appropriate resources to carry out their tasks and maintain their expert knowledge

- Must report directly to the highest level of management

- Must not carry out any other tasks that could results in a conflict of interest.

The GDPR differentiates between roles: data processor and data controller (Chapter IV).

A controller is the entity that determines the purposes, conditions and means of the processing of personal data, while the processor is an entity, which processes personal data on behalf of the controller.

Essential legal principles of privacy in the GDPR are:

- Data Sovereignty

Data sovereignty is the concept that information which has been converted and stored in binary digital form is subject to the laws of the country in which it is located.

- Self Determination

The individual decides on the disclosure and use of his personal data (that explicitly covers the collection, storage, process and disclosure of personal data).

- Autonomy – (the way of handling personal data within the rights granted)

Enabling individuals to extent their privacy and protect them against interferences.

Main aspects of these principles are:

1. Subject of data sovereignty: Personal Data
2. Being holder of rights
3. Clear and specific right to inform – before, during and after the data process
4. Consent requirement
5. Right to correction
6. Right to erase
7. Right to restrict data process
8. Right to appeal – Not being object of pure automatic data process that have legal effect
9. Data controller and processor as holder of obligations
10. Fulfilling principles of data processing
11. Obligation to inform in intelligible and easy language, transparently with the key facts presented
12. Principles of data processing (Art. 5 GDPR)
13. Lawful, fairly and transparent data process

Personal data in GDPR:

According to Art. 4 I GDPR any information related to a natural person or 'Data Subject' that can be used to directly or indirectly identify the person. It can be anything from a name, a photo, an email address, bank details, and posts on social networking websites, medical information, or a computer IP address.

Important is the relative meaning of personal data in context of the term identifiable. Art.4 sec. 1 GDPR differs between information referring directly and indirectly to an identifiable person. Relevant are two categories of data: Personal data and non-personal data. As the first term has already been mentioned, the second category can be divided into two further kind of data:

Anonymous data: Anonymous data are information that do not contain any information about a natural person. The person-related information has been cleared from the datasets. Such data do not fall under the scope of the GDPR and are not relevant in the legal assessment.

Pseudonymous data: Pseudonymization of personal information is a procedure where person-related information is replaced by non-identifiers in order to ensure that these informational cannot be assigned to natural persons anymore.

GDPR Principles relating to processing of personal data are (Article 5):

Lawful, fairly and transparent data process

The data process is bound to the data protection principles, which represent the fundament on which the data process is executed. The data protection principles can be found in Art. 5 GDPR.

Data minimization

According to Art. 5 GDPR, data minimization requires that data are only processed due to a legitimate purpose at the time of collection. The data process shall be restricted to the minimum amount necessary to fulfil the pursuit purpose of the data process. According to this definition, the data process has to be appropriate, substantial and restricted to the minimum amount necessary.

Purpose limitation principle

Processing personal data is only allowed with prove of a particular, explicitly determined and lawful purpose and not for any other purposes afterwards.

Compatible further processing

Nevertheless, it is not excluded to process data on the base of different purposes. For processing personal data, it is recommended to gain the respective consent. Besides, according to Article 6 IV

GDPR, processing data for a purpose other than the original purpose requires to be compatible, and vice versa not incompatible, with the original purpose. With regard to the wording of Art. 6 IV GRPD, "further processing" implies that subject is the extension of the current data process and not a new data process independent of the previous data processes. A new data process requires a new legal basis, whereas the extension of the current data process does not require a new legal basis, but a reasonable justification according to Art. 6 IV GDPR. Decisive criterion is compatibility. Insofar, the further processing of data is not restricted to the pure compatibility, but the decisive criterion whether data process derives from the original purpose.

Accuracy

Accuracy according to Art. 5 sec. GDPR means that personal data have to be objectively correct and if necessary, to be updated. Thereby objectively correct means that all information about a person have to match with reality.

Restriction of storing data

In order to avoid long term storing, personal data have to collected and stored as long as it is necessary for the respective purpose. This constitutes a time limit for storing personal data. Whenever the purpose is reached, all personal data have to be erased from the data storage.

