CIB World Building Congress 2019
Hong Kong SAR, China
17 – 21 June 2019

Smart Building Management and Design Decisions: BIM based Building Performance Monitoring

Ruwini Edirisinghe
RMIT University
(email: ruwini.edirisinghe@rmit.edu.au)
Jin Woo
RMIT University

Abstract

Post-occupancy evaluation (POE) data – quantitative physical measurements and qualitative occupants' reported perceptions – are beneficial to facility operation and management, and to future design decisions. However, the literature suggests that such data are not used effectively due to practical challenges and gaps in the research on data collection and analysis.

The original intention of Building Information Modelling (BIM) was that it be used throughout the building life-cycle, including downstream during facility management (FM). Even though BIM has enabled a paradigm shift in the architecture, engineering and construction (AEC) industry, its use in FM is still in its infancy. Little research has addressed the use of real-time sensor data to enable changes to BIM models for the benefit of facility managers. There is also a research gap in demonstrated uses of correlated POE data sets in building visualization to evidence potential improvement of workspace management, space planning, and future design decisions.

We propose a live, cloud-based system to collect and contextualize two fragmented types of POE data set. We propose to facilitate BIM as a collaborative platform for space planners, designers, and facility managers through visualization of such data using data analytics. This paper presents the prototype development process, in which wireless sensor network-based physical measurement data and mobile app-based occupant perceptions data are collected and cloud-hosted in real-time. The visualization of data is supported by a prototype game engine-based BIM model. Technological barriers to auto-updating the BIM model are yet to be resolved by the vendors.

The process described in this paper demonstrates the ability of BIM to serve as a 'single source of truth' to support post-construction building performance data. It is expected to provide a powerful and practical tool for both designers and facility managers.

Keywords: Post-occupancy evaluation (POE), Building Information Modelling (BIM), facility management (FM), smart technologies, space design

1. Introduction

A recent paradigm shift in the urban landscape towards the concept of Smart Cities has opened a new era of facility management (FM). While the essence of FM is to continually demonstrate value and optimize performance, this is particularly challenging for buildings due to their complexity compared to other infrastructure assets (Edirisinghe et al., 2013). From a financial point of view, organizations' facilities are "fixed items on their balance sheets" (Alexander, 2013), and their dexterous management will influence the business' overall profitability (Amaratunga, 2002). Organizations whose core business is offering services, such as local councils, are also increasingly interested in proactive management strategies for aging buildings stock, with the aim of delivering value-added service (Edirisinghe et al., 2013; Edirisinghe et al., 2015). For a typical facility, it is believed that more than 85 per cent of the life-cycle cost is taken up by FM (Teicholz, 2004). Lee et al. (2012) estimate that the life-cycle costs of a building could be as much as five to seven times higher than the initial investment costs. Regardless of the proportions, however, it is clear that building management plays a key role in ensuring the effective functioning of buildings.

Post-occupancy evaluation (POE) is the process of evaluating buildings in a systematic and rigorous manner sometime after construction and occupation. The evaluation is designed to find the difference between performance criteria and actual building performance, providing insights into the consequences of past design decisions. This knowledge can eventually form a sound basis for creating better buildings in the future, influencing codes, standards and design decision (Preiser et al., 1988). Although POE has typically focused on technical building performance such as HVAC (heating ventilation and air conditioning) systems or on physical indoor conditions, POE must also consider the effects of technical building performance on occupant health and comfort. A conventional POE can be conducted using either objective or subjective methods or a combination. While objective methods include physical measurements and a utility audit in a numeric format, subjective methods include occupant surveys, interviews and walk-through inspections. The current protocols use both numerous sensors and equipment to measure physical conditions, and a standardized survey to collect occupant feedback (Woo & Edirisinghe, 2018). Analysis and reporting of the current POE tools' results, however, uses a 'benchmark', a mean score, to compare the performance of individual buildings against a building-specific database. Although benchmarks can provide an overall indication of building performance, it is less realistic to use them as building diagnostic or management tools (Edirisinghe & Woo, 2018). Furthermore, research has identified the methodological shortcomings of current POE protocols: contextualizing POE results, adding instrumental data side by side with survey results, and producing feedback from surveys that is meaningful to key stakeholders (Candido et al., 2015).

