

BIM and Mixed Reality for Visualizing Building Energy Data

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Abstract

The visualization of building energy data is an open topic, intuitive approaches are rare and new concepts are required to handle big data collected by more and more sensors or even derived from energy simulation results. The interpretation of data, either derived from a monitoring system or from building simulation analysis, can be difficult to handle. Combining geometrical data and energy data into a visualization interface could be a promising way to help designers and facility managers to better understand the use of different spaces, enabling a higher efficiency of building management. In this paper, an application for visualizing monitoring data or simulation results by means of Mixed Reality and BIM is presented. For the purpose, a doll's house concept (third-person observer) has been adopted as a container for the visualization of energy data in a geometrical context. Time-series based interactive diagrams, derived from monitoring system or simulation results, are integrated into geometrical holograms of buildings or parts of buildings (like floors) and they allow intuitive working. Moreover, multi-user scenarios applying cloud anchors are supported. The geometrical models are retrieved by applying Building Information Modelling (BIM).

1. Introduction

One of the main challenges in modern Building Energy Management Systems (BEMS) is related to the visualization of measurement data (Ramelan et al., 2021). Internet of Things (IoT) initiatives produce a large amount of collected data that have become difficult to handle because of the difficulties related to the interpretation of the data and moreover to their visualization before interpretation can take place. In addition, the visualization of simulation results can be difficult to interpret if not

connected directly to a geometrical context. Thus, in the area of BEMS, combining geometrical data and measurement or simulation data into one interface is a main research topic. Integrating real time collection of occupancy data, such as location and behavior, into a BIM model could help facility management (FM) to better understand the use of different spaces, enabling a higher efficiency of building management. Mixed Reality (MR) can be even more useful because it allows virtual information to be displayed in real world, making data interpretation easier. In recent literature, several works deal with new approaches for visualizing monitoring or simulation data in a more intuitive ways, mainly using BIM as a container for information (Gerrish et al., 2017; Marzouk et al., 2014; Truong et al., 2017) as well as using augmented reality (AR) and scanning a QR-code for displaying on-site sensor data (Mylonas et al., 2019). This paper proposes a new approach for visualizing energy or indoor comfort data in a geometrical context, imported from BIM, by combining a doll's house concept (third-person observer) with a real-world concept that was initially proposed in (Siegele et al., 2021). This concept does not only allow a very intuitive exploration of data, but it paves the way for a multi-user interface approach, where several users, at the same place or distributed, can explore data together on-site or off-site. Moreover, in the case of a monitoring infrastructure, by using QR-code scanning, it is possible to check the data of specific sensors on-site directly.

Mixed Reality (MR) has already been applied in different areas of building construction. Most of the time the classical approach for visualization is used: information is overlaid on real world geometry, like by (Riexinger et al., 2018) or

(Schweigkofler et al., 2018). The benefits of using MR and Augmented Reality (AR) have been proved to be efficient for supporting the most critical working phase on the building site. Indeed, this has been tested by several Horizon projects, such as BIM4EEB (BIM4EEB, 2022) and BIMplement (BIMplement Project H2020, 2022). Another interesting application of AR is for supporting the design phase, by visualizing the simulation results in a more intuitive way. (Fukuda et al., 2019) developed a new AR-based methodology for intuitively visualizing indoor thermal environment benefits leads by different renovation design alternatives, based on computational fluid dynamics simulation results. (Carneiro et al., 2019) presented an approach for guiding occupant behavior by visualizing the effects of their preferences on light distribution and energy consumption in an office space by means of virtual reality (VR).

The use of MR and AR for visualizing time-series based data in order to overcome the difficulties of handling a large amount of data derived from the IoT infrastructure has been slightly investigated. Such a concept was presented by (Jang et al., 2019), who used a time-series graph like on a screen. However, this does not allow interaction with the data. Moreover, in a multi-user scenario this approach is non-intuitive. Another concept was proposed by (Aftab et al., 2017). They overlaid shading areas or lines on the geometry (floors, walls) to visualize real-time information about the building. Today's IoT-approaches focus on single-point measurement. Another interesting approach is presented by (Dave et al., 2018). The authors developed a platform that integrates the built environment data with IoT sensors and BIM, which provides information about energy usage, occupancy and user comfort. In this context, multi-point measurement (like thermal imaging) is rarely used and only these kinds of measurements benefit from such an approach. This is likely also the reason why (Aftab et al., 2017) only presented a concept without results of a real use case. It is also very difficult from a technical point of view to reach the necessary accuracy of indoor positioning to achieve this with AR devices (Minnecci et al., 2019; Siegele et al., 2020). Other approaches, related to the different possibilities of visualizing energy efficiency

concepts by means of Virtual Reality (VR), were proposed by (Häfner et al., 2014). They used interactive charts to visualize time-series-based data. However, it was only presented in VR and the representation of the building structure was rudimentary. Applications for MR-devices (like HoloLens), are rare.

