Extending BIM for Air Quality Monitoring

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SUMMARY: As we spend more than 90% of our time inside buildings, indoor environmental quality is a major concern for healthy living. Recent studies show that almost 80% of people in European countries and the United States suffer from SBS (Sick Building Syndrome), which affects physical health, productivity and psychological well-being. In this context, environmental quality monitoring provides stakeholders with crucial information about indoor living conditions, thus facilitating building management along its lifecycle, from design, construction and commissioning to usage, maintenance and end-of-life. However, currently available modelling tools for building management remain limited to static models and lack integration capacities to efficiently exploit environmental quality monitoring data. In order to overcome these limitations, we designed and implemented a generic software architecture that relies on accessible Building Information Model (BIM) attributes to add a dynamic layer that integrates environmental quality data coming from deployed sensors. Merging sensor data with BIM allows creation of a digital twin for the monitored building where live information about environmental quality enables evaluation through numerical simulation. Our solution allows accessing and displaying live sensor data, thus providing advanced functionality to the end-user and other systems in the building. In order to preserve genericity and separation of concerns, our solution stores sensor data in a separate database available through an application programming interface (API), which decouples BIM models from sensor data. Our proof-of-concept experiments were conducted with a cultural heritage building located in Bled, Slovenia. We demonstrated that it is possible to display live information regarding environmental quality (temperature, relative humidity, CO2, particle matter, light) using Revit as an example, thus enabling end-users to follow the conditions of their living environment and take appropriate measures to improve its quality.

KEY WORDS: Building information model, Internet of Things, environmental quality monitoring, healthy living

1 INTRODUCTION

Conservation and renovation of cultural heritage buildings is a priority of the UNESCO Sustainable Development Goals (SDGs) as a part of the culture preservation program1. It is as well a major concern for public and private owners. In this context, Information and Communication Technology (ICT) is ideal to provide stakeholders with crucial information about the building state and its environment and contribute to facilitating renovation processes.

However, current available tools for building monitoring and management remain particularly limited and lack integration capacities. On the one side, most popular software used for designing building (such as ArchiCAD, AutoCAD, Dynamo, Grasshopper, Maya, SketchUp, Revit, Rhino 3D, etc.) remain static, fragmented and barely compatible with each other. On the other side, Internet of Things (IoT) solutions, while they provide highly needed dynamic information about building conditions, are not integrated into existing modeling tools.

In this paper, we describe a solution to exploit data coming from building sensors via building modeling tools. We show how it is possible to use Building Information Model (BIM) attributes in order to provide the building modeling tool with specific information that allows accessing and displaying sensor data. We describe our solution to provide information about IoT sensors deployed in buildings so that modeling tools can access it and provide advanced functionality to the end user. The prototype software plug-in was created in Revit, but the same solution can be replicated in most state-of-the-art programs used by architects. We focus on air quality monitoring, an essential aspect of healthy living and a major concern for building renovation. Our experiments have been conducted with a cultural heritage building located in Bled, Slovenia. We show that it is possible to display live information about air quality (temperature, relative humidity, CO2, particulate matter) in a tool like Revit, therefore enabling stakeholders to follow air quality conditions before, during and after the renovation process.

This paper is structured as follows: Section 2 highlights the need to integrate air quality information into the BIM to enable live monitoring of the building. Section 3 reviews most relevant work in the area and shows how air quality information is not yet integrated into BIM products. Section 4 presents our contribution to enable air quality information to be accessible to end users through BIM integration. Section 5 illustrates our proposal with a use case developed with a building from the Slovenian cultural heritage. Section 6 summarizes the results obtained and gives some guidelines for future work.

2 MOTIVATION

The use of BIM can be widely extended from (relatively sophisticated) designing tool for 3D structure and installations to variety of diverse aspects related to the building itself. Some of the state-of-the-art BIM additions can be used, for example, to simulate the indoor thermal, lightening and acoustic conditions which cumulatively affect the comfort and well-being of occupants. It supports different types of automated evaluation and analyses which are helpful for improving the building operations in terms of human comfort. It provides a 3D virtual environment with a workflow of integrated information through a software package capable to predict and decrease problems and errors [1]. The BIM as a digital representation of the building offers unique possibility to combine diverse information related to the facility, including all phases of its life - from the concept to demolition and recycling. For that reason, it is feasible to consider it as a storage of the overall service-life performance data that can be automatically acquired by sensors or any IoT solutions (among the others). The model of a building will contain therefore an additional layer, simplifying the access to the data. This provides a possibility of early warming of the undesired building conditions that can automatically alert the building owner or users about the treat and recommended solution. On the other hand, an access to the readings from sensors that are well structured (time and location-wise) provides a unique possibility to validate simulation models integrated already with BIM. It is expected that further building modelling tools will develop in a close future. The same data would be highly useful for development of such models and further extension of the BIM usability.