The internet of things (IoT) is revolutionizing the way sensors are used to improve quality of life, public safety and the efficient utilization of scarce and expensive resources. IoT is a holistic platform, bridging the currently fragmented, but potentially precious datasets, once they have been correlated (Edirisinghe & Woo, 2018), to be used for effective building management and space planning decisions in real-time.

Building Information Modelling (BIM) has been described as a holistic system, comprising process, policy and technology, with the potential to add new dimensions to FM (Succar, 2008). The value contribution of BIM revolves around its capacity to enhance FM through increased productivity, efficiency and quality, while also offering more flexibility (Eastman et al., 2011; Becerik-Gerber et al., 2012; Volk et al., 2014; Teicholz, 2013; Yalcinkaya & Singh, 2015; Edirisinghe et al., 2016; Shen et al., 2016). The International Facility Management Association (2015) defines FM as "a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology". With the provision of not only physical, but also human and social infrastructures as integral elements, the Smart Cities paradigm places smart facility management at its heart. Thus, future facility management should undoubtedly be based not only on physical building performance but also on occupants' perceptions. With strategic and timely vision, a holistic facility management system should include real-time, context-aware POE and BIM to be ready for the next century's building management, space design and space planning needs.

2. Literature Review

2.1 Building Performance Data for Facility Management and Space Design Decisions

POE has several benefits over the short-, medium- and long-term. One of the short-term benefits of POE can be identifying successes and failures in building design and resolving any problems. Over the medium-term, it can provide evidence-based justifications for adaptive reuse, re-modelling, or major construction in order to resolve problems, such as making additions to accommodate organizations' changing space needs. Lastly, the results learned from the failures and successes of the building's performance can be applied to the design of future buildings over the long-term (Preiser et al., 1988). In addition, Zimmerman and Martin (2001) point out that the information gathered from POE has financial benefits for building owners and developers, because POE can identify areas where money has been spent without the intended effect, and thus can allow such costs to be avoided in the next design. Although the value and use of POE are well established, including the impacts of design on occupants, evaluation methods and systematic evaluations, there seems to be little evidence that this research has been transferred to practice to ensure future project performance. Despite recent evidence of willingness and desire among British architects to undertake research and evaluation in practice (Dye & Samuel, 2015; RIBA, 2014), only three per cent of these British architectural practices regularly undertakes POE on housing projects (Clark, 2015, cited in Hay et al., 2018).

Intelligent monitoring systems have been used to capture building performance data with a particular emphasis on energy use and occupant behavior. Systems such as energy management systems (EMS) and occupancy sensors have been rapidly developed thanks to ubiquitous computing, including Wi-Fi and GPS technologies (Spataru & Gillott, 2011). Indoor environmental quality (IEQ) monitoring has also been a common practice as a major part of POE and green building rating systems. A UK case study on monitoring environmental parameters, energy consumption and occupancy demonstrated a POE process, including the development of computer interface software. This computationally efficient software, by generating a series of graphs, enabled the researchers to analyze the collected data (Spataru & Gillott, 2011). However, it was only used to process quantitative data in this case study. More recently, application of BIM to building design and operation has been explored in-depth, demonstrated by an exponential growth in publication on the topic of BIM and building performance. Although research has identified building performance assessment as a target of BIM application (Yalcinkaya & Singh, 2015), when it comes to its application to building performance management, this seems to have been limited to ensuring effective handover of information suitable for facilities management use. However, accessibility of information does not necessarily mean that that information is utilized (Gerrish et al., 2017). Furthermore, researchers have demonstrated the potential of BIM to reduce the gap between predicted and actual building performance, while also suggesting the need for more effective data management to support it (Dong et al., 2014).

2.2 BIM-based Building Performance Data for Facility Management and Space Design Decisions

The original intension of BIM was that it be used throughout the life-cycle of the building, including downstream in FM. Even though BIM has enabled a paradigm shift in the architectural, engineering and construction (AEC) industry, slow adoption of BIM in FM by owners reported globally indicates that its use in FM is still in its infancy (Shen et al., 2016, Akcamete et al. 2010, Edirisinghe et al.

2017). Evidence suggests that facility management personnel are unaware of the requirements for BIM use (Shen et al., 2016, Edirisinghe et al., 2016). It appears that slow adoption in the industry is also due to a lack of demonstrative case studies (Edirisinghe et al., 2017).

