Towards the definition of a BIM based framework for Efficient Renovation in Buildings

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Notably, renovation of the existing building stock (where a significant fraction in the European Union (EU) is over 50 years old) offers a huge potential towards successfully meeting the energy savings (80% reduction in primary energy consumption) and emissions reduction targets (80-95% below 1990 levels) set with view to 2050, being also the only truly sustainable solution (with regards to the building sector) for the realization of EU's policy objectives. The realization of such ambitious targets requires a significant acceleration and growth of the EU renovation market, at higher rates; through a radical shift of the Architecture, Engineering and Construction industry (AEC) away from traditional practices and through its digital transformation by adaptation of Information Technology (IT) solutions and implementation of Building Information Modelling (BIM). BIM is presently used by the AEC industry, mainly for new buildings, but several barriers need still to be overcome for enhancing BIM implementation in renovation processes. Utilising BIM (properly extended and enriched) can offer large benefits to the AEC renovation sector mainly by reducing critical mistakes, omissions and improving collaboration between stakeholders resulting in higher quality outcomes with less costs and greater speed.

Within this context, we introduce an innovative BIM-based framework for efficient renovation in buildings comprising of tools supporting the AEC actors and building's stakeholders (owners and occupants). The developed platform will empower semantic interoperability among its own tools, as well as with third-party Information and Communication Technology (ICT) tools; enabling seamless BIM creation and information exchange among the AEC community in an effort to boost the rapid adoption of BIM in renovating of the existing EU building stock, resulting in economical and quicker refurbishments achieved through efficient flow of information, decreased intervention working time, while improving building performances, quality and comfort conditions for occupants. Along with this innovative data management framework, a set of tools towards rapidly reconstructing semantically rich digital models of existing buildings, integrating data in order to perform advanced evaluations of design options for renovations, incorporating energy consumption and occupants comfort data preferences in energy management tools is presented on the way to provide added value energy services during the renovation and operational phase of the buildings. The overall framework is to be tested in three demo sites and the initial activities are also reported in this paper.

INTRODUCTION

Following the global target of governments to tackle climate change, the EU has set the goal to achieve an 80% reduction goal in primary energy consumption by 2050 (European Climate Foundation, 2010). A sustainable and powerful way to achieve these goals, including also the target to reduce the European greenhouse gas emissions by 80-95% below 1990 levels by 2050, is by improving the energy efficiency of the built environment. Towards this direction, EU has set at the top of its agenda the decarbonization of energy use in the European building stock, presently being the most significant consumer of energy (within the EU), collectively accounting for 40% of the total consumption and 36% of CO_2 emissions.

Renovation of the existing building stock offers a huge potential to reduce energy consumption towards successfully meeting the energy savings and emissions reduction targets. As such, EU defined a set of measures forming the appropriate conditions for long-term improvements in the energy performance of its building stock; such as the Energy Performance of Building Directive, the Energy Efficiency Directive (EED) and the Renewable Energy Directive (RED) (SWD (2016) 24). Supplementing this action, the Zero Energy Building (ZEB) and nearly Zero Energy Building (nZEB) targets, further support and provide the means for an accurate implementation among the European Member States. In order to achieve these ambitious targets, a scale-up of the EU renovation market is required at rates of over 3% (over the whole EU building stock) in contrast to the current annual rate of approximately 1%. Identifying this need, the Architecture, Engineering and Construction (AEC) industry is currently being transformed by adopting IT solutions and utilising semantically enriched digital models based on the implementation of BIM along the building's lifecycle. Even though this digital transformation is widely adopted by AEC stakeholders for new builds; this is not the case for the renovation industry. The AEC industry has still several barriers to overcome for enhancing BIM implementation in the renovation industry, mainly due to the complex nature of utilising BIM to digitally transform existing buildings (which is a time-consuming and costly process) and seamlessly integrate semantic data that goes beyond geometric information, in order to perform advanced evaluations of design options for renovations. Further barriers to be tacked are identified in BIM as a domain, which if properly addressed can increase the productivity of all stakeholders involved in a building's lifecycle. These barriers include time-consuming collection of digital data (visible and hidden building elements), provision of digital access to the involved stakeholders, automation issues, connectivity/collaboration among users and interoperability of data deriving from different sources and among the various legacy systems used by the AEC operators.

