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Utilisation of building information modelling for indoor environmental quality assessment – A review

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Abstract. The indoor environmental quality (IEQ) is considered as a social aspect of sustainability that concerns on health, safety and well-being of building occupants. The satisfaction of occupants in the buildings is affected by acoustic, thermal, lighting and ventilation and has been corresponding to the self-estimated workers job performance in the workspace. The poor indoor environmental quality in building has resulted to health problems such as asthma and cancers and this having an effect in frequency of absenteeism and intention to quit job. Therefore, occupant satisfaction is an important factor in the design, operation, and management of buildings. This study reviews the extent to which relevant literature on IEQ has been carried out and the utilisation of Building Information Modelling (BIM) for the IEQ assessment. Reviewed works shows that many works have been carried out on indoor environmental quality of buildings and other aspect of sustainability such as environmental and economic sustainability. However, despite an increased interest in GreenBIM, it is surprising that little empirical research has been conducted on the topic. Most of the studies are directed towards the environmental benefits of sustainability such as energy consumption, carbon dioxide emission, and waste reduction. This study aims to identify areas that are yet to be considered and provides information on interventions that could be used to improve the health and wellbeing of occupants of the building is a compliment to previous studies that are on the other components of sustainability.

1. Introduction

Indoor environmental quality (IEQ) is an important aspect in assessing the general comfort of the building. IEQ is the act of measuring of specific internal physical conditions such as thermal, lighting, acoustic and ventilation which cumulatively affect the comfort and well-being of occupants [1]. The relatively low IEQ hampered the performance of the workers which has invariably affected the overall occupants' productivity. In addition, studies have also associated obesity, cardiovascular diseases and asthma-related matters) to IEQ [2].

On the other hand, BIM is a digital representation of the building process to facilitate exchange and interoperability of information in digital format [3]. BIM can be considered as simulating a building project from the initiation stage to demolition and providing a 3D virtual environment with a workflow of integrated information through a software package [4]. Integrating the deliverables in a model, BIM can predict and decrease problems and errors. The model provides various analytical information for the visualized design which can contribute to digital fabrication and facilitated management [4].

Researchers have examined the concept of application of sustainable practices in building design, and found that BIM utilization in green building for environment and behaviour studies.

In fact, the advent of BIM technology with Sustainable Building concept has modernized the Built Environment in the Western world and it's signified as Green BIM. Hence, Green BIM is defined as, the ability to evaluate sustainability aspects including near-zero carbon in the construction, reducing building impact on human health and the environment during the building's lifecycle, enhancing energy usage, optimizing the environmental performance, effectiveness in managing waste and an enhancement on indoor climate in the building life cycle. Yet according to Wu and Isa [5], the implementation of green BIM is still not encouraging and is yet to be explored by the specialists and engineers due to the inadequate knowledge of the technology and the cost of the software.

This study aims to review the IEQ in building and extent of BIM utilisation in assessing indoor environment quality to date through extensive literature reviews conducted on over 100 articles published between 2007 and 2018. Approximately 43 IEQ related studies were identified and included in the reviewing and the important IEQ aspect in achieving the green building are discussed in this paper.

2. Previous IEQ Studies

Studies on IEQ have been focused since the last decade. There are four important parameters which are thermal comfort, acoustic comfort, ventilation and daylighting. Thermal comfort is the most important parameter of IEQ. Moreover, thermal comfort can be based on thermal adaptation of individual which is correlated to factors such as age, gender, climate and geographical location [6]. Thermal comfort has an impact on energy consumption of any building as any form of discomfort of occupants leads to changing of controls to non-optimal levels [7-8]. Thermal comfort is influenced by six factors; which that could be classified as personal factors such as insulating through clothing and human metabolic rate. The other factors are environmental parameters include mean radiant temperature, air temperature, air velocity and air relative humidity [9]. Occupants thermal comfort is also influenced by the typology and climatic condition of the environments [10]. The perception of individual thermal comfort differs from one climate to the another and also culture can influence the thermal comfort of individual [11]. The perception of individual thermal comfort and adaptation in an environment are defined by three factors: psychological expectation, behavioural adjustment and physiological adaptation as described by [12].

