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*Editors*

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# Preface

Since the last decades of past century, a change of paradigm entered the construction sector: the introduction of Building Information Modelling (BIM) has given the sector new opportunities to enrich the whole process with new potentialities for the relevant stakeholders. In particular the “Information” managed at the level of projects’ objects allowed to apply a set of methods developed in the past century which still were pending as theoretical: for example, the systemic and performance-based approaches has found in the ICT developments the perfect ground to pass from theory to practice. Within this framework this EU project BIM4EEB, represents a step focused on the development of a BIM based toolkit for building renovation, which is fundamental for Europe in a period during which there is the need to recover existing buildings, rather than constructing new ones, considering sustainability development goals.

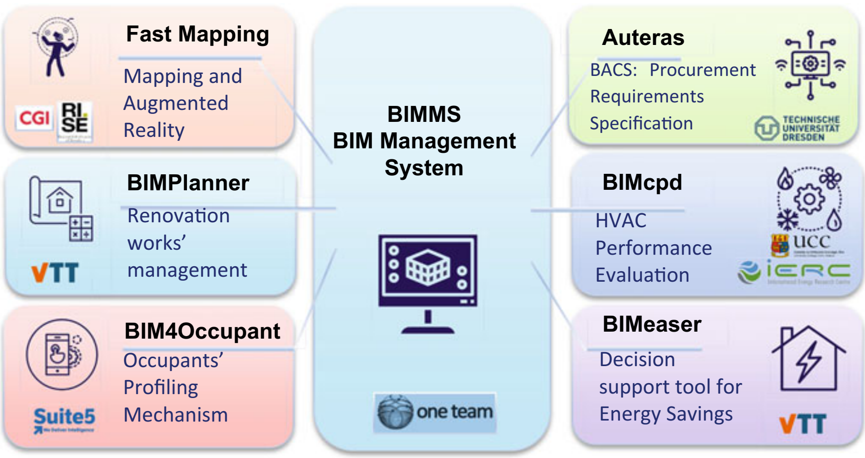


**Fig. 1** BIM4EEB BIM based toolkit

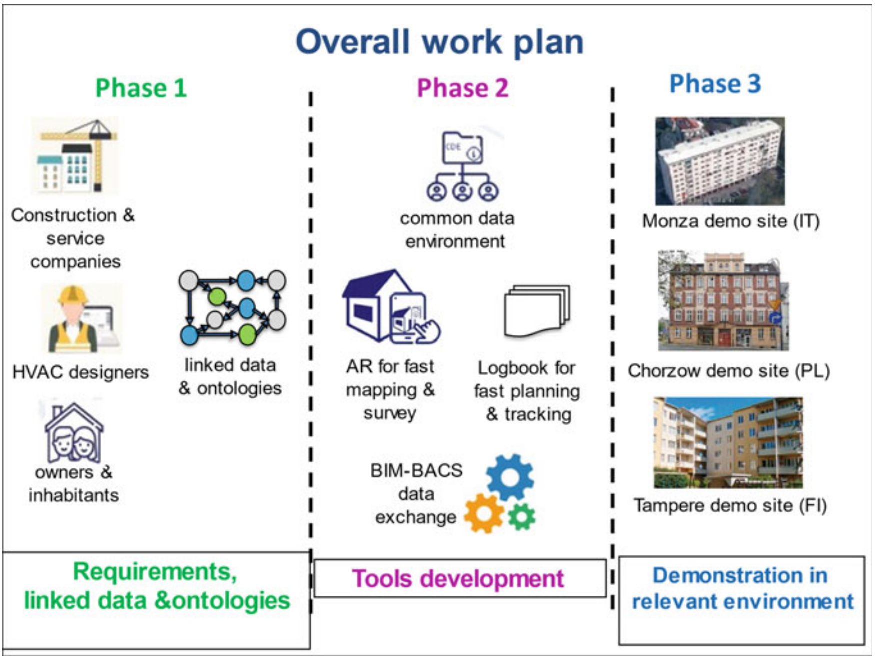


**Fig. 2** BIM4EEB overall work plan

Specifically, BIM4EEB has been developed with the intention to make the flow of information efficient, to decrease intervention working time and costs, and to improve building performances, with a specific focus on quality and comfort for inhabitants. In this book we report the chief BIM4EEB results represented by the BIM bases buildings renovation toolkit (see Figs. 1 and 2).

BIM4EEB project has been developed since 2019, starting with the definition of the information requirements (see chapter 2) and the development of specific ontologies to deal with linked data to support efficient interoperable, open data exchange within the toolkit (see chapter 3).

In the following chapter 4, 5, 6 and 7 the different tools developed by BIM4EEB are presented, while in chapter 8 it's shown the practical application of the toolkit to 3 demo sites (Italy, Poland, Finland) in order to have a complete validation of BIM4EEB results.

The hope in publishing BIM4EEB results is that the contribution of the project will be useful in supporting relevant stakeholders improving the whole renovation process.