To address these problems, we introduce a holistic BIM-based management framework, which, through its central repository of information, namely the Common Data Environment (CDE), will provide methods and different connected tools for overcoming obstacles encountered during the different stages of renovation processes (from field survey, initiation and design to construction and management); developing guidelines for BIM implementation and providing an efficient and user-friendly operational platform, taking into account end users' needs and requirements. The overall architecture and associated tools/services of the proposed framework is presented in the following section. In Section 3, the detailed internal architecture and definition of the semantic BIM platform is presented, while, in Section 4 we present the evaluation methodology for the proposed framework, preliminary demonstration activities performed in the pilot site along with the end-user engagement to ensure a co-creation process for the whole design, development and demonstration period. Finally, the last section presents the main conclusions and the steps for the future work.

A BIM-BASED MANAGEMENT PLATFORM AND THE ASSOCIATED SERVICES

To improve the renovation processes, it is a prerequisite to provide a holistic data management framework to all the involved stakeholders in order to allow their communication and collaboration along the whole renovation process, from field survey, initiation and design to construction. Towards this direction we introduce a Building Data Based Modelling and Sharing Framework supporting the renovation industry incorporating a complete BIM-based management system along with the energy related services and tools that will facilitate the renovation stakeholders to collaborate and interoperable communicate, resulting in time savings while also improving building performances, quality and building occupants comfort.

Overall, this integrated BIM management system consist of a variety of applications ensuring timely and uninterrupted realisation of standardised renovation processes and smooth collaboration between the different stakeholders in a cost-efficient and timesaving manner It is thus supporting the renovation of the existing building stock by providing key enablers in the most critical steps of the process, throughout a building's lifecycle. Moreover, it enhances current BIM-based approaches ensuring seamless collaboration, interoperable communication and efficient data exchange among all actors involved in the renovation industry. The proposed framework and the respective architecture contain three high level functional layers which are further broken down to: (i) the **Common Data Environment** (CDE) used to store the data, forming the core of the proposed BIM Management system, (ii) the **CDE Services Interoperability layer** supporting exchange of data to different authoring applications related to the renovation/operation process and (iii) the **CDE Exchange Layer Services** utilised to connect the Semantic Web to give access to the users about all necessary application framework for file sharing, data repository, visualization, analysis and reporting. In Figure 1, the high-level overview is presented, while the details of the main components of the proposed architecture are further analysed.

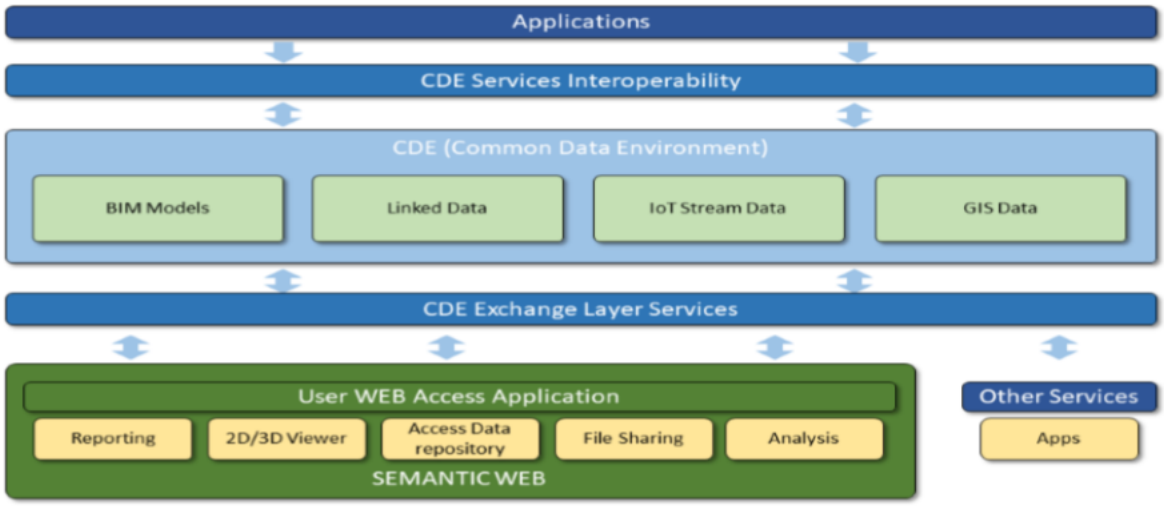

Figure 1 The Linked Building Data Modelling and Sharing framework (BIM4EEB DoA, 2018)