BIM-based approaches have been introduced in pre-occupancy evaluation (Shen et al., 2012) with the aim of enhancing building performance as well as of improving communication between designers and clients during the design and construction stage. Sensor data can be used to gather and utilize data during operation in order to operate and maintain buildings more effectively (Motawaa & Carter, 2013), and to provide a tool to generate and manage building performance data – BIM can serve as a single source of post construction data. Little research has addressed the use of real-time sensor data to enable automated/semi-automated changes to BIM models for the benefit of facility managers. Mccaffrey et al. (2015) developed a web-based temperature sensor data visualization of the building model by rendering the model in a web browser. This approach required significant manual simplification of the geometry. Lather et al. (2017) transferred space geometry according to open standards through semi-automated process, though sensor data were transferred manually to the model. Also, little research has demonstrated the use of real-time occupancy evaluation data to enable automatic model changes as a use case for facility managers. Shen et al. (2012) proposed simulating user activity for building performance evaluation in a BIM model at early architectural design stage to enhance interaction between the designers and users. This pre-occupancy evaluation captures users' requirements and feedback in the model, using avatars to represent users. Recently, Daher et al. (2018) presented a prototype that integrates POE data from building occupants into the parametric model. Despite the inconvenience of the manual POE data transfer process, the POE data are successfully transferred into the parametric model for reconfiguring new space layouts.

Building management data are spatio-temporal (Lather et al. 2017), and innovative visual representation and multi-dimensional analysis of such spatio-temporal data in real-time is critical for efficient building management. There is a clear paucity of research on the subject of a holistic system capturing real-time building performance data and occupants' evaluation data that feeds in to the BIM model. Such a system has the potential to improve future design/space planning decisions.

3. Methodology

An ongoing project aims to contribute to the future of smart facility management by filling the research and practice gaps mentioned above. The objectives of the project are: (i) to develop an IoT-based live platform that captures building performance (both physical measurements and occupants' perceptions) and visualizes the cloud data in the BIM model; (ii) to systematically correlate both quantitative and qualitative building performance data and validate the survey for repeated use; and (iii) to develop a visualization-based, context-aware intelligent decision and reporting mechanism for proactive decision making to assist facility managers, as well as designers, in real-time. This system architecture is shown in Figure 1.

IoT based live platform developed to capture real-time building performance data was reported in Edirisinghe & Woo, (2018). The data capture module of the system captures building performance data in real-time through a wireless sensor network and POE mobile app. The wireless sensor network collects physical measurements (quantitative data) and the mobile app collects data on occupants' perceptions (qualitative data). Both components are cloud–connected, and update the data repository in real time. The web server used in this project is Amazon Web Server (AWS). The pilot data collection was conducted in a university lecture theatre during a class and followed by an immediate data visualisation together with a preliminary evaluation. The pilot data collection, preliminary evaluation and real-time reporting were presented in Woo and Edirisinghe (2018). A summary of the real-time data capture module is given below.

This paper, as a further development of the ongoing project, presents the game engine-based interactive prototype developed to visualize sensor data and occupancy evaluation data in the BIM model. The BIM based building performance monitoring will contribute to optimizing building performance from an immediate day-to-day operation to future building design decisions through the multi-dimensional real-time data collection and analysis.