An application for studying the improvement of HVAC systems in learning factories was proposed by (Czarski et al., 2020). However, no time-series data was visualized in that context. A third-person perspective on-site was presented by (Liu et al., 2020) for visualizing data of a thermal imaging camera that measures the temperature of a façade (and thus the energy efficiency). However, this concept was not based on MR, but on AR by using a tablet.

To visualize measurement data with BIM models, several approaches are available. In the literature they are mainly defined as Digital Twins, even if usually not the complete features of a Digital Twin are proposed. The process for integrating indoor comfort data collected by a monitoring system through the application of a BIM-based model was described by (Penna et al., 2019).

The present work tries to overcome the limitations of time-series data visualization by proposing a digital multi-user interface realized by means of MR for localizing measurement data in a geometrical context, realized through BIM. Moreover, this approach also allows the visualization of the results coming from energy simulation software (i.e., IDA ICE, TRNSYS; EnergyPlus etc.). The approach shows a concept of exploring and analyzing monitoring and simulation data in an intuitive way and, at the same time, of giving the possibility to several users to visualize the data off-site and on-site.

This research is structured as follows: first, we present the adopted method by describing the software used, the proposed software architecture and the implemented features. Second, in the Results section, we describe how the application is working and what can be done with it. Consequently, in the Discussion section, we discuss the impact of our proposed software architecture. Moreover, we discuss how the software architecture can be extended and we propose how industrial standards (IFC, OpenXR) must move to provide such inter-

faces in a more general way applicable to a broader audience.

2. Materials And Methods

The application, which we developed for visualizing sensors and simulation data into a geometrical context, is based on the implementation of a proxy, which represents a data hub. An open API using REST is implemented, with which the gap between data and Mixed Reality is closed. The software architecture of our application is shown in Fig. 1.

As shown in Fig. 1, either the data derived from sensors or from energy simulation analysis are stored and saved in a time-series database. Regarding the monitoring infrastructure, we use LoRaWAN technology, because it allows the use of battery-driven sensors and it has a high coverage. In the same way, building energy simulation data can be evaluated by means of any simulation platform (i.e., Energyplus, TRNSYS, IDA ICE etc.) and results are stored in a time-series database. We used the time-series database *InfluxDB* (InfluxDB, 2022). In general, all kind of time-series databases, if they provide an API, can be used after implementing it into the proxy. We use the REST interface provided by *InfluxDB* to query the data from the database.

We use Unity (Unity Real-Time Development Platform, 2022) to develop the Mixed Reality (MR) application that is based on the Microsoft Mixed Reality Toolkit (MRTK 2.7) (MRTK-Unity Developer Documentation, 2022) and is designed by means of the OpenXR architecture (OpenXR Overview, 2022). Thus, it can also be used on other XR-compatible devices.

We get the models for different environments from BIM models by using the FBX file format, which is a proprietary file format owned by Autodesk. FBX is not a standard format when using BIM. We did not use the industrial file standard IFC, which is usually used for data exchange when working with BIM, because it has some significant disadvantages when used in a non-BIM environment like Unity. A main issue is that textures are not stored in the file, but also information on how e.g., two walls are connected, is not explicitly stored in the file. This

makes it very difficult to use the IFC file format to exchange visual information. Moreover, also the FBX format allows us to store metadata with the model.

This aspect has high relevance for visualizing monitoring data, as in the BIM model, where the unique identifiers (ID) of the sensors are stored as metadata. With this ID, a link between the model and the database is created. In this way, it is easy to assign sensor data in Unity to the corresponding geometry. The ID consists of abbreviations that include the city, the street, the street number, the building part/lot, the floor, the room, and an incremental sensor number.