At the heart of the system and in order to address the interoperability objective, the proposed framework will be supported for semantic information search and retrieval by the centerpiece of the proposed BIM-Management system, namely the **Common Data Environment** (CDE). The CDE will be acting as the core engine within the BIM management system; it relies on semantic interoperability and will be used to link data generated at the building level, as well as create relationships from other data repositories. The data will derive from internal and external sources (Regulations, Costs, Climate, Life-cycle Assessment, open Data Repositories) and will be gathered from Internet of Things (IoT) data-stream coming from sensors and environment and finally from GIS data as schematic representation, location, spatial reference, including also urban regulations and city planning data. The CDE's ultimate goal is to understand, correlate the semantics of the various domain specific data models through ontological linking/mapping techniques and deliver bespoke, on-demand data models for end-user applications by instantiating & populating data models/formats with requested information by means of semantic search and reasoning capabilities. For example, the BIM-assisted Energy refurbishment assessment tool (described below) may require information about the specifications of a HVAC system, the size & characteristics of the building where it is installed, the local climatic conditions and the system usage patterns in order to incorporate it in the building's energy refurbishment assessment. All this information elements will reside in separate models, distributed across the legacy systems of various construction stakeholders. The CDE will be able to instantiate and populate the data model by reasoning, using linked data structures and ontologies in order to find all this information about the building under investigation. The details of this semantically enhanced modeling framework are presented in the following section, providing more details about the linked data principles adopted in the framework.

On top of the core data management layer, **the CDE Exchange Layer Services** is provided to connect the Semantic Web to give access to the users all necessary application framework spanning from file sharing, data repository, visualization, analysis and reporting. Therefore, this is the generic layer for developers but mainly for data analysts to provide users with web access to the CDE to apply innovative analytics and get quick insights about each building performance incorporating in the analysis the different building dynamics, to share and visualize files and to implement frameworks and interfaces for other services and applications that could be implemented during the building renovation phase and later on.

In the same way, **the CDE Services Interoperability layer** will be implemented to give life to the already developed applications, acting that way as the real time interface and API layer to support the different business objectives in the building environment. Associated with the role of this component, we highlight the different services and tools delivered to enable the demonstration of the holistic platform. The main tools and services to be provided by the proposed platform are:

➢ **Digital tool for fast mapping of buildings covering geometrical data and materials**

This is a fundamental step of the renovation process, thus a user-friendly digital tool is developed to combine laser scanning with Augmented Reality (AR) technology, designed to both speed up the mapping process by accurate modelling of the main building elements and to visualize the building (along with any hidden elements), aiding the quality assurance processes. This tool will combine different monitoring techniques for identification of the buildings geometric lay out, installations and materials. Utilizing this tool during building processes will ensure quality by visualizing and checking if the building takes form as per the approved design. The tool will be connected to the BIM model, both to upload information and retract updates when used to visualize. Therefore, this tool is act as the data generator for the CDE and subsequently for the different business applications/services to follow.

Figure 2 Example of Augmented reality view

➢ **BIM-assisted Energy refurbishment assessment tool**

Through the proposed framework a decision support software tool will be developed as part of the BIM management system to evaluate various energy refurbishment scenarios during the renovation design selection phase. The tool will assist in collecting the required input information from the sources according to the national requirements and processing it for evaluating the renovation scenarios in a simulation software. This software will enable utilisation of extended and accurate models for the simulation and analysis of the different aspects of building performance (e.g. acoustics, occupancy, comfort), enabling more accurate assessment results, closer to the post-renovation performance assessment of buildings. In addition, it will provide the means for evaluating alternative renovation scenarios, not only in terms of materials but also with regards to the design and sizing of technical systems (such as HVAC), mainly to address energy behaviour profiles and users' comfort preferences. The high -level architecture of the proposed BIM -assisted Energy refurbishment assessment tool is presented in Figure 3.