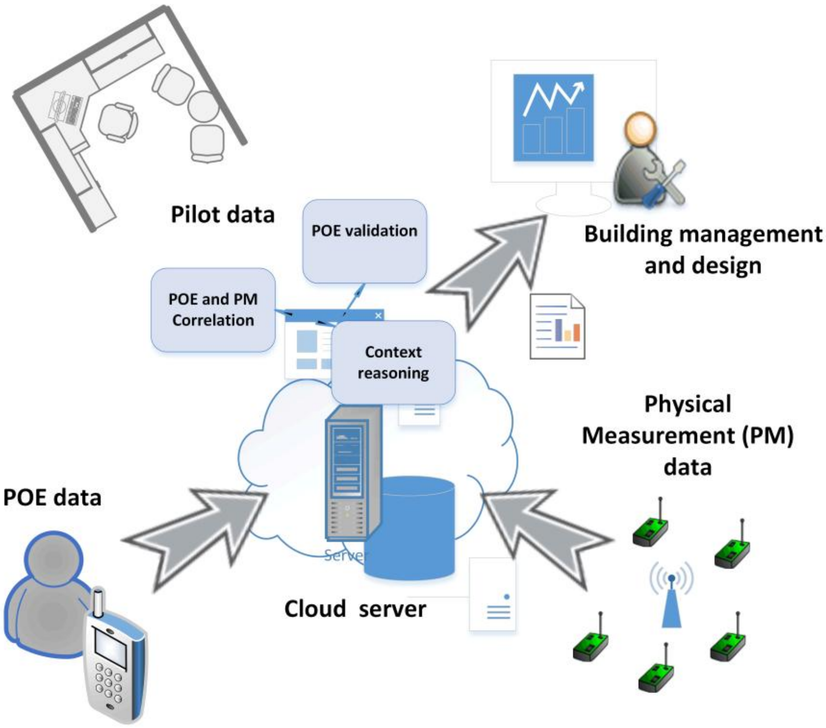
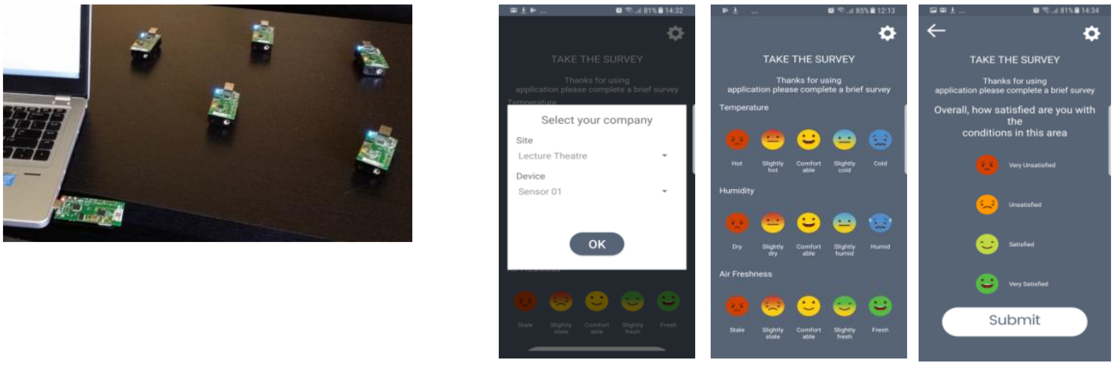


Figure 1: System architecture (Edirisinghe & Woo, 2018)

3.1 Real-time data Capture

A data capture system was developed to explore 3D visualization of sensor data and occupants' perception data. The wireless mesh network consists of six TelosB sensors which capture temperature and humidity data. The network updates the cloud server every five seconds. Occupant perception data (location-tagged through sensor IDs) are captured using the app. The survey in the smart phone app captures indoor environment quality parameters such as temperature, humidity, air freshness and overall satisfaction about the space (Edirisinghe & Woo, 2018). Both Android and iOS versions were available. Building occupants enter data through their personal phones or using a wall-mounted tablet in the relevant space/room. The time-stamped data sent to the Amazon Web Server from both the sensor network and the app are stored in the cloud database.



(a) Sensor network *(b) Mobile app GUI*

Figure 2: Sensor network and mobile app GUI (Edirisinghe & Woo, 2018)

4. Game engine model

A video-game engine environment was chosen for the development for a number of reasons, including: (i) to motivate prompt and direct involvement of end-users; (ii) to make the prototype development process more efficient (quick mock-up and ease of adding interactive elements to rendered model content); and (iii) to promote game engine-based BIM technologies in FM, because the original intention of BIM was that it be used throughout the building life-cycle. Such technologies have been trialed widely in the AEC sector, but the adoption rate in FM remains low. The model was created with Unity, version 2017.1.3, and default components and animations are used. Two separate camera views, overall horizontal view and first-person view, are used. The model user is referred to as "user" and the building user is referred to as "occupant" in the paper.

Game engine model import: The first step in the prototype development process was to import the building information model from the open IFC standard using off-the-shelf modeling software. A Revit model of a sample building went through an intermediate conversion step before being imported to the Unity game engine. This was to make sure that all materials were converted to standard materials and to re-scale the geometry, because non-uniform scale causes rotation and deformation issues with linked geometry. The model was exported out of Revit in FBX format and imported to 3dsMax to modify the settings prior to its final export to Unity.