Milano, Italy Bruno Daniotti

# Contents

# Chapter 6
# Digital Tools for Fast-Track Renovation Operations

**Teemu Vesanen, Kiviniemi Markku, Kostas Tsatsakis, and Gabriele Masera**

**Abstract** Digital tools for fast-track renovation operations developed in the project aim to shorten the duration of renovation and disturbance to the occupants with BIM-enabled methods and tools in operations management at site and with prefabrication to speed up the installation tasks. The chapter presents an ensemble of tools, concepts and use cases. First, two tools are described that are used to support construction production management and user communication. Then a concept how product data could be used as part of the tools and further how the product data and the tools could support in achieving the overall BIM4EEB objectives in the use cases of prefabricated exhaust air heat pump and prefabricated thermal insulation. Target of the work was to improve the state-of-the-art planning and monitoring. A new tool was created that combines the BIM model and typical work breakdown structure (WBS) based project scheduling into location breakdown structure (LBS) based user-interface. Continuously updated LBS provide valuable information to stakeholders with web-service and mobile applications. The 24/7 situational awareness of the renovation activities status provides unprecedented transparency of the project progress. Hence, the system allows scheduling the site activities with shorter lead times to shorten the total construction duration while it is possible to immediately take control of possible deviations in implementation. The reliable progress data is available also to the clients and occupants with right timed guidance and safety instructions. The other aim in the work was to utilise BIM for increasing the share of prefabrication in renovation projects. The BIM-based design allows to manage the compatibility and tolerances between design disciplines and adapting those with mapped geometry of the building will enable the prefabrication and preassembling of structural and

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system components also in renovation. Two best practice examples were developed and described showing how to utilise prefabrication in real renovation scenarios.

**Keywords** Fast-track renovation · Prefabrication

## 6.1 BIMPlanner: A Tool for BIM-Enabled Construction Production Management to Plan and Track Site Operations

BIMPlanner is one part of BIM4EEB toolkit, a toolset for residential renovation projects that share data through a central BIM Management System (BIMMS). BIMPlanner is a cloud-based software for detailed planning and management of construction operations at site. The aim of the software is to share situational awareness of the construction activities at site to all participants of a renovation project. This information provides transparency of all site operations and improves productivity with better information enabling right timing of resource usage. The software allows to plan the site operations with more efficient throughput times and control the implementation with shared tracking of all activities.

The use scenario of the BIMPlanner is based on Location Based Management System (LBMS) that is a part of Lean Construction practices. Location-based management is a planning and control method that aims to optimize the schedule of project and at same time allow the continuous workflow (Kenley and Seppänen 2010). The site activities are planned and tracked by work locations creating workflow through those work locations. This will provide improved control of the workflows enabling faster proactive actions if delays are found.

In BIMPlanner the LBMS is applied with defining the work locations as reference to BIM objects which will define the workflows in relation to building coordinate system. For the indoor activities the work locations are defined with set of IfcSpaces. The work locations outside of the building are defined indirectly with reference other object types. Better approach would be to define these with IfcSpatialZones but such entities are not typically modelled in IFC, so in the current version of BIMPlanner use this indirect method on work location definition for external activities.

The major use scenario in BIMPlanner is the weekly scheduling of the ongoing activities by work locations and inputting the status data of the activities to store and share up to date tracking data (see on the right in Fig. 6.1). Before this weekly planning some input is needed for detailing the master schedule if needed. The master schedule is a high-level schedule agreed by the client and the main contractor as a plan for total construction period. The master schedule is imported into BIMPlanner to set targets for detailed planning, and master schedule timing cannot be changed in BIMPlanner. In the midterm planning (centre in Fig. 6.1), the need to divide master activities in sub-activities may appear for managing the scheduling of different works phases of the activity. Another part of this activity detailing is to plan and define the

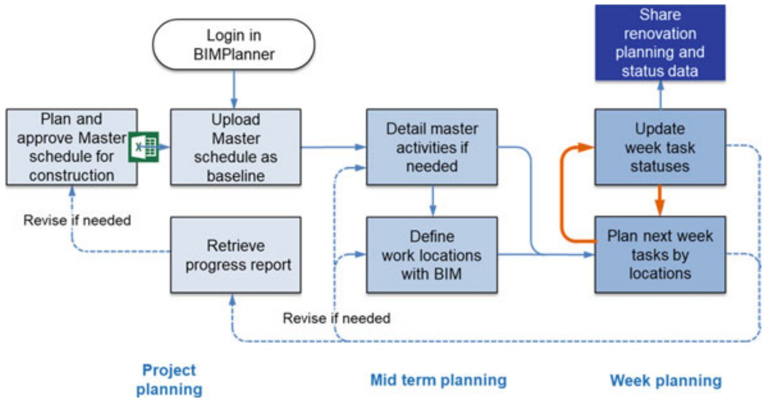


**Fig. 6.1** Main functionalities in BIMPlanner

appropriate work locations for each activity as in weekly planning it is possible to plan each activity's timing separately for each work location.

One main goal in technical implementation of BIMPlanner was applying and testing some parts of the Digital Construction Ontologies (DiCon) developed in BIM4EEB.[1] In the BIMPlanner backend server the scheduling data and needed IFC data for work locations are stored as Linked Data in graph database according the DiCon ontologies. Since the project specific scheduling data and IFC data are confidential, their access is restricted to selected systems and users. The BIMPlanner is implemented as a server-client application where user interface is implemented in a browser and server component is communicating with other backend systems. Between BIMPlanner and BIM Management System (BIMMS) a linking layer called BIMLinker was implemented that maintains linking with BIMMS but also handles data storing/retrieving with graph database. The BIMLinker APIs were implemented as GraphQL[2]-based interface for higher level abstraction of the RDF-data. This GraphQL interface can be offered also to other software to access the scheduling data. For the research purposes the SPARQL endpoint is used also, and in current version BIMMS is retrieving the apartments related activity data with SPARQL query (access to SPARQL endpoint requires login). In this arrangement the BIMMS maintains the privacy issues with linking the apartments of the occupants to the corresponding IfcZones, and BIMPlanner handles only the IFC data.

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[1] https://digitalconstruction.github.io/v/0.5/index.html.

