An occupant-centric approach in BIM environments for energy use and indoor comfort assessment and participative renovation planning

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Abstract
The construction sector is among the main ones responsible for energy consumption and greenhouse gases emissions. Hence, buildings retrofitting shall be encouraged and supported by targeted actions to achieve a European climate-neutrality by 2050, as pointed out by EU Agenda objectives. In this context, the European Commission is promoting a Renovation Wave Strategy. One step towards the renovation action is the exploitation of digital tools such as Building Information Modelling (BIM) and the Internet of Things (IoT). This paper is related to the potentialities of an ongoing EU funded project –BIM4EEB- and it illustrates the application of two BIM-based tools, namely BIMPlanner and BIM4Occupants, developed within the project. The two tools have respectively the purpose of sharing current information about the progress of construction works among renovation stakeholders and sharing with inhabitants tailored information about indoor conditions, comfort preferences and energy consumption of their houses. Thanks to IoT devices installed in a demonstration building permitted the real-time evaluation and control of several parameters. Therefore, a pilot building, namely the Italian demonstration application of the project, is described for testing the proposed tools. Benefits connected to the BIM framework and IoT devices result in an improvement of data sharing and communication between renovation stakeholders, then in an enhanced building process.

Keywords
BIM, IoT, Building renovation, energy efficiency, real-time monitoring

1 Introduction

Europe's boost toward renovation meets the necessity of making buildings more efficient and reaching climate neutrality by 2050. Considering European building stock as one of the major energy consumers and responsible for GHG emissions with values respectively around 40% and 36% of the total consumptions and emissions, and taking into account that 75% of building stock in Europe is strongly energy inefficient, the reply is to focus on renovation to make more efficient the already existing buildings (European Commission 2020, Buildings Performance Institute Europe (BPIE) 2021, European Commission 2020). Retrofitting is a good practice to reduce total energy consumption by 5-6% and CO_2 by about 5%. Considering that only 1% of the European building stock is undergoing renovation to become more energy-efficient, it is fundamental to adopt strategies in this direction (European Commission 2020).

To stimulate the practice of renovating and re-using buildings, Europe has recently launched further initiatives such as policies (e.g., 'Renovation wave' (European Commission 2020)), funding (e.g., InvestEU (Buildings Performance Institute Europe (BPIE) 2020)) and regulations (e.g., EU-level regulatory framework for the creation of the Single Market for Data for better data quality and data management (European Construction Sector Observatory (ECSO) 2021).

Digital strategies for a sustainable built environment enable buildings to be smarter and more efficient from the energy perspective as well as more comfortable for the inhabitants who on average spend 80% of their lives inside a building(Digital Europe 2021). The advent of the Internet of Things (IoT) is changing the way of living by monitoring and managing the building itself. In fact, sensors can be used to monitor and control the temperature inside apartments. This offers better management of building performances enabling users to be more conscious of the effective use of energy. Therefore, more efficient use of resources, more effective communication and collaboration within the design team could lead not only to an improved building process but also to an improved renovation process.

The fostering and use of Building Information Modelling (BIM) in the public sector is another area of interest designed for the renovation wave (Buildings Performance Institute Europe (BPIE) 2021). Many European projects focus on the research and creation of models and digital tools to support this action line (Elagiry *et al.* 2020). In this regard, BIM4EEB, namely BIM-based fast toolkit for Efficient rEnovation, is an Horizon2020 project aimed at making more effective renovation interventions. The research activity develops a set of BIM-based tools that approaches the integration of the stream of data from IoT applied in residential buildings inside an interoperable platform for sharing information among the involved stakeholders (BIM4EEB 2021, Daniotti *et al.* 2021).

The approach of the project is user-centric and it takes into consideration several stakeholders such as designers, construction and services companies as well as owners and occupants. A specific focus has been reserved to owners and inhabitants of residential buildings and social houses, considering that noises, delayed working times, and poor communication are among the main issues that inhabitants and owners have to face.

In this regard, the project BIM4EEB developed two tools – called BIM4Occupants and BIMPlanner – that aim at improving the knowledge of inhabitants and owners about thermal and visual comfort and renovation timing and activities (Törmä *et al.* 2020). The integration of information between the two BIM-based tools is supported by a BIM Management System. It is an interoperable platform where it is possible to integrate the IFC file of buildings with the related data streaming coming from sensors, meters and control devices placed inside. In addition, the current level of renovation activities can be visualised related to the specific location and spaces in the *.IFC (Valra *et al.* 2020).