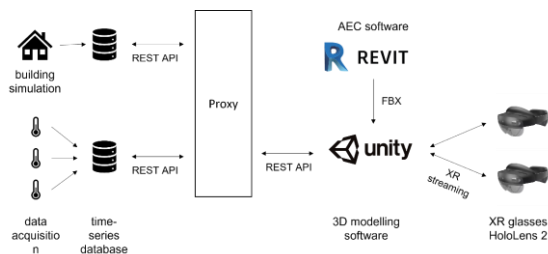


Fig. 1 – Software architecture

To catch specific data from a sensor in an on-site environment, QR-codes are used. *OpenCV for Unity* asset (OpenCv for Unity, 2022) is used to realize this feature. The QR-codes are generated from the ID introduced above.

For visualizing the time-series data in Unity we use *Asset Graph and Chart* (Graph and Chart, 2022). It enables us to visualize real-time data by adding data streams in a programmatic way.

The application itself can run stand-online on a XR-device, like the Microsoft HoloLens 2. However, for better graphics (shading) and better performance, we apply XR streaming. Multiple devices can be operated at the same time, while using the concept of persisting virtual content in the real-world. We share the actual position and orientation of the doll's house model by applying *Azure Spatial Anchors*. The position is stored in a *CosmosDB* database. On the XR device, a localization process is carried out, where the MRTK supports a coarse localization by using Wi-Fi and BLE signatures. The localization itself is realized by matching landmarks.

In the XR application several features are implemented:

Doll's house view of BIM-imported model with display of real-time data and time-series-based interactive diagram, derived from monitoring system or simulation results, as part of the hologram. In the model, values like temperature, humidity or CO₂ concentration are shown as numbers. Occupancy can be displayed with avatars.

Scanning of QR-codes in an on-site environment for reading data of a specific sensor (real-time and time-series-based diagram) and localization of the sensor in the doll's house-view of the model.

Multi-user sessions for the doll's house view for interactive sessions with several persons.

3. Results

The application is run on a Microsoft HoloLens 2 and the result of the developed XR application is shown in Fig. 2. This is the doll's house mode, where a flat within a building is visible. In each room, indoor air quality (IAQ) sensors are installed, whose real-time values can be visualized as tooltips based on the MRTK. The tooltips change their orientation and size according to the position of the viewer and allow an intuitive and clear view of the data. Occupancy can be visualized with avatars in the corresponding rooms. Not only IAQ data can be visualized, but any kind of data measured in the selected rooms or simulated by means of energy simulation software. At the moment, our concept concentrates all data measured from different sensors in one room to a single tooltip. A set of buttons allows control of the model, and the doll's houses are freely scalable and rotatable through the vertical axis. In the future, also a concept of zones will be added to visualize bigger models without dedicated rooms, i.e., shopping centers.



Fig. 2 – View of doll's house with real-time values

In Fig. 3 we show a screenshot of the XR application with a time-series-based diagram. It can be interactively controlled by using finger gestures. Sliding backwards and forwards in time is enabled by this feature. In the future, these diagrams will be enhanced by adding i.e., shading colors to visualize comfort or safety areas. E.g., the CO₂ output can be assisted by using traffic light colors to quickly identify critical rooms or zones and time ranges. co

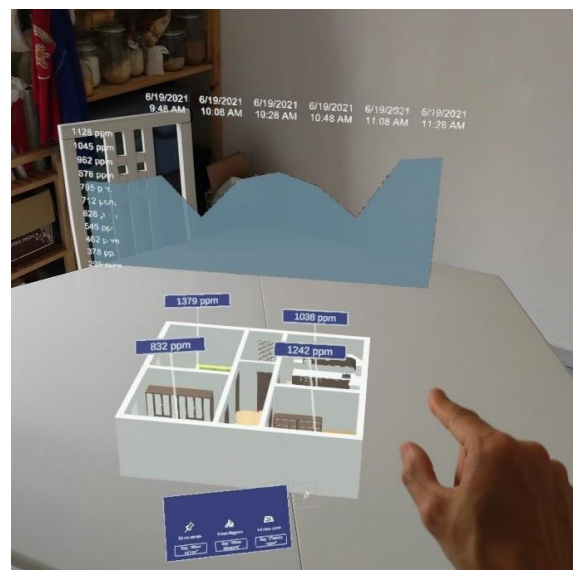


Fig. 3 – View of doll's house with time-series-based diagrams

The user can also change the building, as shown in Fig. 4, where we visualize the floor of an office building.