[2] https://graphql.org/

## 6.2 A Building Occupants-Oriented User Interfaces Enabling Bi-Directional Communication and Information Exchange

One of the key objectives of the building management processes transformation is the incorporation of building occupants, inhabitants, and owners in the overall process. To ensure the active enrolment of the building occupants, it is mandatory to provide the necessary tools and services in order to get engaged. The main purpose of this section is to provide the details of a user-friendly web-based application dedicated to building occupants (i.e., Inhabitants and Owners), enabling them to be part of the building management ecosystem. At first, the building occupants should get informed in real time about the contextual conditions in building premises. Through the provision of context analytics dashboards, building occupants can get insights about their personal comfort preferences and further comfort related context analytics; as well as monitor their energy consumption on the way to raise occupant's awareness in energy efficiency and their buildings energy performance. Moreover, information about building processes (e.g., renovation actions, safety alerts) should be visible through the application.

On the other hand, and apart from the steer visualization of building related information, bidirectional communication flow should be supported to ensure the active enrolment of building occupants at building related decisions. More specifically, the building occupants should be able to provide input regarding their comfort preferences towards the extraction of more accurate comfort profiles, enhancing that way the personalization of the different services. In addition, user feedback about the different processes (e.g., renovation process negotiation, trigger safety alerts) should be supported by such tool. More details about the different functionalities are provided.

### *6.2.1 Real Time Building Management Information Visualization*

This is the first view of the application focusing on real time information visualization about building contextual conditions. More specifically, the delivered application consists of three core features of added value for the building occupants', namely.

**Visualization of both real time and historical information of individual comfort related parameters** (such as indoor/outdoor, temperature, humidity, illuminance, and air quality metrics) supplemented with context analytics. Therefore, the users have access on actual environmental conditions but also on KPIs as extracted from analysis over historical data. Raw sensorial data are received from the BIMMS platform and send to the application where these are presented an intuitive manner. These raw sensorial data are further mapped to the static building related parameters to enhance end user visualization. Along with near real time information, end users of the tool can drill into the history and extract insights about environmental conditions profile. Moreover, as the provided application is intended for both owners and inhabitants dedicated views are provided serving its individual information needs, while also respecting their privacy. In more detail inhabitants can access both near real-time and historical information of its apartment's ambient conditions, while owners are able to see aggregate ambient condition information at building level. Indicative screenshots from the application are presented in Figs. 6.2 and 6.3.

**Input provision from building occupants** regarding their thermal and visual comfort status against set values of temperature **and illuminance in their apartment.** In general, building's occupants' feedback, is considered as a rich source of information towards evaluating environmental design practices and building operations. Therefore, an interactive user-friendly approach is provided to gather inhabitants' input through a five-point emoji-based scale. Inhabitants can select the appropriate emoji corresponding to their comfort status. A view of the approach considered for data gathering is presented in Fig. 6.4.

Correlation of inhabitants' feedback with ambient conditions data as gathered from the WSN is further considered towards extracting users' visual and thermal

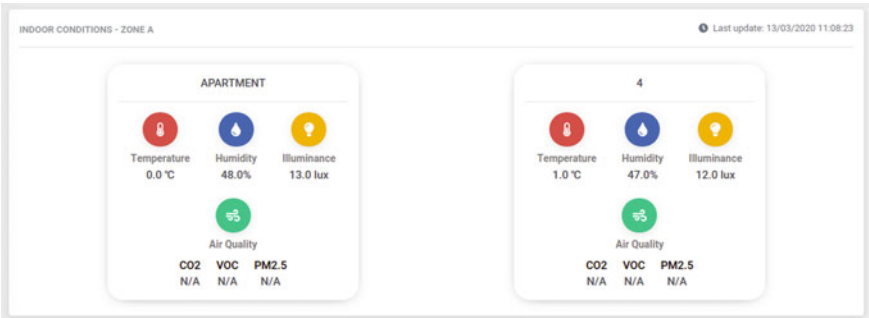


**Fig. 6.2** Real time environmental conditions

**Fig. 6.3** Historical timeseries—environmental conditions

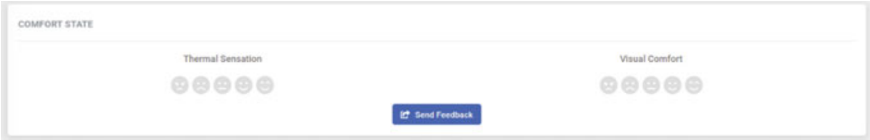


**Fig. 6.4** User settings—environmental conditions

comfort preferences. An indicative view of the thermal and visual comfort boundaries of the users as extracted within the context of the project is presented in Fig. 6.5.

**Visualisation of energy consumption (near real-time and historical)** through a dynamic, user-friendly dashboard, supplemented with context analytics aiming at raising occupant's awareness on their energy consumption and buildings performance. This analysis is performed at the level of detail available from each demo site. More specifically, total consumption information, information from the different energy sources, information at device level may be available for visualization. In addition to timeseries information visualization, intuitive statistics are available for visualisation: Typical consumption profile (daily), Total period consumption/per source, etc. as presented in Fig. 6.6.

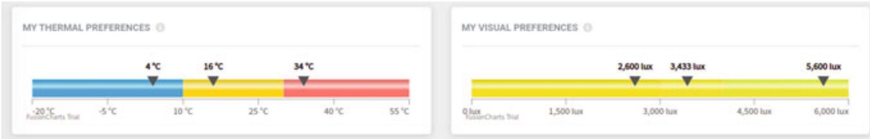


**Fig. 6.5** User comfort profiles and boundaries

**Fig. 6.6** Energy consumption profile

### 6.2.2 *Building Processes Management Information Visualization*

Apart from contextual information visualization, the building occupants should be also engaged on the typical processes performed at the building environment, namely: building renovation processes, building components updates, safety, and security events etc. Towards this direction, this 2nd view of the application should enable building occupants to periodically interact and co-design the different processes running at the building environment. Among the different processes, some key activities have been incorporated in the version of the application, namely:

**Renovation Process Management and Negotiation**: The building occupants should be always and conscious about the management and control of the renovation interventions. The application provides a service to control the renovation interventions, enabling them to actively participate (jointly with contractor) in the management of the intended renovation interventions. A view of the feature that provides renovation management activities overview is presented in Fig. 6.7.