This paper investigates the topic of the BIM framework in connection with IoT devices to enhance communication and share of information among stakeholders, improve the comfort of inhabitants and speed up the renovation process starting from the outcomes of the EU-funded research project BIM4EEB. A description of the case study where the tools are applied is provided and afterwards, the main features of BIMPlanner and BIM4Occupants are presented, discussing the output of the data analysis and, finally, highlighting outcomes and future research developments.

2 Methodology

2.1 The case study building

The considered building, one of the three case studies of the BIM4EEB project, is in Monza, one of the biggest cities in northern Italy. Built in 1981, it is nine floors, residential building for social housing managed by ALER Varese – Como – Monza Brianza – Busto Arsizio (ALER VCMB), with a total of sixty-five apartments (Table 1, Figure 1).

Table 1. Details of the Italian Demonstration site

Year of construction and address	1981, Monza (MI) - Via della Birona, 47
Number of apartments	65
Number of floors	9 (one of which is a raised ground floor and another one is a *pilotis* floor at level -1.50m currently used as a garage)
HVAC system	Centralised methane generator for heating - No cooling system
Renovation interventions	- Realization of ETICS - Replacement of external windows with PVC windows for all the 65 apartments - Replacement of the external iron windows of the common areas - Insulation of heating pipes at the *pilotis* floor

It is composed of plastered external facades and fair-faced concrete stairwells and fronts. The conservation status of the building is relatively poor. There are signs of loss of plaster and flooring as well as damage to the concrete cortical surface.

Figure 1. Italian demonstration site in Monza. From left to right: West façade; East Façade details, East Façade

To improve the performance of the residential building, two activities are being carried out. On the one hand, the realisation of insulating facade coat and the replacement of external windows with PVC windows are the main renovation interventions currently taking place (Figure 2). On the other, environmental sensor devices were installed to make apartments smarter and improve their performances.

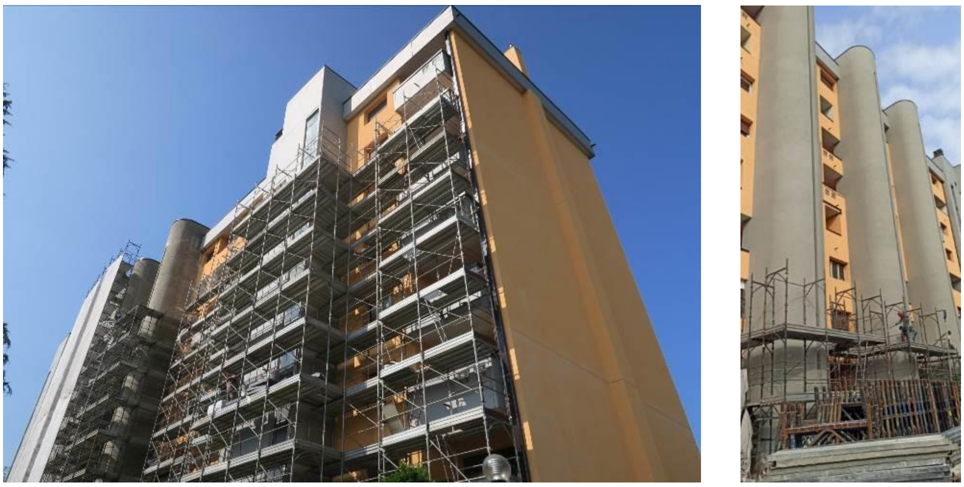

Figure 2. Est Facade during and after the renovation process consisting in the realisation of external thermal insulation.

Among the planned renovation interventions, the realisation of external thermal insulation, as well as PVC windows installation, are going to be finished in April 2022, while the different types of sensors were already installed in some apartments to collect data streaming in the BIM Management system (BIMMS) before, during and after renovation.

2.2 Sensors set-up

Data collection techniques among IoT devices and sensor systems have been selected and studied. Several communication protocols such as Wi-Fi, Z-wave, Zigbee were considered before choosing the hardware topology to address the task requirements about:

- Indoor environmental conditions (temperature and humidity, luminance, occupancy),
- Indoor Air Quality (CO_2),
- Electric power consumption.