[1] https://en.unesco.org/courier/2017-april-june/culture-heart-sdgs

BIM is recently used to document and manage cultural heritage structures. The Historic Building Information Modelling (HBIM) for the integration of contemporary technology and BIM approach in the field of cultural heritage documentation was introduced by [2]. HBIM can be implemented to enhance the performance of existing heritage buildings or plan for the conservation of an unused facilities. The research reported here is a follow-up of the HBIM project conducted for the historic building Mrakova Domacia located in Bled (Slovenia). The old farmhouse was constructed in the eighteenth century and was abounded for more the 40 years after owner's death. The structure and interior were perfectly preserved and represent an authentic example of the ancient culture and habits. Just recently, the Local authorities in collaboration with Institute of Cultural Heritage of Slovenia decided to renovate the building and organize a modern exhibition place attracting visitors and tourists. The original HBIM model developed for the needs of this restoration included inventory of current building elements and its general conditions. It was found however, that several other (than structure itself) aspects are not represented as a data or simulation models. Moreover, an effect of the restoration action on the building microclimate was difficult to predict, not to mention of the reconstruction effects on human health. For that reason, monitoring of Indoor Air Quality (IAQ) was considered as an interesting addition to the HBIM-based model. In this context, the current IAQ state as well as its changes during and after restoration are assessed by the custom developed prototype sensor network, with all acquired data integrated with the HBIM model. As a result, the system allows an easy access to information about indoor pollutants and ambient air conditions that are highly useful to quantify an impact of the activities carried out in the building and during its future occupancy.

3 RELATED WORK

Due to industrial needs and building digitization, Building Information Modelling (BIM) [3] has become more and more important in the last decade. The main objective of the original idea is to support sharing, storing and managing information during the whole building lifecycle from the design phase to the operational period and to facilitate an interoperable communication channel in the architecture, engineering and construction (AEC) industry. More detailed description about the original model and an overview about methodologies can be found here [4,5]. The main advantage of the BIM model, which is regulated by the platform neutral Industry Foundation Classes (IFC) and Green Building XML (gbXML), is to be an open format specification that is not controlled by a single vendor or group of vendors in the field.

The BIM provides an efficient tool to describe the model and the essential properties of the building, however additional features, such as cost estimation, project management and IoT technology support are not available in the original format. It can be stated that with the expansion of the Building Information Modelling, the digital representation of the newly built structures is becoming a general practice in the field, but it is also important to exploit the original idea to create a commonly usable methodology to support existing and old buildings, and extend the functionality of the original model to keep it ready to operate with latest technologies. Since the components of the building in the model are represented by objects, and the objects contain the different properties and attributes of the represented element, the structure of the model gives opportunity to extend the functionality effectively and use the existing digital representations to provide additional functionalities. In the literature, possible extension scenarios were introduced in [6].

3.1 Overview of BIM extensions

Researchers from different fields have demonstrated the extendibility of the original model. The different BIM extensions can be grouped by the application area of the extended model, and in the literature several research is focusing on the extensions that can be used in the existing softwares. In most cases, the architects and designers use CAD based software tools to create the 3D model of the building, such as Autodesk Revit or other CAD based software. An example of the extensions is the multidimensional model (nD) concept where the original model was expanded with dimensions where cost, accessibility, maintainability, sustainability, crime, energy, whole life costing, acoustics, and scheduling were included into the original model [7]. The n dimensional model also includes the life cycle assessment of the corresponding building. Other research papers are focusing on the heat modelling and the structural simulations in a case of fire or other disasters [8], where for example evacuation plans can be tested [9]. The following extension tries to evaluate the sustainability level and architectural designs using the Building Information Model [10]. It can be seen that the different extensions of the BIM are from several different area, and the original model is suitable to handle additional functionalities to provide a general and effective modelling methodology of our buildings.

IoT is the abbreviation of Internet of Things and it refers to the broad range of different devices and physical objects connected to each other and to the Internet in order to exchange and collect data. It includes the use of sensors, actuators, communication equipment, data storage, computing devices, analytical and other software to achieve the desired behavior of connected devices or obtain the needed results. The following paper gives us a good overview about the IoT related extendibility of the original BIM model [11]. Nowadays the IoT solutions are becoming an important part of our life, and the integration of the smart features, sensors, data processing and analysis of the collected data into the BIM is a key research area nowadays. It is also important to see that until now the model was used by researchers and the main contributors of the building industry, nevertheless the IoT solutions gives us an opportunity to bring the BIM closer to the end users, creating a widely used and general computer environment and support the area of the smart building and system development. The usage of the IoT in BIM can be highly important if we are talking about the protection of cultural heritage. The different expansions of the model can be connected to movable objects in the building, HVAC vibration or VOC measuring, energy monitoring and management, or harmful environmental effects. The following articles can give an overview about the IoT and BIM integration in cultural heritage buildings [12,13,14].

