

PAPER • OPEN ACCESS

Smart BIM-AM Journey to Green Buildings

To cite this article: C K Lee *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **290** 012050

View the [article online](#) for updates and enhancements.

Smart BIM-AM Journey to Green Buildings

C K Lee¹, H Y S Chan¹, C Y C Poon¹, K M G Yip¹ and P H F Yuen¹

¹Electrical and Mechanical Services Department, The Government of HKSAR, 3 Kai Shing Street, Kowloon Bay, Kowloon, Hong Kong, China

cklee@emsd.gov.hk

Abstract. Building Information Modelling (BIM) has been widely adopted for buildings design and construction to facilitate coordination works, however, there are a few studies of its application in the long lifecycle of buildings operation and maintenance (O&M). An integrated BIM – Asset Management (BIM-AM) System which enables visual cross-reference from real-world objects to BIM model and even to their maintenance record, O&M manuals, asset relationships, live views of Closed Circuit Television (CCTV) system, real-time data from Building Management System (BMS) and wireless Internet of Things (IoT) sensors as well as location information from a Real Time Location System (RTLS) on one single integrated mobile platform with the aid of Radio Frequency Identification (RFID) scanning technology has been developed. While the BIM-AM System has been proven its novelty, originality, capability and potential towards smart O&M by the patent granted in 2017, BIM can be further developed in green building aspects with the application of Computational Fluid Dynamic (CFD). Different sets of boundary conditions, including supply air temperature, supply air flow, number of people and so on, were simulated for comfort level. A predictive model was formulated to achieve an intelligent control of air-conditioning system, including supply air temperature reset and adjustment of supply and/or fresh air flow, with the balance of human comfort.

1. Introduction

In recent years, BIM, a digital model and process supporting the representation of building elements in terms of their geometric and functional attributes as well as their inter-object relationships, has rapidly emerged in architecture, engineering and construction industry to facilitate early coordination among different disciplines, leading to significant shrink of construction schedules and project costs. However, the approach of adopting BIM for building asset management is yet to be investigated. Whilst there are many research studies and real-world applications of adopting BIM in facility management (FM) / asset management (AM), most of them focus on data population from BIM to FM/AM software [1,2,3,4] either by proprietary add-ins, open BIM standard in IFC format [5], spreadsheets or XML files [4,6,7]. Albeit that there are researches involving information exchange between BIM and FM/AM system with BMS integrated [8] and integrating RFID technology with BIM [9], they are in essence not considered as full and seamless integration among BIM, FM/AM software and multiple O&M systems in terms of their integration diversity and extent. This paper aims to show that, by leveraging BIM in facilitating effective information exchange, a novel framework exploiting BIM in integrating AM and a variety of O&M systems/tools has been successfully implemented. This System has been piloted in our headquarters building to evaluate its O&M effectiveness. The BIM-AM System features multiple O&M



tools in a single integrated application, offering real-time O&M information sharing and exchange capabilities, thus making system handover and O&M much more efficient and effective.

2. Integrated BIM-AM System

2.1. System framework

As far as our knowledge goes, full and seamless integration of BIM with an AM system as well as a variety of O&M systems/tools including BMS, CCTV system, RFID scanning tool, and RTLS has not been realized. Figure 1 depicts the proposed system framework in which the dotted line indicates the integration that may have been implemented in some other FM/AM software applications whereas the solid line indicates the full and seamless integration that was first implemented by us in 2014.