Hence, different sensor devices were installed in the building case study. A sensor hub with a connector and management function has also been installed to enable data integration from different sensors. This hub supports various communication protocols (Bluetooth, Z-wave and Zigbee), enabling hardware to data exchange and transmit. In addition, to collect the acquired sensor data, a system gateway was introduced. Sensors are linked to the gateway and due to the connection to its Application Programming Interface (API) data can be transmitted and stored into the BIMMS developed within the project.

Sensors were placed in 9 representative apartments selected on two main criteria. Firstly, the selection of individual apartments relied on inhabitants' availability considering more cooperative families during the installation phase and data collection. Secondly, the choice was based on considering different exposure and different levels of the building (low, medium, high/ stairs A and B) and analysing the technical conditions of individual apartments.

Selected apartments are two and three-room flats. The multipurpose sensors - measuring temperature, humidity, occupancy, and illuminance – were installed in their living rooms and master bedrooms. The Indoor Air Quality (IAQ) sensor was instead installed only in the living room because it is considered the room of the house where the inhabitants spend the most time, assuring a more significant data collection (Figure 3). The electric power meter was placed to monitor current energy consumption and cumulated consumption.

Figure 3. Sensors set up. Images from the installation in a selected apartment.

As mentioned, thanks to a system gateway and APIs, data can be stored directly in the BIM Management System. However, it is possible also to manually load the incoming streaming data in a .csv format. Once logged in the BIM Management System, a list of apartments appears in a specific section. Selecting a precise apartment, the different types of sensors installed here, and their related identification code and details can be visualised in a dedicated box.

2.3 The BIM-based tool called BIMPlanner

BIMPlanner is a short-term scheduling and tracking tool of site operations in renovation projects. The basic use case is that a site manager can weekly plan the next 1-2 week's activities and at the same time update the status of ongoing activities (started/finished). The master schedule of all renovation activities has to be uploaded from an external system (via Excel in the current version) and set as a target for detailed weekly planning/tracking procedures. The timing of activities is planned and linked to BIM (Figure 4). In practice, this approach divides master activities into shorter duration activities applying a location-based planning method. Weekly planning concentrates on how all activities flow through the predefined work locations. This helps achieving detailed planning and enables fast response to deviations to keep work progresses on track.
To follow such work progresses during renovation, activities are linked to work locations that are also linked to BIM-objects with a geometrical location. Even though this is about the same as BIM-based 4D-scheduling the important feature in the planning method is that the work locations are predefined and reserved to one activity in time to reduce interferences between activities.

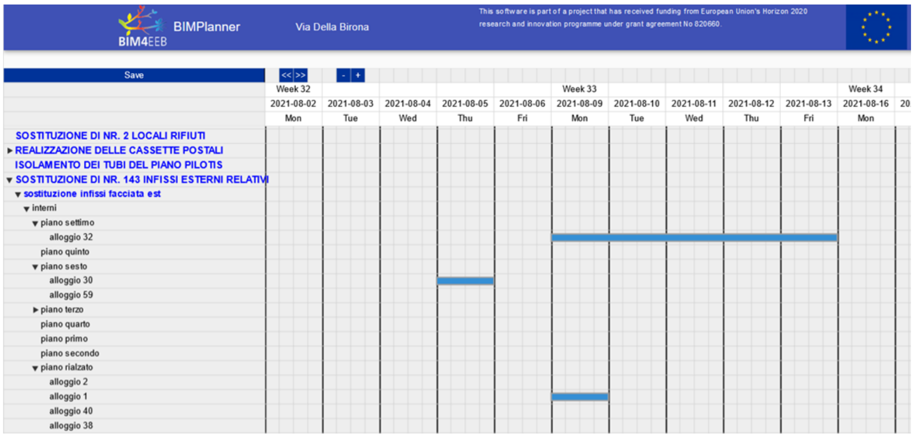

Figure 4. Week planning view in BIMPlanner tool

In technical implementation BIMPlanner stores scheduling and progress data and non-geometrical IFC-data as RDF data in a graph database. This data is modelled according to the Digital Construction Ontologies (DiCon) developed in BIM4EEB and published on Digital Construction Ontologies website (BIM4EEB 2020a).
BIMPlanner operates with the central platform BIMMS that is used for information sharing and communication with other BIM4EEB-tools. BIMMS manages all master identifiers enabling the information transfer between those external systems. In an occupant-centric perspective, the most important feature is to provide the activity timing data to occupants and get their feedback to the proposed scheduling (Figure 5). BIMMS retrieve regularly the activity data from BIMPlanner that is linked to IfcSpace and IfcZone objects of the common IFC-model. BIMMS maintain the linking of the IfcZones to occupant accounts and provide the apartment specific timing data for BIM4Occupants-tool.