**Safety and Security Alerts and Notifications**: Avoiding accidents on-site and preserving the H&S of the building's occupants is critical to any building management project. The application keeps owners and inhabitants of a building informed of the renovation activities by sending security and safety recommendations and/or Health and Safety (H&S) instructions regarding the ongoing and programmed renovation works. In addition, the end users of the app can report safety related situational conditions in the building environment during and post renovation process. A view of the feature that provides safety and security alerts and notifications overview is presented in Fig. 6.8.

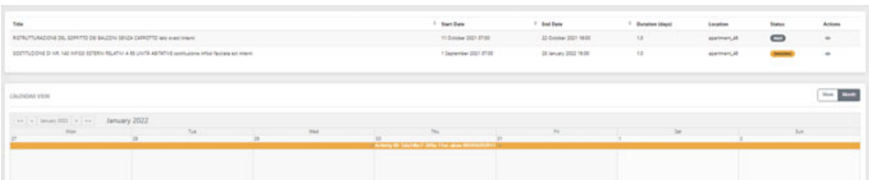

**Fig. 6.7** Renovation process management and negotiation view

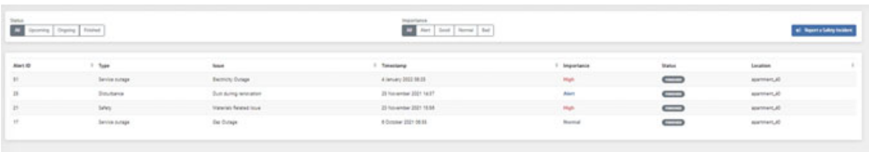

**Fig. 6.8** Safety and security alerts and notifications view

**Fig. 6.9** Building components management and information enhancement view

**Building Components Management and Information Enhancement**: This service is about reporting of various updates on the building structures/elements within a building. The end users will be able to upload information in a structured way that is required to proceed with the fine-grained modelling of the building. On the other hand, information about the updates on building elements will be accessible by the different end users of the app, so they can get access to information that is valuable for the better management of the building structure. A view of the BIM components management and information enhancement is presented in Fig. 6.9.

Overall, the application for the building occupants is the tool to provide 24/7 situational awareness of the status of the building and its activities. The aim is to allow building occupants to become active stakeholders on the management of the building environment by providing tools and services that get the informed and further enrolled on building management related processes.

## 6.3 Managing Construction Product Data Using Linked Data Technologies

Currently, construction product data, which is handled during the design and construction phases of the building, are often stored as static documents (such as PDFs) in project-specific document repositories. The challenge with documents is that the data included in them are not semantically meaningful and require human browsing and interpretation. Thus, these static documents do not efficiently support the supply chain management of construction projects or the operation and maintenance phases of a property.

The starting point for managing product data in a machine-readable way necessitates structured product data and data sharing mechanisms. First, construction-related products should be identified uniquely. At the moment, no commonly used international system for classifying product information or identifying products in the construction sector exist. The retail industry applies the Global Trade Identification

Number (GTIN) that is provided by the international not-for-profit GS1 organisation. The construction sector should start utilising GTIN in identifying construction products more widely. Second, the product manufacturers should begin to use standardized product data templates to describe products.

The connection of product data to BIM models would enable advanced applications, such as digital twins, BIM-based facility management systems, building-related IoT in general, and even building management systems connected to BIM. The linking of product data to BIM also supports machine-to-machine workflows requiring machine-understandable product data. However, the recording of product data cannot be based, in general, to simple copying of all available data to a BIM system or other local repository, even though caching of such data will be useful if availability is critical. Product data itself can have many dynamic aspects, such as the emergence of replacement products, corrections of mistakes, recalls, links to vendors or pricing information, and usage data. Because of the dynamism, it would be useful to maintain the links between the BIM model and the source of product data, ultimately even to both directions.

The current Linked Data technologies already provide a working solution to the problem of connecting product data to entities specified in BIM models. Linked Data means a set of open technologies for decentralized data management, defined by the Web Consortium, including URIs, HTTP(S), RDF(S), and often also OWL, SPARQL, and Turtle. If the specification of a product and a corresponding BIM entity are both identified by a URI, it is a simple matter to represent a link between them in RDF, which is a standard model for data interchange on the Web. The link can be recorded by one party to provide a one-way access, both parties separately, or by a service providing access to both directions. Although such arrangements or commercial offerings do not exist yet, they are easy to envision from a technical perspective, apart from the complications created by access rights and systems security.

## 6.4 A Case of BIM-Enabled Exhaust Air Heat Pump Installation in the Project

An exhaust air heat pump has been selected as an example system as it has become a common solution for improving energy efficiency in renovation pro-jects. The limited example will encourage to implement BIM technologies even at a partial level in renovation projects and support in this way the market uptake targets and to create an example of how the BIM technologies will support the prefabrication of HVAC-installations and speed-up the operation time at the site.

Previous chapters present the construction production management and responsive user interface tools and a concept how product data could be used as part of those tools. This chapter and the next one about prefabricated thermal insulation element present use cases for those tools and product data.

The process for installing the exhaust air heat pump with the supporting BIM4EEB tools in the different phases of the project is shown below.