➢ **Human machine interface tool**

One of the main innovations of the proposed framework is the development and integration of Occupants' Context-Aware Behaviour Modelling and Interfaces for Bi-Directional Information, so as to address occupant profiling and occupant's behaviour as a fundamental factor for the optimization of energy performance of buildings. As such it will enable more accurate predictions at the renovation design phase, closer to the actual performance achieved at the post-renovation stage. The core part of the occupant profiling tool will monitor and learn transparently the operational and other occupant behavioural patterns (user preferences). Furthermore, the occupant profiling itself will transparently align the knowledge regarding building operational patterns to the occupants considering the building's use and will use this information in order to predict basic operations. The Occupant Profiling Tool, will properly manage and train the Occupant comfort models and utilize information streams from sensors/actuators, along with information provided through the interaction with the users

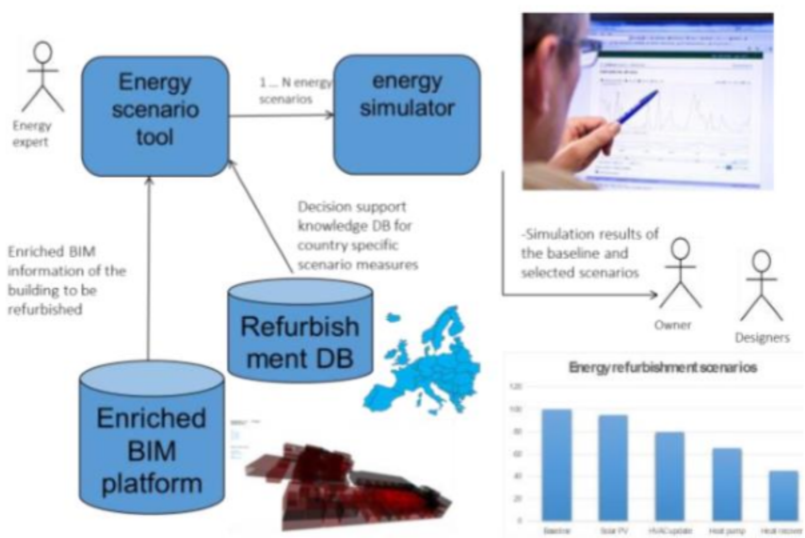

Figure 3 Schematic architecture of the refurbishment scenario tool

in order to define dynamic and context-aware occupants' profiles to be further exploited for simulation (and even more control optimization) purposes, properly balancing energy performance with comfort and indoor quality requirements. The Occupant Profiling Tool will be complemented with Ambient User Interfaces for the building occupants that will allow individual occupants to continuously provide relevant information regarding preferences, daily schedules and control patterns.

- **Fast-tracking tool for renovation operations**

The fast-tracking tool for renovation operations will provide 24/7 situational awareness of the statuses of the renovation activities providing unprecedented transparency of the renovation process. By introducing additional scheduling and procedural planning tools in the overall collaboration and communication framework between renovation stakeholders, it offers advanced flexibility and adaptation to alternative renovation scenarios, ensuring time-efficiency. Hence, this will allow scheduling of the site activities with shorter lead times thus, reducing the total construction duration, while it will be possible to immediately take control of possible deviations in implementation. The reliable progress data will be available also to the clients and building occupants with right timed guidance and safety instructions. In addition, a logbook module will be applied to facilitate decision-making and asset management; enabling continuous updating of BIM-related information and recording of as-built information and documentation, based also on inputs and feedback received by on-site workers and/or building owners and inhabitants.

The proposed BIM management system is composed by specific software and tools able to adapt to the complexity of the construction process with specific reference to renovation activities, also dealing with energy performances. It consists of a set of Application Programming Interface (API) and Services specifically developed to provide complete and interoperable access to the data. It will be realised as a web platform and it will be used by all AEC stakeholders to connect their tools and applications used and developed during a renovation project. It is evident that the potential for the development of different building related applications on top of a centrally placed semantically enhanced data management layer is high. Indicatively, we have presented four representative applications to complement the core part of the proposed framework; applications to be thoroughly applied and tested in the demonstration environment defined for the platform.