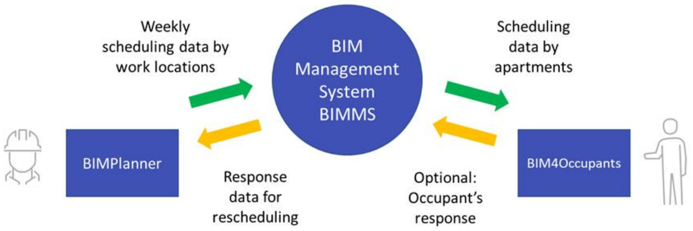

Figure 5. Sharing apartment specific scheduling data to occupants with BIM4EEB-tools

If the scheduling of activity inside the apartment is not possible, the occupant may decline the scheduled task and propose a new timeslot. The occupant's feedback is provided back to BIMMS and BIMPlanner to retrieve response data for rescheduling, implementing a participative approach for project planning (BIM4EEB 2020b, Valra *et al.* 2020).

2.4 The BIM-based tool called BIM4Occupants

2.4.1 Tool description

One of the main innovations of the proposed framework is the development and incorporation of an occupants' context-aware behaviour engine as well as the delivery of the user interfaces to support bidirectional information exchange with building inhabitants, enabling them to be part of the building management ecosystem.

At first, the building occupants should be able to get insights about contextual conditions in building premises, personal comfort preferences and further comfort and energy-related analytics. More specifically, the occupants' context-aware behaviour engine, properly manage and train the occupant comfort models using information streams from sensors/actuators, along with information provided through the interaction with the users 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.

In addition, the building occupants oriented framework allow building occupants to receive notifications and alerts on on-going works, together with safety hints and information (e.g. to avoid specific areas where works have not yet been finished), while, on the other hand, they can upload information that might be requested *ad hoc* by contractors contributing to the constant and collaborative updating of BIM and as-built documentation. Moreover, building occupants can receive information about on-site work planning and schedules, improve planning according to their individual needs and preferences and collaborate on the optimal scheduling without affecting the overall duration of projects.

The overall development of the tool took into account the definition of building occupants' requirements to ensure that a final development is in line with the needs and priorities of the end-users.

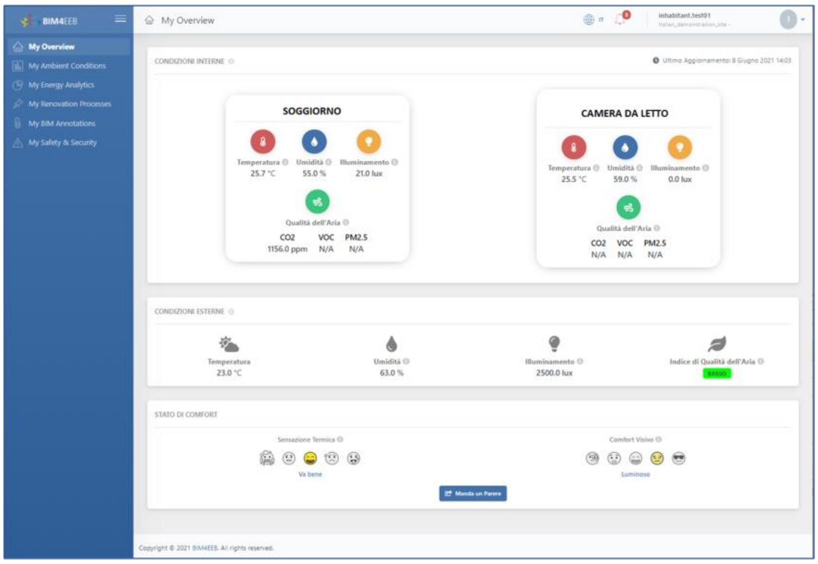

Figure 6. BIM4Occupants homepage

2.4.2 Methods for Data analysis

Following the data collection process, a key step of the methodology is the analysis of data for the extraction of useful insights. The occupants' context-aware behaviour engine has been developed as the ML-based analytics component to extract knowledge related to the contextual conditions and building occupants' performance in building premises. More specifically, the occupant's context-aware behaviour engine incorporates a behavioural profiling module that continuously monitors and learn transparently the operational and behavioural patterns (i.e. the preferences) of building occupants, while at the same time interacting with the occupants to define user preferences and extract comfort levels according to healthy boundaries. The scope is threefold:

- Delivery of an occupancy profiling engine that takes into account temporal parameters such as occupancy settings by the users, occupancy sensorial data (if available), day type characteristics (weekdays, weekends), building zone identifiers and the outcome of this process is a 24-hour occupancy profile.
- Delivery of a thermal comfort profiling framework for addressing both thermal preferences and non-preferences of the building occupants under various temperature/humidity conditions. Thermal comfort profiling is defined as a non-parametric model which aims at collecting and analysing (together with user static preferences) events in real-time to extract dynamic thermal comfort profiles. The outcome of the analytics engine is the calculation of the level of user satisfaction at an environmental condition state.
- Development of the IAQ analytics to evaluate indoor hygienic and health/wellbeing conditions through identifying contamination of the air with various compounds, such as carbon dioxide (CO_2).

3 Preliminary findings and potential applications

3.1 Partecipative planning

One of the key activities to link the planning of activities, to include the participation of the inhabitants is the possibility to carry out activities in which both the building owner and the construction company can communicate with the inhabitants via the interfaces of the Bim4occupants tool, managing the planning of activities and approving the negotiation process via BIMPlanner.
Specifically, the functionality was presented to inhabitants of the Italian demonstration site and it was tested on three different apartments. Among the several activities of the master schedule, the

replacement of external window frames related to housing units was chosen to test the advantages of the tool. The tool developers together with the other project's partners decided to apply the tool and test its benefits considering one of the main disturbing activities for building occupants. The planned duration of this kind of intervention was 16 weeks for all the building and it was characterised by the disassembly of the old window, the ground transport of the material to be disposed of and cleaning of the apartment, the preparation of the support and the transport of the material to be assembled into the apartment by the use of scaffolding and winch, the assembly of the new window and finally the ground transport of the material to be disposed of and cleaning of the apartment.
For the testing process inhabitants and construction company cooperated to finish window frames replacement by a fixed deadline, turning it into an example of enhanced planning as well as negotiation. Occupants of the three selected apartments proposed to the construction company an ideal date to carry out the renovation intervention according to their commitments. In two cases the procedure was very smoothly: occupants and construction company set a date that was accepted and respected. Instead in one case, it was necessary to change the agreed date and arrange another feasible day for taking action.

Figure 7. Occupant Responses management through BIMPlanner and for activity rescheduling.

The process results in improved management of works, better communication, and occupants' satisfaction. The replacement of window frames was finished three days in advance with respect to the master schedule and occupants working in shifts were relieved of the need to know when being present in the apartment. The project is still ongoing so the results could be considered as preliminary.

3.2 Environmental monitoring

The BIM-based application for building occupants BIM4Occupants is an innovative tool to enhance the role of building occupants as active stakeholders in the building management process. As mentioned above, the occupants' context-aware behaviour engine incorporates the logic for analysis of raw data streams towards the extraction of useful insights.
In the field of occupancy profiling, the typical approach is the use of typical static profiles in order to model the operation in the building environment. In BIM4EEB project and within the context-aware behaviour engine, dynamic occupancy profiling analytics techniques have been incorporated to analyse PIR data available from motion sensors as well as information provided by the users in order to extract accurate building occupancy profiles. By applying aggregation and data cleansing techniques over the data streams as well as regression techniques for the correlation of user settings with motion sensorial data, dynamically updated occupancy schedules are extracted as presented in the following figure. This process aims to minimize or even eliminate the deviation of occupancy profiling models from actual occupancy conditions.