Multi-dimensional data representation: The game engine model was designed to be able to visualize physical sensor measurements (represented in the color of rooms' walls) separately from occupants' feedback (with their feelings represented by an emoticon). The sensors collect two parameters, temperature and humidity. An additional parameter called "heat index" was also introduced, derived from the two sensor parameters collected. The heat index values are stored in the webserver as a matrix, and the corresponding index is generated for temperature and humidity values. The sample matrix used for the heat index is shown in Figure 3, below. Ranges of values are represented using colors. The user can assign custom colors to the parameter ranges/thresholds when configuring the model. The model is loaded with default colors for walls and feelings.

Sensor data representation: The sensors are placed in the functional areas/rooms of the building, hence sensor data changes are represented by changing the color of the corresponding room. Once the FBX model was imported to Unity, 3D representations of the sensor zones were created, each linked to relevant sensor data. A mesh was created surrounding the relevant area of the model to set up color changes according on the basis of sensor readings.

POE data representation: The occupants are represented using avatars. The avatar carries a feeling (a simple cube) above the head corresponding to the overall satisfaction face texture (emoticon) in the occupants IEQ mobile app (see Figure 2, above). All the avatars reside inside the mesh surrounding a room; are assigned a tag, so that the corresponding occupant feedback color is assigned once the data is received from the occupants' feedback app. When the occupant moves from one room to another, the feedback data from the app/device (in the new room) is picked. The system links the app (wall mounted tablet based) with the physical space through the sensor ID of room. Humanoid moves were achieved using a combination of standard human animations (from Unity Standard Assets).

Data feed interface: An intermediate web-based data feed interface was developed by implementing database APIs for two reasons. Firstly, the limited ability of real-time sensor data to visualize model changes: indoor conditions are normally regulated. The sensor set-up captured a regulated average temperature of 22^{o}C and relative humidity of 51 per cent. In order to represent model changes across a range of values, the sensor values had to be changed manually to cover a range. The second reason was for the web-based data feed interface was internal testing. The model developed iteratively, with thorough testing conducted prior to linking with the production environment. Figure 4, below, illustrates the data feed interface linked with the web-server which feeds the data to the Unity model.

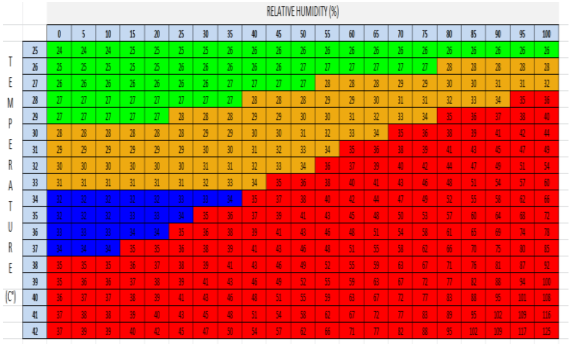


Figure 3: Heat Index

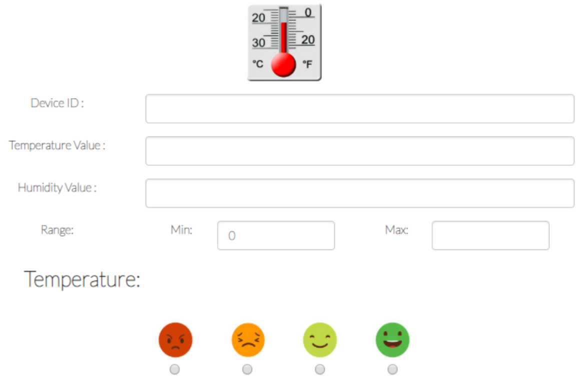


Figure 4: Data feed interface

5. Prototype Results

Users can configure the model's parameter ranges and legend colors as shown in Figure 5, below. For example, the default model configurations for indoor temperate settings are: 15℃–19℃ to represent "too cold" in green; 20℃–26℃ to represent "warm" in yellow; 27℃–30℃ to represent "hot" in red; and 30℃–40℃ to represent "too hot" in black. The humidity and heat index ranges and representative colors can be independently configured in a similar way.

Upon entering the system, user can select the physical performance model parameter (temperature, humidity or heat index) as shown in Figure 6, below. The model generates data according to user selection and pre-set legend configurations.