### *6.4.1 BIM-Based Order-Delivery Process of an Energy Renovation Project Using the BIM4EEB Tools*

The installation of an exhaust air heat pump is expected to be profitable to building owner. A contractor drives the business case by identifying potential buildings/clients and offering the solution actively with cost–benefit based tendering. Currently one-of-kind construction project implementation may contain too much project-specific work and variation, concluding that such rather small projects may not be profitable for the contractor. To avoid this, the contractor needs to have pre-designed and configurable sets for main components of the system and a standard process for efficient implementation of the project.

**Sales and marketing process** includes activities for HVAC contractor to identify potential clients and marketing energy efficiency renovation services proactively. The HVAC contractor tries to identify potential sales opportunities for both existing and new clients with basic information on the buildings of the targeted clients. After the identification, the HVAC contractor contacts the client, and if the client approves to proceed with the initial contact, then proceeds to the next phase.

The **tender planning and contract phase** starts when the HVAC contractor inquires the client and collects the needed initial information for preparing the tender.

The AR fast mapping tool is applied to create a partial inventory model of needed spaces and HVAC installations. The contractor benefits from scanning the technical spaces, where the heat pump unit and heat storage tanks will be located, as well as routes for transfer of goods.

With the IFC-file from the AR fast mapping tool, the HVAC contractor studies the partial inventory model for building-specific boundary conditions and special designers design the product, i.e., the exhaust air heat pump. Energy experts generate renovation scenarios and estimate costs and benefits (OPR), applying BIMeaser.

The results gained by using BIMeaser are discussed with the client to make sure the client understands the impact of each renovation scenario in terms of owners' project requirements (OPRs). When the renovation scenario has been selected, a system-level design for tender is created. The system-level plan incorporates all major parts of the product that aims to reduce the energy consumption of the building. During the detailed design and prefabrication process phase, the system is detailed and documented for procurement, prefabrication, and installation at site.

Prefabrication has been found to increase the productivity of construction projects. In addition, previous research shows that prefabrication reduces the loss of building materials, improves the quality of construction and the safety of workers. Prefabrication can also be used to achieve cost benefits that result from good planning at different stages of the design and construction process, as lead times are shortened, design quality is improved, the site remains tidy, and logistics chains and installation efficiency will improve. (e.g., Bekdik et al.2016; Hanna et al. 2017; Khanzode et al. 2008; Wuni and Shen 2019).

After the contractor has received the detail design from the design consultant, the contractor defines and procures the system parts for the product package based on the design. Then, for the **prefabrication** the contractor sends orders to the manufacturer/pre-fabricator for the assembling of the product packages. Finally, the HVAC contractor receives the information that the product packages are is assembled.

At the beginning of the **logistics and installations phase**, the HVAC contractor plan the construction schedule and prepare operations at the site by procuring needed installation resources and planning site logistics. The contractor manages site operations with weekly planning and tracking site operations using BIMPlanner tool for documentation. The planning approach is following the basis of the location-based management method defined in Lean Construction literature (Tzortzopoulos et al. 2020). The plans and work status are shared to the client and occupant with BIM4Occupants tool. Work locations are defined with the BIM.

BIMPlanner tool sends schedule, and other relevant information to BIMMS which then sends the information to BIM4Occupants tool, which provides a guide for the building occupants during the on-site renovation works. The tool provides the occupants with safety alerts and insights into the ongoing and planned renovation processes. This enhances safety and security on-site.

During the **commissioning phase**, the renovation project and the installations are documented and commissioned. The HVAC contractor gives training to the client's facility management and maintenance personnel and/or service providers to use the system properly.

In case the HVAC contractor is the main contractor of the project, they are responsible for testing the systems and keeping a record of measurements. Inspections are arranged to ensure the system is installed and working according to regulations and deliver related documentation to the HVAC contractor. The HVAC contractor documents installations into the Digital Building Logbook of BIMMS.

The facility **operation and maintenance phase** focuses on monitoring the energy performance of the installed product and indoor conditions and making adjustments when needed. Client feedback data can also be collected and stored into BIMMS.

If the maintenance contract includes a promise for energy saving, a baseline for the energy has been set with some assumptions, and it is also important to monitor that those assumptions are still valid in the monitoring phase. For example, the energy-saving promise might assume that the indoor temperature in apartments varies between 21 and 25 degrees, but if some apartments are empty, having only 16 degrees for long periods of time, it could change the heat gain from the heat pump significantly.

## 6.5 A Use Case of BIM-Enabled Design for Prefabricated Thermal Insulation Components

This section presents an example of how BIM technologies can support a more widespread use of prefabricated thermal insulation components for the energy retrofit of existing buildings.

Considering the contribution this type of elements can offer to the EU's carbon neutrality targets, and their advantages over traditional solutions during the construction process, this chapter proposes a framework for the application of prefabricated insulation panels for energy retrofitting in a BIM environment. A broader application of BIM-based design tools, such as the guideline introduced in this report, can indeed support a more widespread adoption of prefabricated solutions among common envelope retrofitting options, allowing more informed decisions throughout the design and delivery process and a more structured engagement of the supply chain.

### *6.5.1 Modern Methods of Construction, Prefabrication, and BIM*

The construction sector faces, among others, the double challenge of supporting the European Union's targets for energy efficiency and decarbonisation through solutions that allow to at least double the annual energy renovation rate by 2030 (European Commission 2020); and doing that while improving the efficiency of the process in terms of cost, time and use of resources (Hammond et al. 2014).

Modern Methods of Construction (MMC) are widely regarded as a promising solution to these challenges and, more in general, to many shortcomings of the construction industry. MMC are a broad term that encompasses different dimensions of innovation, such as off-site construction and related digital tools and techniques (MHCLG 2019). Prefabrication, often referred to also as off-site construction, is an approach to construction projects that seeks to move the construction process away from the site and take advantage of efficiencies from manufacturing approaches and standardisation.