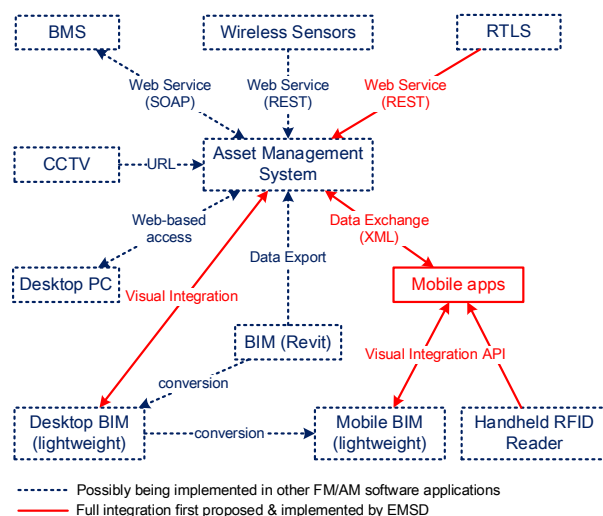


Figure 1. The novel framework for BIM-AM System

Under this framework, AM system is considered as an O&M application for building asset management, preventive and corrective maintenance management. One of the most distinctive differences is that the AM system in the proposed framework serves as a middleware to integrate/interface with other systems/tools whereas other research works take BIM as a middleware for information exchange with other systems/tools, thus increasing the integration complexity. This is because direct integrations between BIM and other systems/tools would result in high complexities in the Application Programming Interface (API) developments on BIM software and the systems/tools. Moreover, BIM cannot replace the role of AM system in storing and upkeeping AM-related information as well as performing other comprehensive AM features. Another distinctive difference between the proposed works and other researches is that the visual integration developed between BIM and AM system is in a seamless and intuitive manner, in the sense that the BIM-AM System allows locating and visualising any particular asset with its real-time asset information by maneuvering freely in the BIM model in one single integrated system, instead of mere data exchange between BIM and AM system.

2.2. Visually intuitive cross-reference among real-world, BIM model, and static asset information

2.2.1. Cross-reference between asset and BIM model. The BIM-AM System enables visually intuitive cross-reference of real-world objects to BIM model and even to asset attributes, maintenance records, asset relationships, system topologies, manuals and system drawings at a mobile terminal.

As shown in Figure 2, a VAV box can be visualised and quickly located in its approximate real-world physical location, enabling easy cross-reference to a BIM model for pre-diagnosis. System topology generation was purposely developed to visualise the asset relationships within a particular system for further cross-referencing among assets information. Figure 3 shows a graphical view of the asset relationships of a VAV box within the overall system. A logical parent-child relationship is

represented by a “dependent” arrow pointing from a parent asset to its child asset whereas a logical associated relationship is represented by an “associated” arrow pointing from an asset to its associated asset, indicating that an asset relates to its associated asset but has no dependence of it. The system topology is found useful and effective for fault locating.

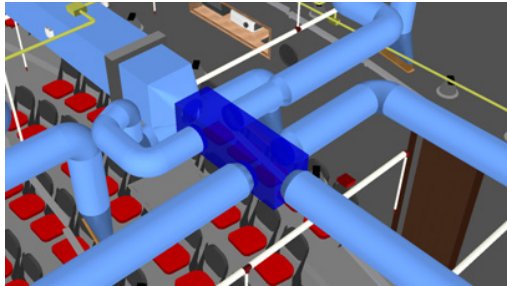


Figure 2. A VAV box in a BIM model

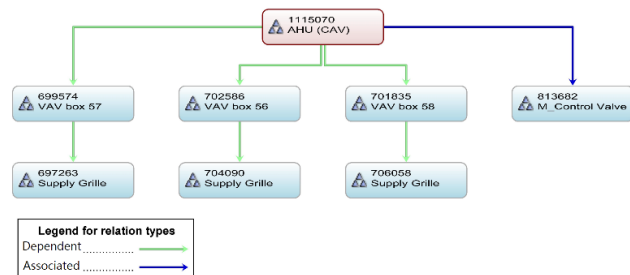


Figure 3. System topology of a VAV box

2.2.2. Standardised asset templates for Mechanical, Electrical, and Plumbing installations. A number of BIM-AM asset templates for Mechanical, Electrical, and Plumbing (MEP) installations have been established by our organisation. Apart from typical system specific attributes, the standardised asset templates also contain the information of asset relationship, wireless tag ID and geometric related attributes for system topology generation, RFID/RTLS application, and BIM visualisation respectively.