Integrity and Confidentiality

The data controller has to guarantee the safety and security of personal data during the data process. Thereby, he is fully responsible and so, according to this principle, obligated to implement suitable technical and organizational measures in order to prevent unintentional harm of personal data.

Lawful data processing

The GDPR strengthens the conditions for consent, as the request for consent must be given in an intelligible and easily accessible form, with the purpose for data processing attached to that consent. Consent must be clear and distinguishable from other matters and provided in an intelligible and easily accessible form, using clear and plain language. It must be as easy to withdraw consent as it is to give it.

Further information can be found at the European Commission Webpage (https://www.eugdpr.org/). While the new legislation standard all around Europe, a reference to the current local legislations is provided.

Greece - Hellenic Data Protection Legislation

The Hellenic Data Protection Authority (HDPA) is a constitutionally consolidated independent Authority.

The Hellenic Data Protection Authority was established with Law 2472/97, which incorporates into the Greek law European Directive 95/46/EC. This Directive sets new rules for the protection of personal data in the member states of the European Union.

The primary goal of the HDPA is the protection of citizens from the unlawful processing of their personal data and their assistance in case it is established that their rights have been violated in any sector.

Law 2472/1997 protects citizens' rights vis-a-vis those who keep and process their personal data (Data Controllers). These rights are the following:

The right to information

The Data Controller must inform you about the collection of your personal data. You have the right to know the identity of the Data Controller, the purpose for which your data is being collected and processed, as well as the identity of anyone to whom your data is disclosed.

The right to access

You have the right to know whether your personal data are being processed or have been processed. More specifically, you have the right to request and obtain from the Controller, without undue delay and in an intelligible and express manner, information about the nature of your personal data, their origin, the purposes of processing and the recipients, if any, thereof.

In order to exercise the right of access you can send a letter (by registered mail) to the Controller. Keep a copy of the letter, the postal receipt and any response you might receive from the Controller.

The right to object

You have the right to object to the processing of your personal data by sending a notice to the Controller requiring them to correct or to delete your personal data.

Data Controllers must respect the provisions of Law 2472/1997 (and 3471/2006 regarding electronic communications) and more specifically:

1. They must collect personal data fairly and lawfully.
2. They must process only the data which are necessary for one or more specified purposes.
3. They must make sure that they keep data accurate and up to date.

4. They must retain data only for as long as is deemed necessary for the purpose of the collection and process thereof.
5. In order to carry out the data processing, the Controller must choose employees with relevant professional qualifications providing sufficient guarantees in terms of technical expertise and personal integrity to ensure such confidentiality.
6. The Controller must implement appropriate organisational and technical measures to secure data and protect them against accidental or unlawful destruction, accidental loss, alteration, unauthorised disclosure or access as well as any other form of unlawful processing.
7. If the data processing is carried out on behalf of the Controller, by a person not dependent upon him, the relevant assignment must necessarily be in writing.
8. The Controller must respect the data subject's rights to information, access and objection.
9. They must meet their obligations vis-a-vis the DPA (notification, granting of permit).
10. They must be kept informed on any Decisions, Directives or Recommendations issued by the DPA that may be important to them.

Spain – Organic Law 15, LORTAD

The Spanish Data Protection Agency is the independent Public Authority in charge of the Data Protection and was established with the Organic Law 5/1992.

The Spanish Data Protection Legislation has incorporated the European Directive 95/46/EC (General Data Protection Regulation). This Directive sets new rules for the protection of personal data in the member states of the European Union.

In order to adapt and develop certain matters contained in the European Regulation, the Spanish Parliament has approved the Organic Law 3/2018 of 5 December on the Protection of Personal Data and the Guarantee of Digital Rights.

Organic Law 3/2018 of 5 December

The Law facilitates the exercise of the specific rights conferred to the data subjects by requiring that the means for exercising such rights are easily accessible.