The use of prefabricated panels for energy retrofitting—incorporating insulation, services, and finishing—can support the mentioned EU's goals about decarbonisation and increased renovation rates, while at the same time providing improved structural, thermal, acoustical, and architectural performances to existing buildings. Indeed, a wider use of prefabrication can be a game-changer for the construction industry, also for retrofit purposes, since it has the potential to reduce renovation times and ensure higher quality thanks to the industrialised fabrication of components (Sinclair et al. 2013).

A core aspect for the large-scale implementation of MMC, such as off-site façade panels for the energy retrofit of existing buildings, is their integration in a BIM

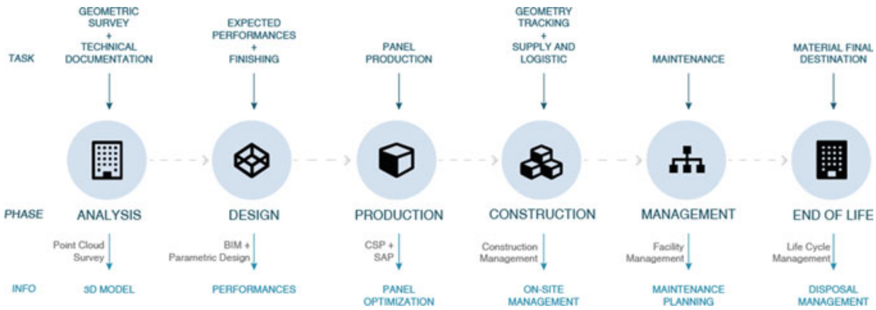


**Fig. 6.10** Typical information flow for a panelisation process

approach and the consequent adoption of rich digital communication. Such an integrated approach requires that all data (finished models, geometric components and CNC—computer numerically control models, etc.) be effectively structured, properly managed and updated through all design and construction phases, therefore highlighting the importance of shared guidelines and standards to support the design and production process (BCA 2016; Alfieri et al. 2020). The research work on the state of the art, however, highlighted that the situation is currently rather fragmented, with several tools and guidelines mostly available only for specific aspects of the design and delivery process.

In the framework of the BIM4EEB project, therefore, a general-purpose guideline supporting decision-making in the early stage of design, when choices about construction technologies need to be made, was developed. Starting from the information gathered from an overview of existing prefabrication technologies, detailed experience from past research projects, and interviews with manufacturers, the whole life cycle of façade panels was articulated according to standardised phases with general applicability (Fig. 6.10).

### *6.5.2 Guideline on the BIM Implementation of Off-Site Façade Panels for Retrofit*

Based on the abstraction of the typical information flow presented above, a process mapping of the design, fabrication and installation of façade panels was developed, leading to a guideline about the BIM implementation for the design of prefabricated thermal insulation components. The guideline highlights the correlations between the different project stages and identifies the actions necessary by the involved actors to optimise the workflow according to a MMC approach.

The whole process analysed refers to the design activities carried out by the design team (e.g., architect, cladding specialist, etc.) and is specifically targeted to the design and implementation of prefabricated insulation solutions on existing facades (i.e., a specific use case of MMC). Every effort was made to present an accurate description of the process, while remaining at a general level that is independent of the specific construction technology.

The guideline is articulated in nine stages, consistent with the structure of information adopted in the BIM4EEB project. Considering the limited space, only the contents of these nine stages are presented here.

**Stage 1—Initiative**

This stage defines the project scope and objectives formally. Targeted retrofitting actions on the existing building are defined, identifying the areas of intervention and verifying the regulatory feasibility of the intervention. Functional, aesthetic and cost requirements are collected from the Client. Finally, after a formal pre-contract BIM Execution Plan proposal, it is necessary to agree with the Client on the as-is modelling of the existing building to be renovated, and MMC adoption strategies. These guidelines need to be shared with all the Stakeholders. No model data is produced at this stage.

**Stage 2—Initiation**

Once the rules on data acquisition and BIM Execution Plan are formally defined, it is possible to proceed with a site survey and the subsequent modelling of the building; this can be done with laser scanning and/or other tools such as the BIM4EEB Fast Mapping Toolkit. This stage is crucial, producing a joint base for all future work. Technical, historical, and occupancy information are collected. After the definition of the MMC adoption strategies in Stage 1, an early assessment is conducted about the opportunities for their use. A detailed as-is BIM model of the existing building is developed.

**Stage 3—Concept Design**

An early-stage project is developed, verifying its coherence with the overall project scope and objectives. This stage includes geometrical and design explorations, using meta-technological objects for design optioneering purposes.[3] The Concept Design Stage is fundamental to understand the feasibility of the retrofit with off-site prefabricated insulation panels, identifying possible issues or limitations (both geometrical and energy-related).

Starting from the Stage 2 as-is BIM model and from several knowledge-based constraints from the designer (e.g., dimensions of the panels, possible integration with façade elements and installation, etc.), parametric placeholders' panels are added to the model, including only basic meta-technological information. The meta-technological panels are used for a first optioneering of the project. This optioneering phase is mostly based on geometric and architectural factors, while identifying possible issues for the panelisation and minimising the number of different panels. Information incorporated in the placeholder object for this stage are dimensions, area and volume and anchors. This step is useful to minimise unwanted design changes

[3] Optioneering is the commonly used term to describe the in-depth consideration of various alternatives and options to find the best or preferred alternative or option.

in subsequent stages and is obtained through the automated or semi-automated comparison between different proposals that can be easily shared with the Client for feedback.