2.3. Integrating with BMS, fixed CCTV system, wireless IoT, RFID, and RTLS

Integrating BIM-AM System with BMS and fixed CCTV system for accessing real-time remote site information with control functions at a mobile terminal could facilitate efficient offsite pre-diagnosis and possible rectification. Based on the pre-diagnosis, maintenance engineer would be able to bring necessary tools / spare parts to the site in one go. Moreover, wireless IoT sensors over WiFi, Bluetooth, and cellular networks, such as temperature sensor, humidity sensor, power meter, and wireless camera, were developed for prompt installation and monitoring. These sensors are considered useful in incident handling, condition monitoring, generation of pre-fault alerts, or energy management. In this pilot, web services have been employed for the data communication from BMS and wireless sensors to the AM system and vice versa. Having integrated the mobile terminal platform of BIM-AM System with a handheld RFID scanning tool, maintenance engineer could efficiently and effectively locate critical equipment for further enquiry of asset information even if the equipment is hidden above a false ceiling or underneath a raised floor. To extend the locating feature from fixed assets to movable assets such as working platform and biomedical equipment, RTLS over WiFi and Ultra-Wide-Band technologies were piloted. The latter was adopted and installed due to higher positioning accuracy. The user interface for the maintenance engineer provides readily accessible asset information, such as asset attributes, maintenance record, system topology, manual, and system drawing as well as creating service request and cross-referencing to BIM model. Additionally, the System can timely notify users to fill in an electronic pre-work safety check form such that the safety compliance can be easily achieved.

3. Demonstration, BIM-AM Standards and Guidelines, and Pilots

Simulated maintenance showcases using an AHU model, a fire sprinkler system model, an emergency lighting model, and a general lighting model in the BIM-AM System were recorded in videos for demonstration purpose [10]. The results demonstrate that the BIM-AM System can improve productivity in fault response, workflow management, safety compliance, retrieval and appending of maintenance record, access of asset details, relationships and manuals, etc. The benefits of the BIM-AM System differ according to venues and applications. One of the key benefits worth mentioning is that the integrated system can enable O&M staff to respond faster to incidents and emergencies, especially at mission critical venues such as hospitals and airports.

To ensure the smooth handover of BIM deliverables from construction stage to operation stage, a BIM-AM Standards and Guidelines, aiming at providing BIM modelling standard, coding standard and information requirement for electrical and mechanical systems and assets at handover stage for building operation and conforming to our BIM-AM System, was established [11]. Since the first version of our BIM-AM standards and guidelines launched in Nov 2017, it was reviewed based on the outcomes of several pilot projects to ensure its practicality for smooth handover of the as-built BIM-AM model of existing buildings. The comments from the trade have been incorporated in the new version. Version 2 of the Standards and Guidelines was officially released in Jan 2019. To evaluate the practicality of the BIM-AM System and the Standards and Guidelines established, several pilot projects (including a new government office building, our existing headquarters building, and two hospitals) have been selected to build the full BIM models for asset management purpose. Furthermore, with a view to raising the awareness and facilitating hands-on BIM-AM training for the trade and industry, the implementation of BIM-AM for Zero Carbon Building in Hong Kong is being carried out.

In addition, a room-sized immersive Cave Automatic Virtual Environment (CAVE) was established in our headquarters building for viewing BIM models via a lifelike visual display. With the immersive CAVE system, multiple staff are able to interact concurrently with BIM models and communicate in a more efficient and effective way. Also, the CAVE system serves as innovation training platform for internal staff to carry out walkthrough and manoeuvre BIM models from different perspectives with enhanced flexibility.

4. Benefits of adopting the integrated BIM-AM System

A novel system framework exploiting BIM in asset management has been proposed and the concept has been realized in an integrated BIM-AM System featuring multiple O&M systems/tools in one single platform. A graphical summary of the System features is exhibited in Figure 4.