A SEMANTICALLY ENHANCED BUILDING LINKED DATA FRAMEWORK

From the architecture definition, it is clear that the CDE layer consist of the heart of the BIM management system. The CDE will act as the common repo to share BIM and GIS models, linked data and IoT streaming data from sensors and will serve data to Tools, Applications and Services. Users have access to data with a rich set of functionalities as reporting systems, viewers, data sharing and analysis tools. Hence, the CDE is defined as the data management system with data repository, services, applications and interoperability capabilities to serve all activities performed from all involved AEC stakeholders.

In order to deliver this complex functionality, the CDE utilizes a graph data model based on Resource Description Framework (RDF)/Web Ontology Language (OWL) Metadata, with the developed ontologies to support the relationships between data stored and linked in the CDE. The CDE handle the BIM models (2D/3D Models, Point Clouds, and Analysis Models) and their representation as Linked Data. Moreover, extensions to address other building dynamics, e.g. IoT data, occupants behaviour profiles, building acoustics, building energy systems are incorporated in the analysis, harmonizing and orchestrating existing ontologies in the construction domain, while investigating intermodel and inter-ontology relationships to address concepts that are currently absent from building-relevant ontologies (e.g. occupants' comfort, occupancy, energy performance, workflow, process management etc..). Relationships and data are also structured to manage the Level of Detail (LOD) in order to support different data analysis for the different renovation processes.

As a fundamental point of the platform, the Linked Data shared within the CDE will be managed developing high levels of security and authorization features, versioning and high level of document management capabilities. BIM

Authoring applications will access the CDE with a set of application services for interoperability that will be used to upload data directly from application. The high-level overview of the CDE layer of the platform is illustrated in Figure 4.

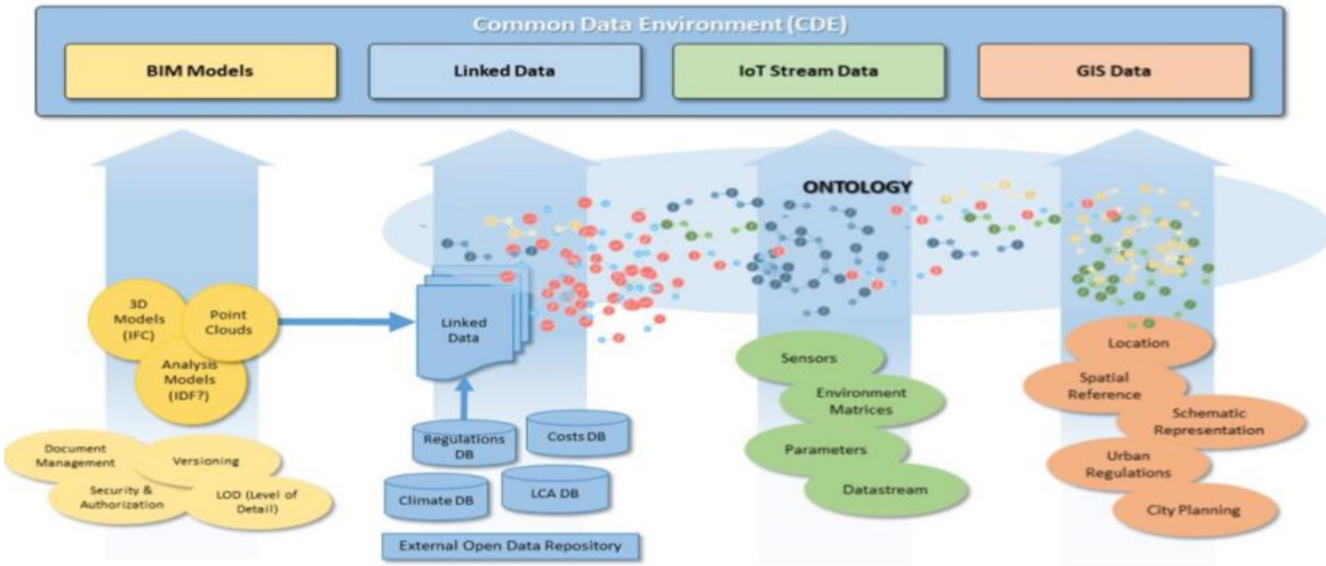

Figure 4 The **Common Data Environment layer of BIM Management System** (BIM4EEB DoA, 2018)