**Stage 4—Preliminary Design**

The Preliminary Design Stage starts with the review of the Client's feedback on the different layouts previously explored in Stage 3. After a meta-technological option is confirmed, it is necessary to acquire performance targets, such as the U-value, to evaluate different technical solutions, each with its typical materials, are evaluated. Manufacturers can now be included in the process to provide the necessary information through early engagement; otherwise, available technical information or knowledge bases can be used. Each time the panels are modified, their technical data change accordingly, thanks to the parametric evaluation of the previous stages. This allows the team to export bills of quantity and using the model to show the stakeholder's feedback. Early datasheets containing dimensions, number of different elements, total number of anchors, and thermal performances are generated from the model for approval.

**Stage 5—Developed Design**

This stage aims to select a technical solution according to the Stage 4 Client's feedback. After the identification of a technical solution, several analyses and calculations are performed, starting a recursive process in collaboration with the Supply Chain. This includes performing energy, structural and LCA simulations. After the chosen solution is analysed and detailed, a first parametric time and cost definition can be shared for a budget validation phase. By the end of this Stage, after the budget is validated through early Contractor and Supply Chain engagement, detailed parts are studied and prototyped, and data-rich models generated. The Stage 5 BIM models can be shared with other disciplines for early coordination.

**Stage 6—Detailed Design**

In this stage, the digital model form Stage 5 is refined to incorporate inputs from the Supply Chain, producing a Construction BIM model. In this stage, time and cost are implemented into the Construction model, allowing the design team to produce a WBS.

An overall construction programme schedule and assembly sequencing are developed and can be shared with the Supply Chain to verify the construction process. This can be issued by developing fabrication and installation sequences, method statements and a resource management plan. This information can then be used in the BIM4EEB BIMPlanner tool to produce a lean and area-based representation of the construction works at each moment in time.

In this stage, there is a strong necessity to collaborate with the Supply Chain and manufacturers. In fact, most of the data needed for the development of the Construction model, such as the assembly sequencing, are delivered from the manufacturer itself. This exchange of information is the starting point for the production stage

(Stage 7.1, Pre-Construction), allowing a smooth transition between designer and producers.

**Stage 7—Construction**

The two phases of off-site fabrication and on-site assembly are strictly connected. For this reason, Stage 7 is subdivided into Stage 7.1—Pre-Construction and Stage 7.2—Construction. Façade panels are manufactured during the Pre-Construction stage. Time-related data embedded into the Construction model allows planning of just-in-time logistic to study delays and storage periods of panels.

Thanks to the cooperation with the manufacturers, shop drawings are integrated into the model. Transferring the manufacturer information into the model is crucial for the following stages.

During the On-site Construction stage, thanks to the BIM4EEB BIMPlanner and BIM4Occupants tools it is possible to track and share construction activities with the users in an all-in-one model considering the planned programme and assembly sequence, therefore significantly reducing disruption.

The output of the Construction stage is an As-built BIM model, fully integrated with all the information from the construction site and uploaded nearly in real-time as activities advance.

**Stage 8—Building Use**

During the Use Stage, the main objective is to update the as-built model with information about maintenance, facility management and, moreover, with the data coming from the BMS. The updated model is a Digital Twin of the physical building. With an accurate Digital Twin, it is possible to keep the ordinary maintenance plan up to date and to define the Life Cycle costs for the whole life cycle of the building. The model has to be integrated with the Facility Management system and the information about maintenance for each element.

Moreover, linking the BMS information into the model allows to identify possible issues and unwanted expenses in advance.

**Stage 9—End of Life (EOL)**

The end-of-life requirements are mainly related to the information from the manufacturer. Including this information into a regularly updated Digital Twin can help produce a fully developed EOL support documentation and, consequently, an EOL action plan.

Figure 6.11 shows graphically some of the data that is exchanged between actors of the process at the different stages of the process.

### 6.5.3 *Test of the Guidelines on a Case Study*

The guidelines summarised above were finally tested on a case study, to verify that the steps of the process and the information flow can actually be used in practice.

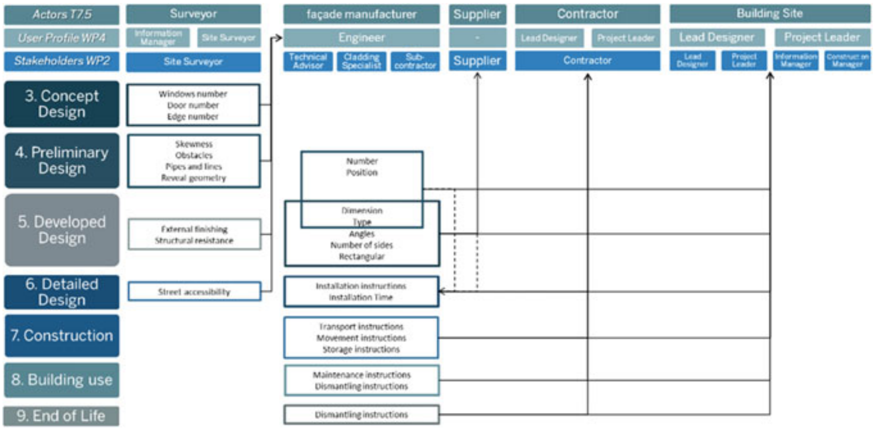


**Fig. 6.11** Panelisation dataset and data exchange between various actors across the process stages

A simplified version of the Italian BIM4EEB case study project was used for this purpose.