3.2 Air quality monitoring

Air quality monitoring plays a big role if we are talking about the human health in a building environment. It is well known that the air pollutants (e. g NO_x, CO, BTEX, PAH, PM_{10}, $PM_{2.5}$, PM_1, O_3, SO_2) can cause serious health problems. With the spread of the IoT solutions the air quality monitoring became a widely available and, in most cases, cheap solution to protect the users of the actual building. In Europe, the World Health Organization (WHO) identified and recommended QA (Quality Assurance) and QC (Quality Control) activities to create a comparable methodology for the Air Quality measurements. The following article gives us a good overview about the sensor systems for air quality monitoring [15]. The installed sensor systems in public or private buildings are mostly low-cost sensors [16], however a good description about the low-cost sensors can be found here [17]. It can be seen that the integration of the air quality sensors into the BIM system is an important research area both from health and technological point of view.

The originality and the main advantage of our research is to create an extended format which can be passed along the different environments and encapsulate the information from the installed sensors in the building. The methodology proposed extends existing and commonly accepted IFC attributes, that results in direct integration of IoT solutions available for air quality assessment with BIM modelling approach.

4 CONTRIBUTION

Our contribution relies on the exploitation of BIM model attributes to enable access to sensor data. We designed an architecture that supports data collection and storage as well as its access through a Revit plugin that we developed. Our architecture presented in Fig. 1 shows the organization of our solution.

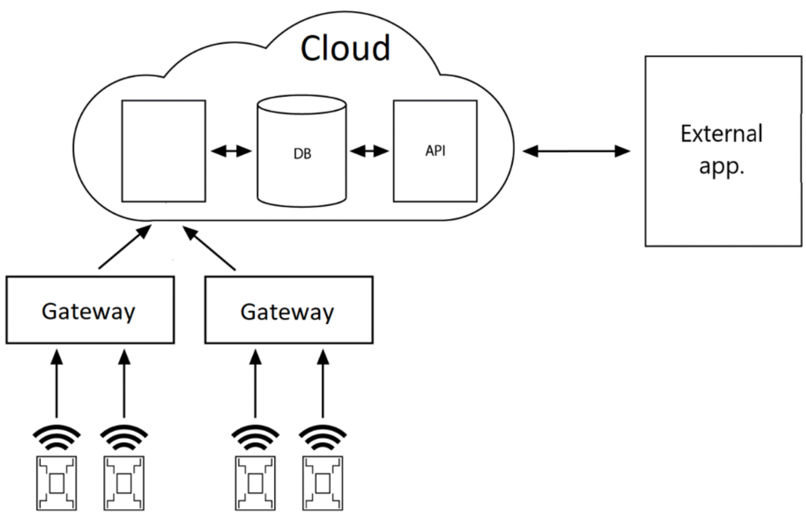

Figure 1: General Architecture Overview

Sensors connect to a gateway that forwards data to the cloud (we relied on the Microsoft Azure solution). Our cloud software receives data through its Application Programming Interface (API) and stores in a database that provides long term storage and makes data accessible to any external application such as Revit through another API. Our data model allows each organization to register buildings and store related sensor data. Management of building, sensors and data is realized through our developed Web interface or Revit plugin. Our plugin is visible in the Revit program above the ribbon “BIMSockets” and offers the following actions: “edit sensor”, “last record” and “report”.

Fig. 2: Revit plugin

Our plugin communicates with our REST API hosted in Azure cloud. First users must authenticate, then select building from their list. Once a building is selected its parameters are written to Revit project information. The plugin saves building identification number and name, obtained from the API available online[2].

For displaying and storing data we created new BIM objects which represent sensors. To add a sensor, users are provided with a list of sensors, defined for a building. After selecting a sensor, the user must place it in a room, representing its physical location, on an object face. Selected sensor information is stored in the project. To ensure data transfer from Revit to other applications implementing BIM we decided to reuse common properties of objects, more specifically “Identity data”. Sensor identification number is written in the “Mark” property and its display name is stored in the “Comment” property. With this solution, exporting model for other programs also exports data added with our extension. Each sensor can only be added once per building.

After successful deployment of sensors throughout building and connecting them to our platform, we can access their data through Revit. This can be accomplished with selecting desired sensor and selecting either “Last Record”, if we are looking for last reading transmitted from sensor, or “Report” where user select period and type of data aggregation. To test that data transfers from one BIM program to another, we exported our model to IFC format and import it in free IFC viewer “BIM Vision”. After exporting all the required data transfer from Revit to IFC file. Fig. 3 shows measures displayed for a temperature sensor in Mrakova Domacia.