The right to information

In order to enforce the principle of transparency, the new Law regulates the way in which citizens are informed about the processing of their data and opts for a layered information system. In a first layer, Data subjects shall therefore be informed about the basic aspects of the processing Data collection: identity of the Data Controller, the purpose of processing and the rights the subjects possess among other basic information. They must be informed also about how to access to more detailed information -through a direct link- contained in a second layer, if they so require.

The right to access

The new Law recognizes the right of access and, where appropriate, the right to rectify or suppress the data of deceased persons to persons connected with them, unless the deceased had prohibited such access, rectification or deletion.

Minors consent

With regard to the processing of the personal data of minors, the Law sets the minimum age for autonomous consent at 14 years. Similarly, it regulates the right to be forgotten in relation to data provided by minors to social networks and other information society services. This right may be exercised by the minor her/himself or by third parties while she/he´s still a minor.

Whistleblowing systems

The Law also contains a specific article relating to the processing of personal data within the framework of whistleblowing systems; It allows anonymous dilation from employees to communicate infractions in Data Protection.

Video surveillance, sound and digital devices

The Law updates the guarantees applicable to citizens in relation to the use of video surveillance devices, geolocation, sound recording and other digital devices in the workplace. The employer can use these devices to control their employees' work nevertheless they must be previously informed and the devices cannot be placed in changing rooms, rest or dining areas.

Video and audio surveillance devices can be used in public places but only for security or safety reasons. All non-criminal related Data must be deleted in less than a month.

Processing Personal Data

Controllers must retain data only for as long as is deemed necessary for the purpose of the collection and process thereof (3 months unless specific cases).

Controllers must keep it accurate and up to date.

Controllers must block Personal Data and avoid any possibility of Data processing and display, once it has been required to be rectified or deleted.

Credit Information System

The new Law requires a minimum amount of 50 Euros for the inclusion of a person in a credit information system (delinquent file) and reduces from 6 to 5 years the maximum period of inclusion of debts in such files.

Digital Rights

The Law specifically includes new "digital rights" such as universal access to internet, secure and appropriate use of Personal Data, and the right for users to rectify and object that applies in digital media and social networks.

Poland- *Polish Act -GIODO*

Personal Data Protection Act was established the 10th May 2018 and implements GDPR in Poland. It establishes public entities responsible for the enforcement of data protection laws in Poland, and it regulates procedures for naming the heads of those entities as well as procedures to be executed in case of violation of Data Protection Regulations.

Under the Act, the new governmental organisation Personal Data Protection Office (Urząd Ochrony Danych Osobowych) was created to be responsible for the implementation and enforcement of GDPR in Poland. The President of Personal Data Protection Office is the highest-ranking official within that office. This person is responsible for monitoring GDPR enforcement in Poland. The President also periodically reports on his activities to the Parliament and other entities. The President is also responsible for issuing an opinion on drafts of legal acts related to Personal Data.

According to aforementioned act, each Administrator (any entity that processes Personal Data) is required to name a Data Protection Officer that supervises the Data Processing within the organisation that has named the aforementioned Officer. Each Administrator is also required to inform the Personal Data Protection Office about the appointed Officer and provide his/her contact information. The Administrator can also ask the President of the Personal Data Protection office for consultation in cases that are named in article 36 of Directive 2016/679.

The certification and accreditation of entities authorized to certify compliance with the regulations are also regulated within the act. The entity that authorizes the organisations to certify their compliance is the Polish Centre for Accreditation.

In cases of suspected legal violations regarding the Personal Data Protection, proceedings are conducted by the President of Personal Data Protection Office. In the case of public entities, the maximum fine is 100 000 PLN.

The Act also specifies sanctions (including incarcerations) for processing personal data without justification and permission of the person from whom the data is extracted (up to 2 years imprisonment for personal data, and up to 3 years of imprisonment for sensitive data as defined in the act), and for obstruction of the enforcement of Data Protection regulations and control procedures (up to 2 years of imprisonment).

While the laws establish core principles both at European and National level, they do not establish clear lines for the field of research. The BIMERR consortium will abide by the above-mentioned legislation and will act with respect to the rights of any human being that is involved in the project either as a participant or not. The Horizon 2020 legislation defines the ethical principles that BIMERR will follow throughout its lifecycle.