Some details about the different data layers defined in the figure are presented

- BIM Models: Building information models which can be exported in the standard Industry Foundation Classes (IFC) format from all major BIM tools, the ontology version of which is called ifcOWL. IFC has been successful standard: it is supported by all major BIM tools and it has been adopted broadly in the BIM domain. It is already pretty stable, being in development for over 20 years. It stands as the BIM Base ontology for the proposed framework
- Linked data: aiming to address aspects not fully covered from BIM models. As a first version, we aim to properly configure and refine relevant ontologies referring to occupants' behaviours and comfort, energy performance of systems and components, and acoustics. Also, a workflow ontology for renovation processes, covering tasks, subtasks, task precedencies, task object relations (to both information objects and physical objects defined in BIM models), location breakdowns, reusable resources, and status events is required
- IoT Data streams: referring to data coming from sensors deployment. Sensor model is a description of sensor system including metadata about units of measurement, warning and alarm limits, linking to BIM models, and positions of sensors. The interfaces to be used in addition of the sensor model to provide access both to real-time values or streams, and sensor histories over time. Thus, some flexibility needs to be maintained in order to support this extended functionality. This would favor the adoption of the Semantic Sensor Network Ontology (SSN) as the basis of ontology work in this specific field of interest.
- GIS Data: as the mathematical construction for representing geographic objects or surfaces as data. GIS data model should not describe the content, properties and data structures but also the rules and relations between the entities of the data model. In the field of linked GIS Data, the large-scale adoption of Linked Data (has started in 2006 and a number of the largest spatial datasets, like LinkedGeoData, already contain spatial information. A considerable number of users and organizations contribute and work with structured geospatial data on the web. The idea of large-scale collaborative spatial data management is one of the biggest challenges in the area of intelligent information management: the exploitation of the Web as a platform for geospatial data integration as well as for searching and querying for geographic information.

We presented above, the basic principles for the different data models that will set the framework for the **Common Data Environment** defined in the proposed solution. As a next step of the work is the extension of the existing work and further harmonization of the different models towards setting the common data framework of BIM management platform.

EVALUATION OF THE PROPOSED FRAMEWORK & END-USER ENGAGEMENT

Following the definition of the various layers of the proposed architecture and the detailed analysis of the common data environment, the extended evaluation of this integrated BIM-Management system and associated tools will be performed in three demonstration sites in Italy, Poland and Finland (see Figure 5). All of the selected pilot sites are representative of the application target, including both social houses with fragile inhabitants and residential apartments; constituting also typical examples of buildings in Northern, South and Central Europe; as such the proposed framework will be evaluated under different construction technologies, processes and methods, as well as, different climatic, socio-economic, cultural and behavioural contexts. In addition, the renovation activities performed in these pilot sites will be compared to traditional renovation processes on buildings located in the surrounding areas which will be used as baseline, allowing a direct comparison of the renovation duration and cost.

The Italian pilot site is located in Monza and is selected for its size and age, as a representative example of the residential public housing in Italy. It is an 8-storey building, with 65 apartments, with a central heating and no previous renovations or energy refurbishments. Tools for fast mapping and for fast tracking of the on-site activities will be applied and different kind of sensors will be installed in the selected building, in order to tackle the energy consumptions, the conditions of Indoor Air Quality (IAQ) and the comfort conditions of inhabitants. By applying the tool for HVAC-Design, Operation and Efficiency Management, not only the decision-making process will be enhanced in the design stage, but also the evaluation of as-built performances and their comparison with predicted one will be carried out. Eventually, an active participation of inhabitants will validate the tools developed for monitoring the construction activities and the way buildings are operated (e.g. through feedbacks on comfort conditions). The Polish pilot site is a residential building located in the center of the Chorzow (near Katowice) Town, in the Silesian Region. The building was realised in 1902 and has 5 floors with 1330 m2, with 12 apartments and 3 commercial areas. The Polish building will be used to provide building and user's profiles specification for the CDE interface development and validation. The building will demonstrate the application of the BIM management system, together with the fast mapping tool and the sensors monitoring for the HVAC design, operation and efficiency management tool. The Finnish pilot site is located in city of Tampere consisting of two 5-storey residential buildings built in 1998. The buildings are owned by a private company owned by local municipalities such as City of Tampere, City of Turku and other municipalities. The site includes 52 apartments with a total volume of 12700 m3, a reinforced concrete technology for structures and district heating system. The pilot presents the most common building type in Finland that proves a good replicability potential. The Finnish pilot site has been selected in order to control energy consumption, indoor climate in existing residential building; perform economic evaluation; demonstrate simplified information collection from existing residential building and use that information as input for BIM models. In addition a BIM-based energy analysis for residential renovation projects will be demonstrated by combining BIM with ERP system to provide BIM models that can be updated along the whole lifecycle of the building; additional demonstration activities include the combination of specified Building Automation equipment with BIM models to enable close to real time indoor climate and energy monitoring.