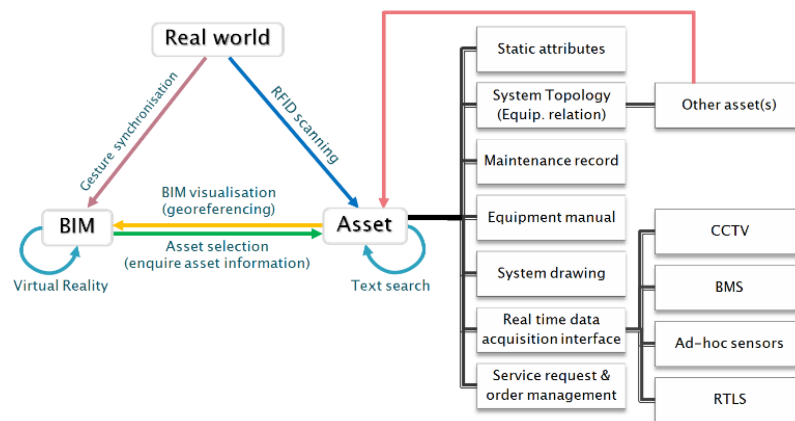


Figure 4. A graphical summary of BIM-AM System features

The integrated platform has proved effective in streamlining workflow, facilitating responsive incident handling and sustainable asset management. The tool has great potential to bring major benefits including long-term cost savings in the O&M building lifecycle. Though the successes arising from the framework and pilot BIM-AM System are only on a limited scale, it is envisaged the integrated BIM-AM System would not only benefit the services in operating and maintaining about 5,800 government buildings, but also encourage and facilitate the construction industry in Hong Kong to better deploy this new technology for smart building O&M services, ultimately benefitting the public.

5. BIM Application for Post Occupancy Evaluation and Optimized Control

BIM can be further developed in green building aspects with the application of building energy simulation tools. A preliminary study on the BIM application with the aids of CFD was carried out. CFD was used to evaluate the indoor thermal comfort based on the spatial data from BIM (e.g., space geometry and construction materials) and operational data from the on-site BMS (e.g., supply air temperature set points).

Various boundary conditions and the corresponding Predictive Mean Vote (PMV) of the concerned space were simulated. The simulated data set was then extracted to develop a regression model to mimic the correlation between the input variables (i.e., outside air condition and the supply air temperature) and the resultant PMV for optimized Heating, Ventilation, and Air Conditioning (HVAC) control.

5.1. Thermal Comfort Analysis

To evaluate the thermal comfort, six parameters have to be measured, including air temperature, mean radiant temperature, air velocity, water vapour pressure, occupants' metabolic rate and the thermal resistance of clothing [12, 13]. However, in reality, it is a challenge to measure all the parameters, thus building energy simulation software (i.e., IES VE) was adopted to calculate the values of some of the input parameters, such as the radiant temperature. CFD simulation for thermal analysis in this study was based on two sources of boundary conditions which were (i) spatial thermal conditions exported from the building energy simulation model and (ii) the operational data of supply air grilles recorded in on-site BMS. A multipurpose hall with maximum capacity of 150 occupants was selected to evaluate the performance of HVAC system in respect to the thermal comfort level in summer season. Figures 5 and 6 illustrate the floor plan and the geometry of the multipurpose hall.

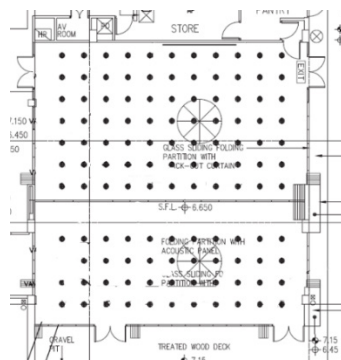


Figure 5. Floor plan of multipurpose hall

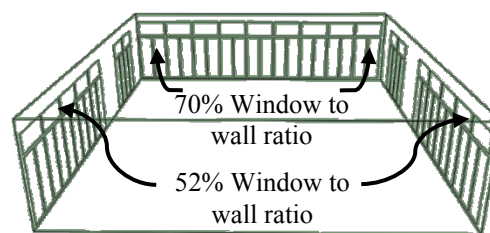


Figure 6. Geometry of multipurpose hall

5.2. Methodology

5.2.1. BIM application for building energy simulation. The building geometry of a BIM model can be exported to green building Extensible Markup Language (gbXML) file for performance analysis in simulation tools. Prior to the export, it is important to develop the BIM model with proper assignment of rooms, thermal zones and construction properties to streamline the data exchange between BIM and the BIM-based energy simulation models [14]. The hourly spatial cooling demand together with the thermal data were simulated based on the weather file. Boundary conditions of the spatial environment, e.g., wall/floor/ceiling surface temperature, and internal heat gain etc., were then exported for the next step of thermal comfort analysis.