Personal Data

According to the Article 5 of (EU) 2016/679, Personal Data is required to:

- Be processed fairly and lawfully;
- Be collected for specified, explicit and legitimate purposes and not further processed in a way incompatible with those purposes. Further processing of data for historical, statistical or scientific purposes shall not be considered as incompatible provided that Government provides appropriate safeguards;
- Be adequate, relevant and not excessive in relation to the purposes for which they are collected and/or further processed;
- Be accurate and, where necessary, kept up to date; every reasonable step must be taken to ensure that data which are inaccurate or incomplete, regarding the purposes for which they were collected or for which they are further processed, are erased or rectified;
- Be kept in a form which permits identification of data subjects for no longer than it is necessary for the purposes for which the data were collected or for which they are further processed. Within the project, anonymization of personal data will be considered as the goal is the analysis over business roles and processes (user specific profiles will not be considered in the project).
- Be processed in a manner that ensures appropriate security of the personal data, including protection against unauthorized or unlawful processing and against accidental loss, destruction or damage, using appropriate technical or organizational measures (‘integrity and confidentiality’).

Acquisition and storage of human related information

- The Pilot Supervisor should inform the participants with clarity about the procedure of the pilot tests, the system operation and the objectives, the data retrieval and storage and the

exact dates the tests will be running. The participants can ask any question related to the project to ensure that they fully understand the scope of the pilot tests and their role in these tests.

- No sensitive personal data should be collected. In no case more personal data should be collected than the necessary ones, according to the requirements of *European and National legislation.*
- No personal data, if any, should be centrally stored. Instead, they should be scrambled/anonymized where possible and abstracted in a way that will not affect the final project outcome.
- No data should be collected without the explicit written consent of the occupants under observation (group-based and individual scenarios). The participants should be able to revoke their consent at any time of the project
- No data collected should be sold or used for any purposes other than the current project.
- A data minimization policy should be adopted at all levels of the project and should be supervised by the BIMERR Ethics Advisory Board. This will ensure that only data that is strictly necessary to the completion of the current study will be collected and processed.
- Any shadow (ancillary) personal data obtained during the course of the research should be immediately cancelled. However, this kind of ancillary data should be minimized as much as possible. Special attention should also be paid to compliance with the Council of Europe's Recommendation R(87)15 on the processing of personal data for police purposes, Art.2 :
    - "The collection of data on individuals solely on the basis that they have a particular racial origin, particular religious convictions, sexual behaviour or political opinions or belong to particular movements or organizations which are not proscribed by law should be prohibited. The collection of data concerning these factors may only be carried out if absolutely necessary for the purposes of a particular inquiry".
- No additional effort should be required from the enrolled subjects than that imposed by participation in standard market research.
- Specific measures to avoid any breach of privacy/confidentiality or discrimination should be applied in case of recruiting new participants from partner organizations or partner universities. In particular, their names should not be made public and their participation should not be communicated to their managers. Any incidental findings should be kept strictly confidential and erased from files under request from the enrolled subject though no incidental findings are expected in the project. In the case that employees of any partner organization participate as test subjects in the process it should be ensured that the recruitment method and informed consent procedure are particularly stringent to ensure no coercion (not even soft or indirect) is exerted.
- The research to be conducted should be in full compliance with the principles and guidelines of ethics for research projects in Horizon 2020 framework.

The following guidelines are Smart Grid specific and are defined within the Smart Grid Task force guidelines (SGTF, 2011) and are applicable to the BIMERR pilot users.

- In the case the participant changes location, the data from the previous meter must be directly erased after being transferred to the new location
- Participants are entitled to unlimited access to their current meter readings and historical data, at any time and free of charge.
- In the case a utility is required to retain personal data, it must be encrypted and access controls must be applied.