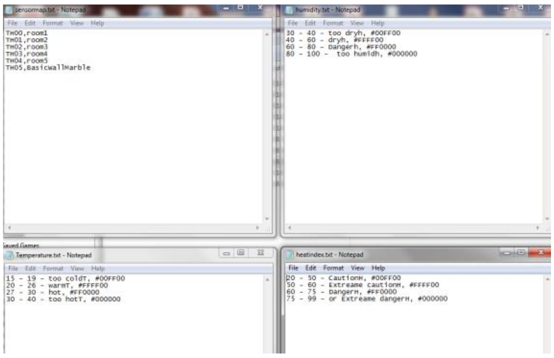


Figure 5: Model configuration settings

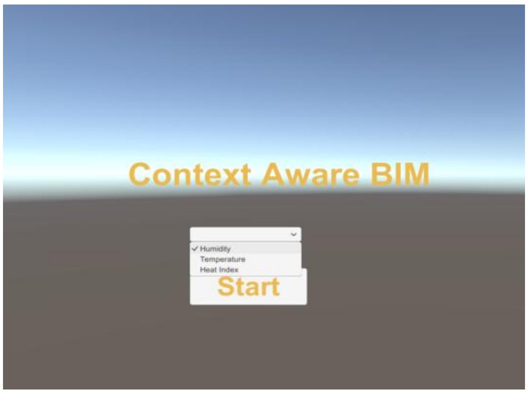


Figure 6: Model parameter selection

Figure 7, below, illustrates the default model (without real-time data), when the user selects temperature as the model parameter. The walls are colored grey, and no feelings are displayed for the avatars.

Figures 8–10, below, illustrate real-time data visualization in the model. When the data are received in real-time from sensors attached in the various rooms, the wall colors in the BIM parametric model represent corresponding indoor temperature values, as shown in Figure 8, below. Figure 9 shows how the game engine model visualizes actual occupants' feedback coming from the app through the avatars' feelings. As shown in Figure 10, once the occupant changes location (through humaroid animations discussed above), the corresponding avatar's feelings are changing according to the data coming from the smart device (tablet) mounted in the physical location/room in which the avatar is now situated.