5.2.2. CFD application for thermal comfort analysis. Analysis of air flow was conducted by numerical algorithm in CFD in which the indoor air flow pattern, velocity, air change, heat transfer and contaminant transport (i.e., CO₂) were simulated according to the selected boundary conditions [15]. Thermal sensation by means of PMV under various scenarios was evaluated. The settings of boundary conditions for CFD model are summarised as follows.

- The surface temperature and heat flux inside the multipurpose hall were exported from the result of building energy simulation as mentioned in Section 5.2.1.
- Set-point air temperature and flow rate of supply air diffusers were collected from the BMS.

- The actual operational data of supply air diffusers were also collected for analysis, because the on-site temperature sensors reveal that the system currently operates beyond the set points.
- Occupant's metabolic rate and clothing level were set at 58.2 (i.e., seated at rest) and 0.5 (i.e., summer clothing) respectively.
- Indoor relative humidity was controlled at the maximum of 65%.

11 scenarios were strategically selected for thermal comfort evaluation. Scenarios 1 and 2 were under the same design conditions, i.e., the peak cooling demand on 26 July at 16:30, whilst the supply air temperature is different with 18°C (i.e., the system set point) for Scenario 1 and 22°C (i.e., the actual operational data in BMS) for Scenario 2. The PMV contour plot for Scenario 1 is shown in Figure 7. All the PMV values inside the entire multipurpose hall present negative with a range of -1.9 to -0.2 that represents the space is cool to slightly cool. Occupants experienced discomfort when they were located right above the floor diffusers. With the capability of tracing particles movement by CFD, the spatial CO₂ concentration was also explored. Figure 8 illustrates the containment removal with average CO₂ concentration around 970 ppm, which is regarded as “good class” of indoor air quality (IAQ) in public places as stipulated in guidance notes of IAQ Management Group. That represents the fresh air provision was still sufficient to maintain a healthy indoor environment for 150 occupants.

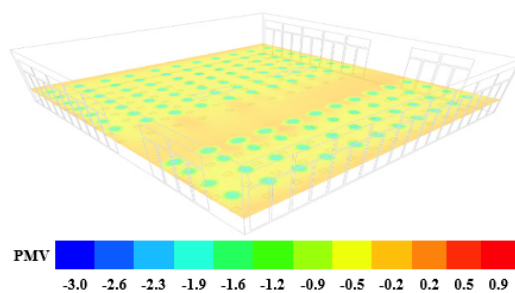


Figure 7. PMV Colour Contour of Scenario 1 with Supply Air Temperature at 18°C at 1m above ground

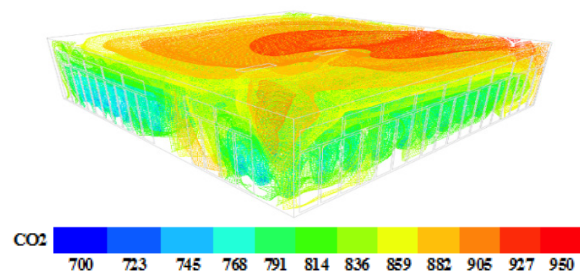


Figure 8. Colour Contour of CO₂ Concentration of Scenario 1

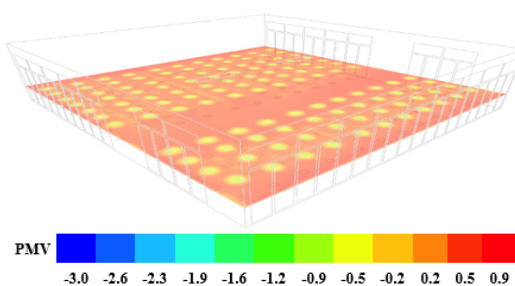


Figure 9. PMV Colour Contour of Scenario 2 with Supply Air Temperature at 22 °C at 1m above ground