Collection of data from participants

The pilot leader or his/her representative must provide participants from whom data related to themselves are collected with at least the following information, except where he/she already has it:

- the identity of the controller and of his/her representative, if any;
- the purposes of the processing for which the data are intended;
- any further information such as
    - the recipients or categories of recipients of the data,
    - whether replies to the questions are obligatory or voluntary, as well as the possible consequences of failure to reply,
    - the existence of the right of access to and the right to rectify the data concerning them

Overall, derived from the GDPR regulation ((EU) 2016/679) BIMERR commits to perform a clear process towards managing any possible ethical concerns related to Data Management, namely.

1. The research to be conducted will be carried out in full compliance with the principles and guidelines of the BIMERR Grant Agreement (Anon., 2018), Article 34 on Ethics and Research Integrity.
2. BIMERR will assign dedicated “Data Controllers” and “Data Processors” as soon as the scenarios are clear and name them personally.
3. The **Data Controller** of each demonstrator must:
4. guaranty that the collected data will be only used for the purposes of the project and they will not be sold or used for other activities.
5. guaranty that all personal or sensitive data stored will be encrypted. In addition, data will be scrambled where possible and abstracted in a way that will not affect the final project outcome.
6. guaranty that in the case that any ancillary personal data are obtained during the course of the research, it will be immediately deleted if it is not used for the research activity. However, the plan is to minimize this kind of ancillary data as much as possible. In particular, the names of the research participants will not be made public and their participation will not be communicated to third parties. Any incidental findings will be kept strictly confidential and erased from files under request from the enrolled subject.
7. inform the participants about all data that will be collected and the purpose of that;
8. provide their personal contact data to the participants and will be available to further explanation on the data collection and management;
9. implement appropriate technical and organizational measures (e.g. PET technologies) to protect personal data against accidental or unlawful destruction or accidental loss, alteration, unauthorized disclosure or access, in particular where the processing involves the transmission of data over a network, and against all other unlawful forms of processing
10. ensure that no data will be collected without the explicit written consent of the participants
11. describe the way the data is supposed to be handled in a detailed way and set the consent forms for the end users to participate in the demonstrator.
12. Data Processors will ensure that:
13. Collected data will be saved on secured servers,
14. Collected data will not be available to anyone outside the Project’s team;
15. Collected data will be destroyed as soon as it is allowed by the EU regulation about H2020 projects.

Rights of Participants

Taking into account the most recent legislation, the information that must be made available to a Data Subject when data is collected has been strongly defined and includes:

- the identity and the contact details of the controller and DPO
- the purposes of the processing for which the personal data are intended
- the legal basis of the processing
- where applicable, the recipients or categories of recipients of the personal data
- the period for which the personal data will be stored, or if this is not possible, the criteria used to determine this period
- the existence of the right to access, rectify or erase the personal data;
- the right to data portability
- the right to withdraw consent at any time
- and the right to lodge a complaint to a supervisory authority

Overall,

- Participants will have the right to access their personal data as well as their extracted parameters.
- Participants will be able to quit the experiment at any point, if they wish, without any consequences. He/she can exercise his/her right to access, correct and delete his/her data at any moment also rectify or erase the personal data.
- Participants will enroll to the pilot tests as part of their daily activities, as no further work is requested for their participation in BIMERR Project.

Moreover, every participant has the Right to obtain from the pilot representative without constraint at reasonable intervals and without excessive delay or expense:

- confirmation as to whether or not data relating to him/her are being processed and information at least as to the purposes of the processing, the categories of data concerned, and the recipients or categories of recipients to whom the data are disclosed,
- communication to him/her in an intelligible form of the data undergoing processing and of any available information as to their source,
- knowledge of the logic involved in any automatic processing of data concerning him/her;
- rectification, erasure or blocking of data the processing of which does not comply with the provisions of this Manual, in particular because of the incomplete or inaccurate nature of the data;
- notification to third parties to whom the data have been disclosed of any rectification, erasure or blocking, unless this proves impossible or involves a disproportionate effort.