The first part of the test focuses on the first stages of the guidelines (from 1 to 5), demonstrating the framework's effectiveness, and facilitating the selection of the configuration that best meets the requirements set by the Client. The test also aims at demonstrating the possibility, through inputs given by the data-rich BIM model provided in Stage 7 and by design constraints, to obtain coherent and integrated results in a design flow shared by the different project actors. The output (design of the prefabricated panels fitting the specific case study) contains the necessary information to interface with production and site operations. The second part of the exercise, interfacing with the BIMPlanner tool for the construction-related activities (Stages 6 to 9), demonstrates the possibility of its integration in the workflow and, at the same time, how the organisation of operations on site deriving from a prefabricated system is different from a traditional one. As part of the test, two alternative technologies for the prefabricated panels, namely TRM (textile-reinforced mortar) sandwich and timber frame, are considered. Only some highlights of the test will be presented in this section.

In Stage 3—Concept Design, the BIM model is acquired from the BIM4EEB BIM Management System, with some simplifications of the actual geometry for the purposes of this test. Thanks to parametric tools, a first round of optioneering is conducted about the geometry of the panels; in particular, the goal is to maximise the number of equal panels, minimise the total number of panels, and reduce or eliminate completely unique panels. Figure 6.12 shows the output of this process, which provides information such as total number of panels, the number of different panels to be produced, and a datasheet with the identification of individual elements.

In Stage 4—Preliminary Design, the performances of the solutions are evaluated thanks to the addition of technical information, allowing to move from meta-technological objects to a panel with more details. Once the preferred technological

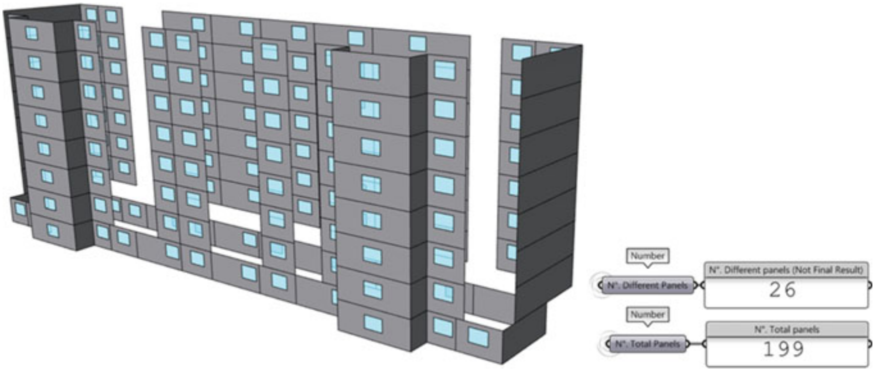


**Fig. 6.12** First panelisation step with meta-technological panels, timber frame solution

solution is chosen, in Stage 5—Developed Design the IFC model including the panels is exported and shared with the manufacturer for validation. The panel layers are designed in detail, defining aspects such as the specific materials, their thickness and other properties, and anchors positioning. After further structural and energy analyses are completed, a fully verified and integrated BIM model is exported and ready to be shared with all the stakeholders, and in particular downstream with the manufacturer (Fig. 6.13).

Finally, in Stage 6—Detailed Design, the BIMPlanner tool is used to assess how the significantly shorter installation times allowed by the retrofit process with prefabricated panels impact the organisation of construction activities on site. The BIMPlanner tool requires the knowledge of the location and duration of each construction phase: in the case of prefabricated façade panels, it is therefore necessary to define their number for each front of the building and the related installation time. The number and location of panels are extracted from the BIM model obtained

**Fig. 6.13** Perspective view of the BIM model with the selected panelisation

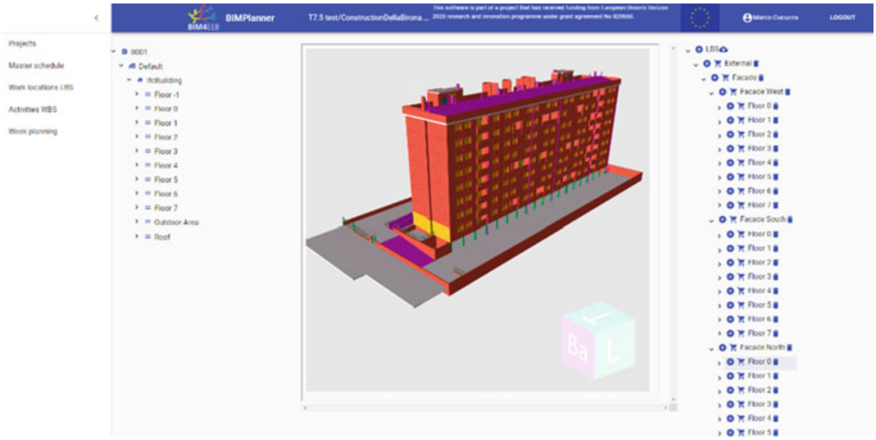


**Fig. 6.14** BIMPlanner work location LBS page: upload of the fully panelised IFC model

in Stage 5, in the form of a spreadsheet also presenting their dimensions. Installation times are instead derived from a generalisation of available information from previous case studies and literature. The installation time for each panel is estimated based on its size, the number of anchors required (larger panels need more anchors), the length of perimeter joints, the connection details and its position in the façade (panels higher up in the façade imply longer lifting times).

After defining the necessary panelisation times for each façade, the compiled master schedule can be uploaded in the BIMPlanner tool; the BIM model is also loaded, with the façade panels as independent elements (Fig. 6.14).

After the WBS is associated on the Work Location LBS page of the BIMPlanner tool with specific elements, such as the individual panels, a fully articulated weekly planning is available.

At the end of Stage 6, thanks to the interoperability of the process with the BIMPlanner toolkit, a fully articulated weekly planning is available; a comparison of the panelised solution with a traditional ETICS insulation system shows a reduction of the installation time by 2/3 thanks to prefabrication.

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