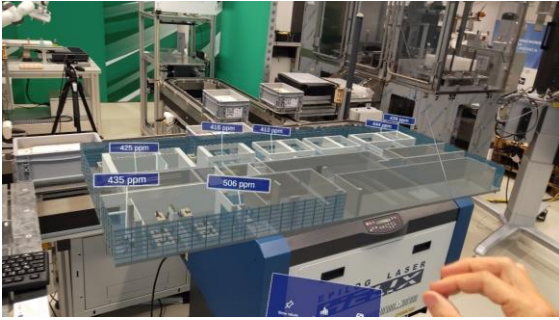


Fig. 4 – View of doll's house of a different building

When on-site, the feature of Fig. 5 can be used by a facility manager. Scanning a QR-code assigned with the ID of the sensors allows an additional hologram with the time-series based interactive diagram to appear. In addition, in the geometrical model the position of the sensor is highlighted as a tooltip, which is not visible in the figure presented. On-site orientation for the user is significantly improved by this feature. To allow free movement on-site, the hologram shown in Fig. 3 can also be detached and follows the user automatically. Moreover, an arrow always shows the position of the doll's house, if it is not in the field of view of the user.

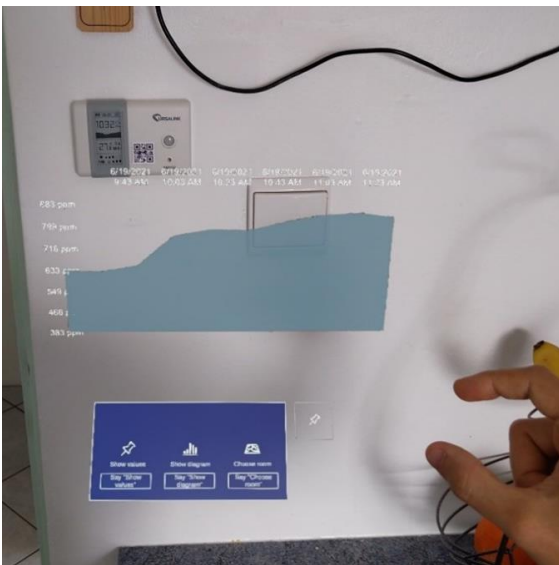


Fig. 5 – Time-series-based diagram assigned to a sensor

4. Discussion

Displaying time-based data in MR devices provides a very intuitive option of showing data in an interactive way. In the multi-user mode people can

use the application, e.g., in a workshop to discuss aspects on data collected.

By this paper we want to present the principal concept of displaying time-series-based data in MR devices. There is a need to implement several additional features before it can be tested in a real-world scenario, like in the facility management. The diagram to display data must be improved. For now, it is not possible to choose different timestep sizes or to scale the diagram on the time axis. Here, we need also to develop new ways to apply e.g., hand gestures or speech recognition for activating these advanced features. For now, it is also not possible to load a BIM model dynamically into the application. This must be done manually in Unity. It is also necessary to manually export the BIM model into the FBX file format. This aspect can be particularly problematic: developing complex interfaces, which would be necessary for these tasks, is very difficult in MR. There is, so far, no common guideline available, as to how such a task – which, using a PC and a mouse, may take a matter of minutes – can be carried out on an MR device.

Additional features for a real application should include comments and drawings. In the future, a real-time coupling with the BIM model should also be achieved. However, implementing these features requires XR streaming and a server-based software architecture.

5. Conclusion

In this paper, we presented a concept of an XR application for visualizing data in building energy management systems. Using time-series-based interactive diagrams integrated into a geometrical hologram of a zone can help to improve the usability of such applications. Using time-series-based databases allows fast querying of data, and thus provides a seamless integration into the overall experience.

In the further development, we want to get rid of the QR-codes on the sensors by implementing a BIM-based navigation algorithm for pre-positioning in combination with cloud anchors (based on landscapes) for an accurate positioning

within a room (the same approach we use for robotic applications (Follini et al., 2020)). This will allow even better immersion and usability. In addition to the time-series based diagrams, we will add additional diagram types. We want to add additional features for visualization, like better visibility of sensors with sprites and surface shading for multi-point data or simulation data. In the long term, we want to achieve a close-to-real-time import of the BIM model, where we target a server-based solution as an application on its own (automatic conversion from Revit-files or IFC to FBX or similar).

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