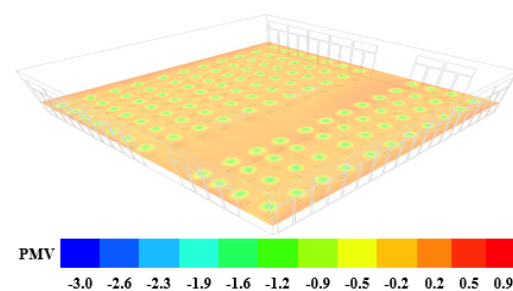


Figure 10. PMV Colour Contour of Optimized Tuning with Supply Air Temperature at 20 °C at 1m above ground

In reality (i.e., Scenario 2), the HVAC system operated beyond the set point with supply air temperature rising 4°C to achieve energy saving. The PMV contour plot as shown in Figure 9 reveals the reddish orange colour (i.e., PMV in the range of 0.5 to 0.9) taking up most of the portion. That implies the thermal sensation in the hall was slightly warm. As shown in the previous results, neither the system set point condition nor the actual operation performed well in terms of thermal comfort. Thus, more scenarios were simulated with the changes of supply air temperature to identify the optimal operational

condition with the balance between energy saving and thermal comfort. The optimal comfort with PMV approximate to zero was at the supply air temperature of 20°C and the PMV contour is shown in Figure 10. Prior to the next step of predictive model for optimized HVAC control, eight more scenarios with different boundary conditions were selected to evaluate thermal comfort level. The dataset was then used for training the regression model.

5.2.3. Predictive model for optimized HVAC control. The dataset of boundary condition for CFD simulation corresponded to the input parameters of the predictive model, while the resultant PMV values were the output parameters. Linear regression model was used to identify the correlation between the input and output parameters through learning process. According to the results of CFD simulation, the set-point temperature of floor diffusers was a dominant factor to thermal comfort in occupancy zone. Weather is also a significant factor to the spatial cooling demand and the intelligent HVAC control, therefore outdoor dry bulb temperature and relative humidity were included in the training in order to formulate an equation for advanced HVAC system control.

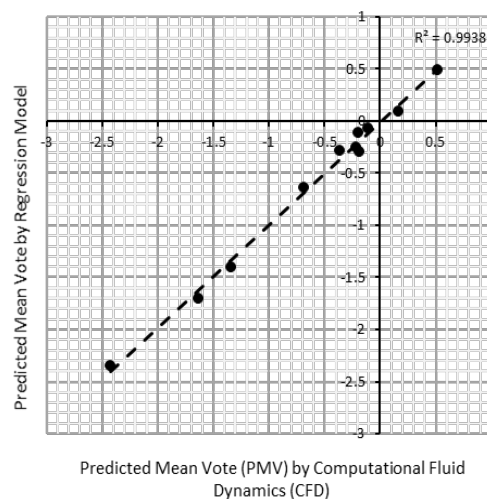


Figure 11. Performance of the Predictive Model

The regression model was trained by the dataset of the first ten scenarios. Equation obtained after the learning process was used to calculate the comfort level of the “unseen” 11th scenario. The difference between the predicted PMV by the equation and the CFD simulation result was 0.07. This small difference demonstrates that the regression model was capable to capture the correlation of dataset from training a limited number of scenarios. The values of PMV by CFD simulation and the predicted PMV by linear regression model for all 11 scenarios are shown in Figure 11 which revealed the good performance of predictive model with the coefficient of correlation of 0.99. This methodology will be useful to operators as a reference to adjust the system set point for optimizing the spatial thermal comfort with minimum energy consumption. The equation can be easily adopted for advanced HVAC control, i.e., supply air temperature reset, based on the instant indoor and outdoor condition.