The participant has the Right to Object:

- at any time on compelling legitimate grounds relating to his/her particular situation to the processing of data relating to him/her, save where otherwise provided by national legislation. Where there is a justified objection, the processing instigated by the pilot controller may no longer involve those data;

- on request and free of charge, to the processing of personal data relating to him/her which the pilot controller anticipates being processed for the purposes of direct marketing, or to be informed before personal data are disclosed for the first time to third parties or used on their behalf for the purposes of direct marketing, and to be expressly offered the right to object free of charge to such disclosures or uses.

Data Confidentiality and Security

- Any person acting under the authority of the Data Controller, including the processor himself/herself, who has access to personal data must not process them except on instructions from the controller, unless he/she is required to do so by law.
- The controller must implement appropriate technical and organizational measures (e.g. PET technologies) to protect personal data against accidental or unlawful destruction or accidental loss, alteration, unauthorized disclosure or access, in particular where the processing involves the transmission of data over a network, and against all other unlawful forms of processing.
- Having regard to the state of the art and the cost of their implementation, such measures shall ensure a level of security appropriate to the risks represented by the processing and the nature of the data to be protected. The carrying out of processing by way of a processor must be governed by a contract or legal act binding the processor to the controller and stipulating in particular that:

    - the processor shall act only on instructions from the controller,
    - the obligations, as defined by the Governments laws in which the processor is established, shall also be incumbent on the processor.

The regulation provides specific suggestions for what kinds of security actions might be considered "appropriate to the risk," including:

- The pseudonymisation and/or encryption of personal data.
- The ability to ensure the ongoing confidentiality, integrity, availability and resilience of systems and services processing personal data.
- The ability to restore the availability and access to data in a timely manner in the event of a physical or technical incident.
- A process for regularly testing, assessing and evaluating the effectiveness of technical and organisational measures for ensuring the security of the processing.

Especially for pseudonymisation, we are adopting the principles of the new GDPR legislation towards keeping the de-identified data (tokenized datasets) separately from the "additional information," then the GDPR permits data handlers to use personal data more liberally without fear of infringing the rights of data subjects. This is because the data only becomes identifiable when both elements are held together.

Installation of Sensors & Notification

- All sensors utilized during the pilot should be privacy-preserving and should neither acquire sensitive personal data nor violate personnel's privacy.

- The controller of the study or his/her representative, if any, must notify the supervisory authority (Project Coordinator) before carrying out any data collection process. The information to be given in the notification shall include at least:
    - the name and address of the controller and of his/her representative, if any;
    - the purpose or purposes of the processing;
    - a description of the category or categories of data subject and of the data or categories of data relating to them;
    - the recipients or categories of recipient to whom the data might be disclosed;
    - proposed transfers of data to third countries;
    - a general description allowing a preliminary assessment to be made of the appropriateness of the measures taken to ensure security of processing.

- All offices/areas that will be monitored and controlled with any type of sensors and equipment should be appropriately marked with notification Posters, describing in detail equipment used and monitoring procedures taking place towards project's objectives.
- All occupants, whose working offices/areas will be monitored during the pilot, should be thoroughly informed and their signed approval should be requested.

Aggregation-based scenarios

- Only aggregated information should be extracted per space. No individual data should be gathered or analysed. For example, when monitoring office's business patterns, only data concerning the overall business process will be considered, not including information about each user behaviour. In a similar sense, when monitoring air-conditioning settings, these data should not be correlated to specific people working in each office but instead to the office/ business process itself. The demonstration of the app should be zone oriented and not user oriented, avoiding that way the need to handle individual data.
- All personnel working in the selected pilot sites should have been notified on the project's objectives, the pilot duration, the test procedures, the sensor infrastructures and the occupancy and user preferences profiles extraction procedures that will take place and have signed the respective consent form before the data acquisition process begins.
- In case one or more people working in a selected space (e.g. office) refuse to participate in the group-based scenarios, the responsible partner for pilot audits along with the project coordinator will decide on excluding/substituting this office with one with similar characteristics, or consider to proceed to temporary personnel shifting in other offices for the time period the pilot tests will take place (the duration will be from a couple of weeks to no more than a few months).