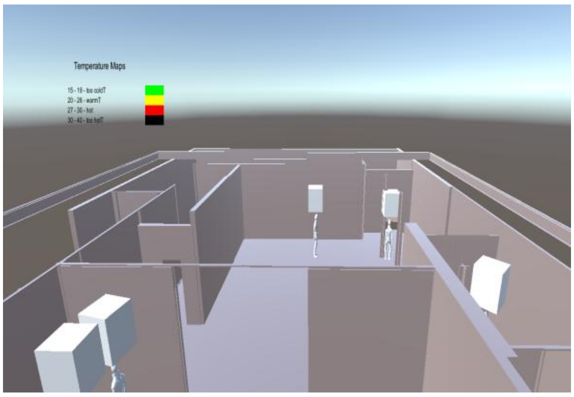


Figure 7: Model loaded with default settings

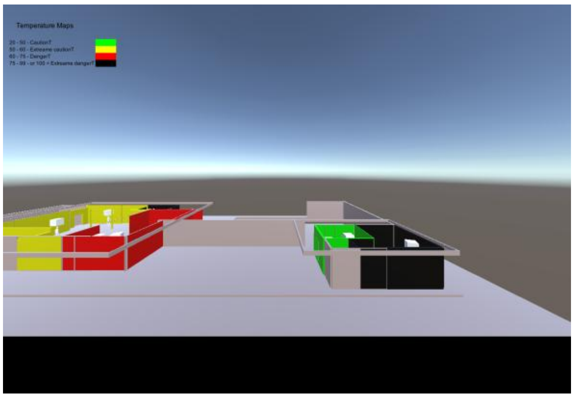


Figure 8: Sensor data representation

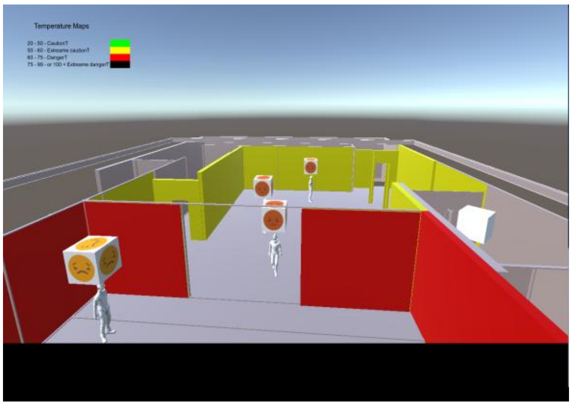


Figure 9: Occupant perception data

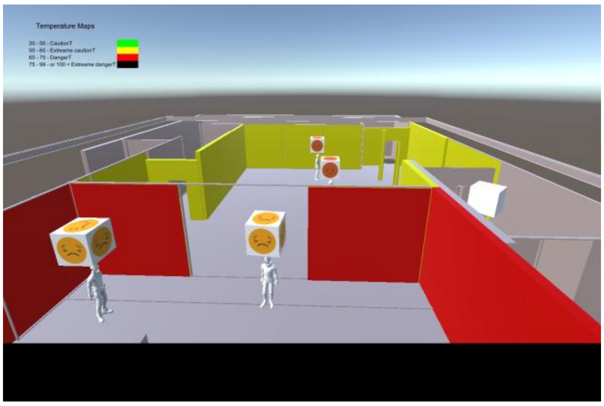


Figure 10: Occupant movement

6. Discussion and Conclusions

The prototype demonstrated a possible solution for visualizing building performance data, both physical sensor measurements and occupancy evaluation, in real-time in an interactive gaming environment. Incompatibility of some of the software tools (e.g., Revit and Unity) required some semi-automated intermediate steps. As Mccaffrey et al. (2015) noted, this intermediate step was required in larger projects with complex geometry. With the maturity of technology, and market demand, this step can likely be fully automated.

Development of the model to enable temporal data is ongoing. The historical graphical representation of data will be a feature added to the model in the future. This is expected to provide details over the short-, medium- or long-term, providing useful insights about how well buildings perform. Adding network functionality to the game engine-based model is another desirable extension. This will allow the Unity server to load FBX models and convert them into our custom format (Edwards et al., 2015) which buffers at the network layer for incoming clients to load. In this way, multiple users, such as facility managers and workspace designers, will be able to access the model concurrently. At present, occupants' behaviors are simulated in the model. Accurate mapping of user behavior in the BIM model by integrating IoT-based user tracking technologies is another future extension currently undergoing trial and development of behavior modeling algorithms (McGinley & Fong, 2015).

This concept has the potential to enable a step change in building management practice by assisting facility management decisions and providing feedback on workplace preferences and space needs to designers. This paper also demonstrates the ability of the BIM model to link the currently fragmented disciplines of FM and design, and to serve as a single source of truth.

References

Becerik-Gerber, B., Jazizadeh, F., Li, N. & Calis, G. (2012), "Application areas and data requirements or BIM-enabled facilities management", Journal of Construction Engineering and Management, Vol. 138 No. 3, pp. 431-442.

Candido, C., Kim, J., De Dear, R. & Thomas, L. (2015) BOSSA: a multidimensional post-occupancy evaluation tool, *Building Research & Information*, 44(2), pp.1-16

Clark, T. (2015, February 13). AJ housing survey: Post-occupancy not on architects' radar. Architects' Journal. Retrieved from https://www.architectsjournal.co.uk/home/aj-housing-survey-post-occupancy-not-on-architects-radar/8678486.article

Daher, E., Kubicki, S. & Guerriero, A. Post-occupancy Evaluation Parameters in Multi-objective Optimization–Based Design Process (2018) proceedings of CIB W078 IT in Construction, Chicago, USA, 1-3 October 2018.pp 463-470.

Dong, B., Neill, Z. & Li, Z. (2014) A BIM-enabled information infrastructure for building energy Fault Detection and Diagnostics, *Automation in Construction*, 44, pp.197-211

Dye, A. & Samuel, F. (2015) *Demystifying architectural research: Adding value to your practice*. London: RIBA Publishing.

Eastman, C., Teicholz, P., Sacks, R. & Liston, K. (2011), BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, John Wiley & Sons, Hoboken, NJ.

Edirisinghe, R., London, K. A., Kalutara, P., & Aranda-Mena, G. (2017). Building information modelling for facility management: are we there yet?. Engineering, Construction and Architectural Management, 24(6), 1119-1154.

Edirisinghe, R., Setunge, S., & Zhang, G. (2013). Application of gamma process for building deterioration prediction. Journal of Performance of Constructed Facilities, 27(6), 763-773.

Edirisinghe, R., Setunge, S., & Zhang, G. (2015). Markov model based building deterioration prediction and ISO factor analysis for building management. Journal of Management in Engineering, 31(6), 04015009.

Edirisinghe, R., London, K. & Kalutara, P. (2016), "An investigation of BIM adoption of owners and facility managers in Australia: institutional case study", The RICS Annual Construction and Building Research Conference (COBRA 2015), Toronto, 19-22 September.