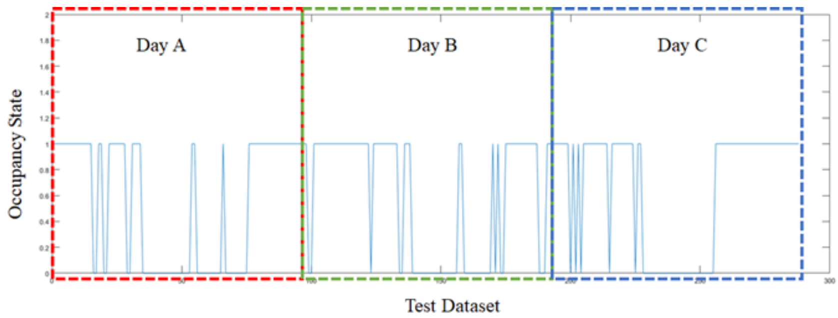

Figure 8. Raw occupancy data - 72-hour period

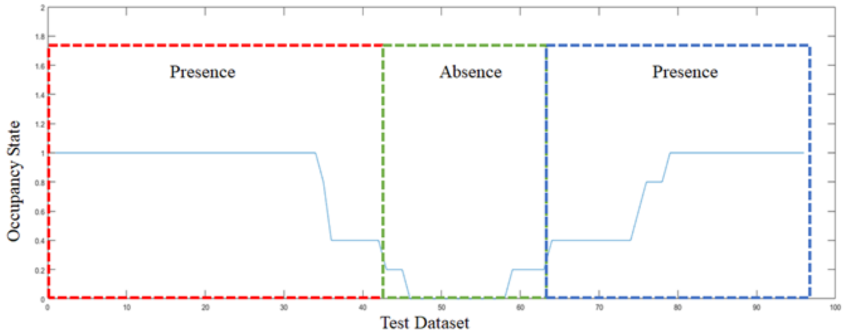

Figure 9. Typical occupancy profile

The same analysis applies also to the extraction of occupants' comfort profiles. Raw data measurements about temperature are correlated with users' settings about their context conditions in order to extract the desired temperature of a user once at a specific indoor temperature condition. In Figure 10 the raw environmental (temperature) conditions from a building zone are presented covering a 2-month period (mid-October – mid-December 2021). These data are further correlated with the user settings about thermal preferences and non-preferences. The results of the statistical analysis over the data reveal the typical thermal comfort profile for the user of the zone, as a probabilistic function of being at a thermal comfort state under different environmental conditions.

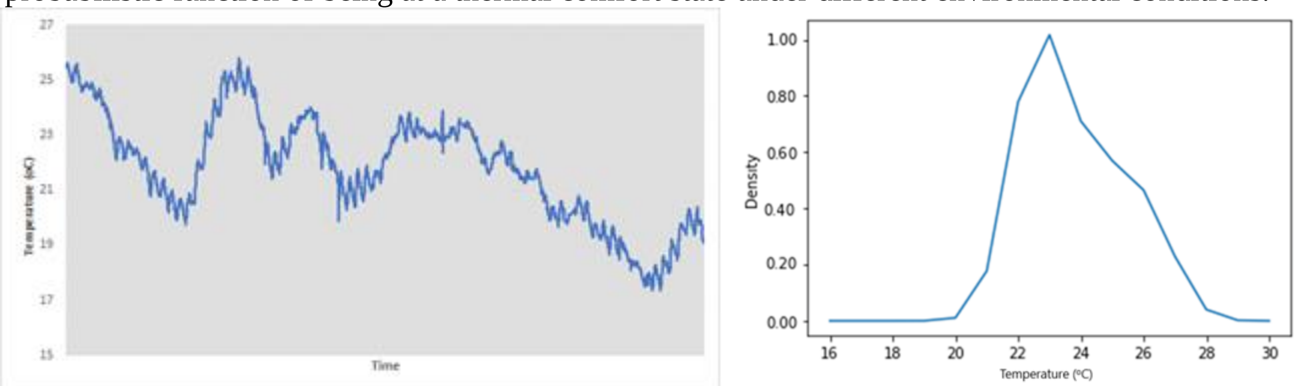

Figure 10. Thermal comfort profiling analysis – From left to right: temperature conditions over two months, distribution curve

4 Conclusions

Among the preliminary considerations of the BIM4EEB project, it can be stated that the analysed tools are in general able to improve the communication between all actors involved in the building project.

The application is providing the opportunity to building occupants (owners and inhabitants) to receive information about on-site work planning and schedules and further "negotiate" with contractors based on their individual needs and preferences and jointly decide on the optimal schedules without affecting the overall duration of projects.

Improved planning and interaction activities are considered as a first positive test with encouraging results for better management of site activities and the reduction of discomfort for tenants by planning through negotiation

Some additional key findings from the evaluation period are the positive perception from the testers of the tool as the application is giving the opportunity to the building occupants to receive notification and alerts on on-going works, receive safety hints and information (e.g. to avoid specific areas where works have not yet been finished), while on the other hand, enabling them to receive information about the comfort parameters and indoor variables such as temperature and CO_2.

Given some initial problems of sensor acceptance by the occupants, the need for a participatory process in which there is support in the management of information and in the use of the tools is emphasized, especially for those more fragile users with less technological skills.

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