We presented above the detailed ethics manual documentation towards handing any ethical concerns in the project. A simpler version is available for the control group of users (acting as the baseline group for the project activities). This manual version is available on project portal. This is a living document as we have to adapt the overall solution taking into account the aforementioned mandates.

9. ANNEX III - LIST OF SYSTEM SERVICES

BIMERR Interoperability Framework APIs	**Responsible BIF module**	**Description**	**Interface Type**	**Consumer/Provider** **(note: if the interface type is consumer, this column will specify the corresponding provider and vice versa)**
Data Collection API	Collection Information and Enrichment	API to receive building information from BIMERR apps and sensors	Consumer	Renovation Support Tools, Building Digital Model Creation Tools, Middleware
Mapping Configuration File API	Building Semantic Modelling	API to send the mapping configuration file from the Building Semantic Modelling subcomponent to the Middleware, in order to perform required transformations and mappings on data from apps	Provider	Middleware

Query Response API	Building Information Secure Provisioning	API to send the well formulated query response as a reply to a data request by an app and for visualisation to the BIM management platform	Provider	Renovation Support Tools, Building Digital Model Creation Tools, BIM Management Platform
Query ID API	Building Information Query Builder	API to send just the query ID from the Query Builder to the apps for future reuse	Provider	Renovation Support Tools, Building Digital Model Creation Tools

Table 31: List of BIF APIs

Middleware API	**Responsible Middleware module**	**Description**	**Interface type**	**Consumer/Provider (note: if the interface type is consumer, this column will specify the corresponding provider and vice versa)**
User Profile	Gateway Security	Given the username, the middleware requests for the user profile from the openID provider. This is required by the Gateway security module of the middleware	Consumer	BIF (Building Information secure Provisioning

Authorization Rules	Gateway security	API for addition or removal of rules related to authorization to the Gateway security module	Provider	Administration tools
Application/Sensor Data API	Registry and Data Storage Service	Sensor data is stored in the middleware's storage. This is queried by the interested services for fourther analysis. The enriched data is stored again in the middleware. This is exposed by the Registry and Storage Service of the middleware	Provider	BIF (Information Collection & Enrichment) Legacy applications and sensors
Registry API	Registry and Data Storage Service	API to exchange the metadata related to the source of the datastream	provider	Legacy applications, device abstractors and BIF (Information collection & Enrichment module)
Core models & semantic Data API	Data Processor	API to exchange BIM models and semantic data	Consumer/producer	BIF (Building Semantic Modeling)
Service registry API	Service Registry	API for CRUD operations on the Service Registry	Provider	Other BIMERR or middleware components using Service Registry

Table 32: List of Middleware APIs

BIM Management Platform APIs	Responsible BIM Management Platform module	Description	Interface Type	Consumer/Provider (note: if the interface type is consumer, this column will specify the corresponding provider and vice versa)
Authentication Service API	Auth interface	API for user management and authentication	Provider	Consumers: All BIMERR Components
Notification API	Notification Service	API for notifications regarding updates and changes to models	Provider	Consumers: BIF, Middleware, ARIBFA
BIM Model Access API	BIM Server	API for query, checkout, retrieval, storage, merging and comparison of BIM Modes	Provider	Consumers: BIF, Middleware, ARIBFA

10. ANNEX IV – COMPONENT DESCRIPTION TEMPLATE

Name of New Component/Service:	*<please write here the name of the architectural element e.g. Baseline Flexibility Estimation>*
Type:	*<Component, Software, Device etc.>*
Functionality:	*<please write here in free text a short description of the operation of this module/component. A list of functions and operations will be an added value.>*
Input Connections & Interfaces: ***From which components it receives input***	*<please write the components from which it receives input (input dependencies) and mention also the available connection interfaces e.g. API etc.>*
Output Connections & Interfaces: ***To which components it sends the results***	*<please write the components to which it sends the results (output dependencies) and mention also the available interfaces e.g. API etc.>*
Relevant Use Cases	*<specify the use case where the module is participating, write the IDs of those use cases >*
Functional Requirements	*<write the functional requirements that the module satisfies, mention the respective IDs from the relevant template>*
Non-Functional Requirements	*<write the non-functional requirements that the module satisfies, mention the respective IDs from the relevant template>*