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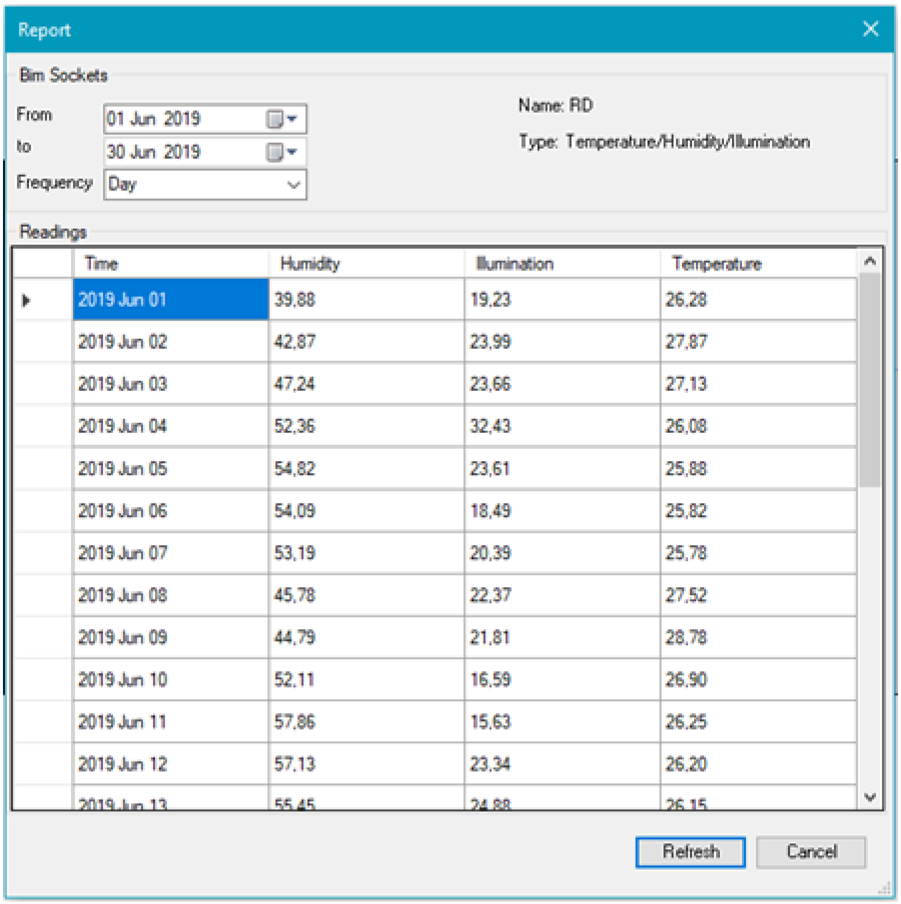
[2] http://kanduti.com/docs/index.html



Time	Humidity	Illumination	Temperature
2019 Jun 01	39,88	19,23	26,28
2019 Jun 02	42,87	23,99	27,87
2019 Jun 03	47,24	23,66	27,13
2019 Jun 04	52,36	32,43	26,08
2019 Jun 05	54,82	23,61	25,88
2019 Jun 06	54,09	18,49	25,82
2019 Jun 07	53,19	20,39	25,78
2019 Jun 08	45,78	22,37	27,52
2019 Jun 09	44,79	21,81	28,78
2019 Jun 10	52,11	16,59	26,90
2019 Jun 11	57,86	15,63	26,25
2019 Jun 12	57,13	23,34	26,20
2019 Jun 13	55,45	24,88	26,15

Fig.3: Sensor measurements displayed with our Revit plugin

5 CONCLUSION

In this paper, we show an architecture to collect data sensor networks and enables their visualization in building modeling tools. We describe how we exploit specific attributes of the Building Information Model (BIM) in order to provide building modeling tools with specific information that allows accessing and displaying sensor data. Our prototype software plug-in was created in Revit, but our solution applies to most state-of-the-art programs used by architects. We focus on air quality monitoring, an essential aspect of healthy living and a major concern for building renovation.

Our experiments have been conducted with a cultural heritage building located in Bled, Slovenia. We show that it is possible to display live information about air quality (temperature, relative humidity, CO2, particulate matter) in a tool like Revit, therefore enabling stakeholders to follow air quality conditions before, during and after the renovation process.

Future work includes developing advanced recommendation mechanisms that can assist BIM users to design better buildings, to improve building performance and to spot weak points in building structure by exploiting sensor information. Such advance requires integrating AI algorithms into our plugin and further integration into BIM software.

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