Figure 5 Demonstration sites: (a) Italian pilot site (Monza), (b) Polish pilot site (Chorzow), (c) Finnish pilot site (Tampere)

Overall, activities to be performed in the preselected pilot sites, account for the installation and demonstration of smart equipment and sensors, comparison of the renovation duration and cost with similar renovation interventions in other buildings (used as baseline) located in the demonstration areas, validation of the technical solution and then full evaluation period of the proposed framework. At all this pilot design and demonstration process, a User-Driven innovation approach will be established. Within the proposed framework, end-users and main beneficiaries (AEC sector representatives, building owners/residents, construction companies, contractors/workers, etc.) are collectively placed at the center of all research, innovation, demonstration and communication activities performed, which adopts a user-driven innovation approach towards addressing emerging end-user and market needs, critical for the successful framework implementation. This user-driven innovation approach aims to involve renovation professionals, as well as buildings residents and owners throughout all stages of the project lifecycle, as key enablers of the proposed innovation process, towards encouraging active and collaborative contributions in the development of a BIM-based ICT system to accelerate energy efficiency renovations across Europe. Agile ICT implementation methodologies in conjunction with continuous validation and verification processes will be incorporated in the overall User-Driven Innovation Approach to manage cross-functional teams and ensure the establishment of an effective BIM Management system using innovative, cross-disciplinary integrated ICT solutions.

As part of this cocreation process, the end stakeholders have been participated in the requirements elicitation effort; to get information directly from the proposed end-users of the system. Within this context, preliminary engagement activities were performed among the pilot site stakeholders (i.e. building owners and inhabitants) in order to extract their need and requirements. The extraction of the requirements was based on a "hybrid" engagement approach; driven by the feedback received from online questionnaires circulated in the pilot sites of Italy, Poland and Finland, along with engagement of the pilot site representatives in semi-structured interviews.

Figure 6 A user centric engagement methodology

A non-exhausting list of end-user's requirements were extracted incorporating also some technical constrains. In addition to the end user requirements, regulatory and legal barriers imposed in the different pilot sites were examined to define the framework requirements by engaging the pilot site's stakeholders in the semi-structured interviews. Therefore, a holistic and user-oriented design and development concept is defined to ensure the delivery of applications and services that best fit to end users' needs and expectations.

CONCLUSIONS

The major factors hampering productivity and causing significant cost and time overruns in renovation processes of buildings are poor planning, lack of automation, insufficient communication, inadequate risk management and unsophisticated supply chain practices. In this paper we address these factors by presenting a holistic BIM-based framework providing advantages from an improved information management along building processes through the adoption of BIM-based approaches and tools in order to overcome barriers of traditional renovation processes, while addressing different AEC stakeholders, as well as building's end users (i.e. owners and inhabitants) needs and requirements. Along with the presentation of the proposed framework and the associated toolkit, the architecture of the main system is presented,

The next steps of this work consist the evaluation of the proposed framework in three different European pilot sites over a long period, followed by appropriate optimizations.

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NOMENCLATURE

AEC = Architecture Engineering Construction
API = Application Programming Interface
AR = Augmented Reality
BACS = Building Automation and Control System
BIM = Building Information Modeling
CDE = Common Data Environment
EC = European Commission
EU = European Union
EPBD = Energy Performance of Building Directive
GIS = Geographic Information System
ICT = Information and Communication Technology
IoT = Internet of Things
IT = Information Technology.
LoD = Level of Detail
OWL = Web Ontology Language
RDF = Resource Description Framework

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