Input Parameters					
Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Received From***
<please mention the input parameters. Each row corresponds to one parameter>	*<mention a short description of the input parameter if necessary>*	*<please mention the data type of this parameter (e.g. (e.g. int, string, etc. or complex type, e.g. list, object, etc.)*	*<e.g. XML, JSON etc.>*	*<indicate measurement unit and range of values for this attribute/parameter and frequency-sample rate>*	*<please mention the source component or module that provides input data to this parameter>*
Output Parameters					
Attribute/Para-meter	***Short Description***	***Data Type***	***Data Format***	***Value Range & Frequency***	***Data Sent To***
<please mention the input parameters. Each row corresponds to one parameter>	*<mention a short description of the input parameter if necessary>*	*<please mention the data type of this parameter (e.g. (e.g. int, string, etc. or complex type, e.g. list, object, etc.)*	*<e.g. XML, JSON etc.>*	*<indicate measurement unit and range of values for this attribute/parameter and frequency-sample rate>*	*<please mention the source component or module that provides input data to this parameter>*

Software Requirements/Development Language	*<specify any software requirements related to the architectural element, explain the Programming Language that is used during the development of the component>*
Hardware Requirements	*<specify what hardware requirements are of the module, give specifications about the hardware requirements which are necessary for the best functionality of the component>* *In case it needs any special sensor that is included in the sensor specification, it can be included also here as a reference.*
Communications	*<address specific communication requirements either for data input or for data output>*
Status of the development of the component	*<specify if the component is "already developed" or "partially developed" or "to be developed from scratch">*

Table 33: Architectural Components Detailed Specifications Template

Sensors/Gateways/Infrastructure Specifications

Sensor/Gateway/Infrastructure Description and Functionality	
Name	*<provide the name of the sensor>*
Short Description	*<provide a brief statement of the sensor, mentioning its WP/Task Number within the overall architecture>*
Measurement	*<provide description of the sensor measurement (directly, how, any restrictions)>*
Digital/Analog Signals	*<describe the signalling mode (analog, TTL, CMOS, etc), if applicable for the sensor>*
Functionality	*<describe how the sensor functions within the BIMERR system architecture>*
Physical Sensor Characteristics	
Dimensions	*<L x W x H in mm>*
Weight	*<total weight of sensor in kg>*
Material	*<materials used for its construction>*
Mounting	*<how is sensor attached>*
Operational Sensor Characteristics	
Measurement Range	*<minimum to maximum values that can be measured by the sensor (e.g. -40 to +80 °C)>*
Measurement Resolution	*<level of measurement (e.g. to 0.01°C)>*
Accuracy	*<accuracy of the measurement (e.g. ±x% of actual reading)>*
Zero Error	*<amount required to pre-calibrate sensor and/or adjust readings by (e.g. ±0.05°C)>*

Humidity	*<minimum to maximum humidity levels in %: range in which the sensor can operate>*
Pressure	*<minimum to maximum pressure levels in Pa/kgm^{-3}/N etc.: range in which the sensor can operate>*
Lifetime	*<specify approximate lifetime under standard operating conditions>*
Hardware Sensor Requirements	
Power Requirements	*<specify electrical power supply required for sensor to operate without disruption>*
Data Connections	*<specify the communication networks and protocols involved e.g. USB, GSM, WiFi, Bluetooth etc.>*
Data Format	*<specify the output format of the sensor>*
Data Rate	*<specify at what rate data is read/extracted/logged>*
Data Availability	*<specify whether data stream is continuous, periodic, on demand etc.>*
Transmission Frequency	*<specify the power of the data stream, e.g. X mW, if applicable>*
Software Sensor Requirements (e.g. API creation)	
Software Required	*<yes/no>*
Software Details	*<provide details of software required for proper sensor function>*
Note	*<write any important note related to the sensor>*

Table 34: Sensors/Gateways/Infrastructure Specifications Template