5.3. Conclusions

This preliminary study presented the application of BIM-based simulation tool and computational fluid dynamics to evaluate the HVAC system performance in respect to the thermal comfort level. The boundary conditions for CFD simulation and the resultant PMV values provided a holistic dataset for machine learning. With the algorithm generated from regression model, the HVAC system can be intelligently controlled according to the actual number of occupants and the instant outdoor condition. Besides, a trial pilot for IoT sensors installation is being carried out. The IoT sensors will be deployed at strategic locations to assess the actual building system performance together with the advanced control based on the simulation results. To measure the outdoor conditions, a Government-Wide IoT Network (GWIN) adopting Low Power Wide Area Network technology at terrestrial level in Hong Kong is being

deployed since Mar 2019. IoT gateways, network server and application server are being implemented to collect and visualise the sensors data. Upon the completion of the GWIN deployment, the result of the data analytics of the outdoor sensors data will be visualised on the BIM-AM System which has been put in place in several pilots as mentioned.

5.4. Future Work

It is envisaged that with the use of thermal cameras on-site and deep learning, adaptive comfort model taking into account the dynamic interaction between occupants and their environment (e.g., real-time human body location & behaviours) would be developed in future. In addition, to develop a more accurate thermal comfort model perceived by human as compared with the Fanger's PMV comfort model, our future research will focus on thermal comfort model by leveraging various machine learning algorithms.

References

- [1] Schevers H A et al 2007 "Towards digital facility modelling for Sydney Opera House using IFC and semantic web technology" *J. of Information Technology in Construction* **12** 347–62
- [2] Sabol L 2008 Building Information Modeling & Facility Management DC: Design + Construction Strategies (Washington)
- [3] Ding L et al 2009 "Towards Sustainable Facilities Management", in Newton P., Hampson K. and Drogemuller R. (Eds). Technology, Design and Process Innovation in the Built Environment. Taylor & Francis pp 373–92
- [4] Teicholz P M 2013 BIM for facility managers, (IFMA, Ed.), Wiley, Hoboken, N.J.
- [5] Lewis A 2013 "Case Study 5: State of Wisconsin Bureau of Facilities Management, Division of State Facilities, Department of Administration", IFMA (Ed.), BIM for Facility Managers, Wiley, Hoboken, N.J. pp 250–93
- [6] Aldaham O et al "Case Study 1: Mathworks", IFMA (Ed.), BIM for Facility Managers, Wiley, Hoboken, N.J., pp 147–63
- [7] Beatty R, Eastman C and Kim K 2013 "Case Study 2: Texas A&M Health Science Center", IFMA (Ed.), BIM for Facility Managers, Wiley, Hoboken, N.J. pp 164–84
- [8] Aspurez V and Lewis P 2013 "Case Study 3: USC School of Cinematic Arts", IFMA (Ed.), BIM for Facility Managers, Wiley, Hoboken, N.J. pp 185–232
- [9] Motamedi A, Soltani M and Hammad A 2013 "Localization of RFID-equipped assets during the operation phase of facilities." *Advanced Engineering Informatics* pp 566–79
- [10] Videos of Building Information Modelling – Asset Management (BIM-AM), Electrical and Mechanical Services Department, HKSARG [online]. Retrieved from: http://www.emsd.gov.hk/en/engineering_services/project_management_consultancy/highlights_of_work/bim_am/index.html [Retrieved on 7 November 2018]
- [11] BIM-AM Standards and Guidelines Version 2.0, Electrical and Mechanical Services Department, HKSARG [online]. Retrieved from: https://www.emsd.gov.hk/filemanager/en/content_1148/EMSD%20BIM-AM%20Standards%20and%20Guidelines%20v2.0.pdf [Retrieved on 10 March 2019]
- [12] Fanger P O 1970 "Thermal Comfort, Analysis and Applications in Environmental Engineering"
- [13] Bahar Y N, Pere C, Landrieu J and Nicolle C 2013 "A Thermal Simulation Tool for Building and Its Interoperability through the Building Information Modelling (BIM) Platform" *Buildings* 380–98
- [14] Lim Y W 2015 "Building Information Modeling for Indoor Environmental Performance Analysis" *Am. J. Environ. Sci.*
- [15] Pazhoohesh M, Shahmir R and Zhang C 2015 "Investigating the thermal comfort and occupants position impacts on building sustainability using CFD and BIM" *proc. of the 49th Int. Conf. of the Architectural Science Association* pp 257–66