Edirisinghe R. & Woo, J. (2018) Drive towards real-time reasoning of building performance: Development of a live, cloud-based system, in the proceedings of CIB W078 IT in Construction, Chicago, USA, 1-3 October 2018.

Edwards, G., Li, H., & Wang, B. (2015). BIM based collaborative and interactive design process using computer game engine for general end-users. *Visualization in Engineering*, *3*(1), 4.

Gerrish, T., Ruikar, K., Cook, M., Johnson, M., Phillip, M. & Lowry, C. (2017) BIM application to building energy performance visualisation and management: Challenges and potential, *Energy & Buildings*, 144, pp.218-228

Hay, R., Samuel, F., Watson, K. J. & Bradbury, S. (2018) Post-occupancy evaluation in architecture: experiences and perspectives from UK practice, *Building Research & Information*, 46(6), pp.698-710

International Facility Management Association (2015), "What is Facility Management?", available at:www.ifma.org/about/what-is-facility-management (accessed September 2015).

Lee, S.K., An, H.K. & Yu, J.H. (2012), "An extension of the technology acceptance model for BIM-based FM", Proceedings of the Construction Research Congress: Construction Challenges in a Flat World, ASCE, pp. 602-611.

Lather, J. I., Amor, R., & Messner, J. I. (2017). A Case Study in Data Visualization for Linked Building Information Model and Building Management System Data. In *Computing in Civil Engineering 2017* (pp. 228-235).

MCCAFFREY, R., Coakley, D., Keane, M., & Melvin, H. (2015). Development of a Web-based BMS Data Visualisation Platform Using Building Information Models. In *CIBSE 2015 Technical Symposium*.

McGinley, T., & Fong, D. (2015). Mapping occupant behaviour in BIM. In *Proceedings of the 20th International Conference of the Emerging Experience in Past, Present and Future of Digital Architecture* (pp. 365-374).

Preiser, W.F.E., Rabinowiz, H.Z. & White, E.T. (1988) *Post-occupancy evaluation*, Van Nostrand Reinhold Company Inc., New York.

RIBA (2014) How architects use research. Retrieved from https://www.architecture.com/-/media/gathercontent/how-architects-use-research/additional-documents/howarchitectsuseresearch2014pdf.pdf

Shen, L., Edirisinghe, R. & Yang, M.G. (2016), "An investigation of BIM readiness of owners and acility managers in Singapore: institutional case study", Proceedings of CIB World Building Congress, Tampere, 30 May-3 June.

Shen, W., Shen, Q., & Sun, Q. (2012). Building Information Modeling-based user activity simulation and evaluation method for improving designer–user communications. *Automation in Construction*, *21*, 148-160.

Spataru, C. & Gillott, M. (2011) The use of intelligent systems for monitoring energy use and occupancy in existing homes, *Intelligent Buildings International*, 3(1), pp.24-31.

Succar, B. (2008), "Building information modelling framework: a research and delivery foundation for industry stakeholders", Automation in Construction, Vol. 18 No. 2009, pp. 357-375.

Teicholz, E. (2004), "Bridging the AEC/FM technology gap", Journal of Facilities Management,p.2.

Volk, R., Stengel, J. & Schultmann, F. (2014), "Building information modeling (BIM) for existing buildings literature review and future needs", Automation in Construction,Vol.38, pp. 109-127.

Woo, J. & Edirisinghe R. (2018) 'Enhancing students' experience in real-time data collection and utilisation: A cloud-based post-occupancy evaluation app', *Engaging Architectural Science: Meeting the Challenges of Higher Density: 52nd International Conference of the Architectural Science Association 2018*, Melbourne, Australia, 28 Nov – 1 Dec 2018.

Yalcinkaya, M. & Singh, V. (2015) Patterns and trends in Building Information Modeling (BIM) research: A Latent Semantic Analysis, *Automation in Construction*, 59, pp.68-80

Yalcinkaya, M. & Singh, V. (2015), Building Information Modeling (BIM) for Facilities Management Literature Review and Future Needs Product Lifecycle Management for a Global Market, Springer, Berlin and Heidelberg, pp. 1-10.

Zimmerman, A. & Martin, M. (2001) Post-occupancy evaluation: benefits and barriers, *Building Research & Information*, 29(2), pp.168-174.