Acoustics have a very important impact on the overall IEQ of a building and the amount of noise emission to the environment. The levels of background noise, privacy and separation between particular types of spaces have important implications for the work environment of building occupants. Acoustic comfort and privacy have been identified as major issue affecting the productivity of the occupants in an open plan office [13]. Proper selection of materials and window, wall insulation and wall framing are essential to remove noise from outside. Some sound insulation materials, such as straw-bale construction and acoustic ceiling tiles can offer the advantage of using natural materials and recycling. Building occupants might have to speak louder than usual to be heard when using noise masking for example. And this will normally cause annoyance for everyone around them in the building. Green building guidelines such as Leadership in Energy and Environmental Design (LEED) which is one of the most popular green building guidelines have started including acoustic comfort as one of the criteria but the overall priority for this is low, a lot more need to be done to make it a mandatory element of green building guidelines [14]. According to the study conducted by [15] on evaluation of acoustic comfort of classrooms in public schools. The physical evaluation and acoustic measurements of three construction designs revealed design errors in all the schools of this study. The error involved both the materials used in the interior finishes of the school buildings and architectural design. The findings of this study reveal a lack of acoustic comfort in classrooms building and advice for the need for urgent interventions.

Good ventilation is an essential aspect to bring a needed amount of fresh air for the health and well-being of occupants in the building. The ventilation effectiveness of the building can be measured on how well this quantity serves the building occupants [16]. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) current ventilation standards is ASHRAE Standard 62-2001, "Ventilation for Acceptable Indoor Air Quality", that addresses the basic of good indoor air quality such as air filtration, contaminant source control, correct ventilation, and humidity

management. A study conducted by [17] found that the energy cost of providing additional ventilation was compensated by the savings that resulted from reduced sick leave. This study recommended that ventilation rates be increased well above the applicable standard for offices at that time, ASHRAE Standard 62-1999. Furthermore, a study by [18] suggested that increased ventilation effectiveness will facilitate the perceived air quality and productivity of the occupant as well as reduce Sick Building Syndrome (SBS) symptoms intensity

Daylighting is the practice of bringing light into a building interior and distributing it in such a way that provides better quality illumination than artificial light sources. Surveys shows that ninety percent of employees like to work in spaces with windows and have access outside view [19]. Daylighting requires the correct placement of openings in the building to allow light penetration while providing adequate distribution and diffusion of light. To control excessive brightness, windows are often equipped with additional light shelves. The benefits of daylighting include reduction on solar heat gain, improved visual quality, improved visual performance and productivity. Research has also examined the difference in response between a good view versus no view where a good view was found to result in increased productivity, mental function, and improvement in memory recall [20]. One such study surveyed 3,000 students in one school with both windowed and windowless classrooms. It found that 94% of the participants preferred classrooms with windows; only 4% specified a preference for windowless classrooms. In addition, the teachers at the school described the students in windowless classrooms as more timid and likely to complain [21].

Comprehensive research on lighting were carried out in 1999 regarding the standardized math and reading test scores over the course of an entire year of more than 21,000 elementary school students located in school districts in CA; Seattle, orange country, CO and Fort Collins. An improvement around 20-26% in the test score were showed by the California students over the whole year in daylighting, whereas Fort Collins and Seattle students reported an increase of 7-18% at the end of the year. The study found that performance is 26% better on reading test and 20% better on mathematics test for students in classrooms with the most daylight. Rooms with larger window areas correlated with a 15-23% overall improvement in academic outcomes [22]. When the light had a more natural appearance; the highest test scores and behaviour were observed in students that exposed to natural light, the research found a positive impact on behaviour and test scores when the light had a more natural appearance. Views of the outdoors were also found to contribute to better performance [22]. Possibly because of the human body's ability to adapt to changes in light levels and quality quickly, more natural light from windows resulted in 7-26% higher scores as well as faster completion times on math and reading tests.

3. BIM utilisation for sustainable building

Sustainability advocates the efficient use of natural resources in the construction of building so as to maximize the quality of the built environment while maintaining low operating cost and waste production, in such a way as to reduce the negative impact on the external environment from the building project. The global attention to the impact of construction on the environment has raised the needs for green building developments. The most important objective of designing built environment is to study this interaction and find measurements to manage and control it properly in order that the standard of life can be improved throughout varied strategies and methods such as sustainable design [23]. Recently, building constructions have had various harmful effects on the ecosystem and environment as a result of the restricted sources of materials and biological capability. It is enormous challenge and responsibility for present occupants of the earth to contemplate it carrying capability and manage it in an exceedingly manner to satisfy the wants of future generation. The aim of sustainable development is additionally to seek out long solutions to support well-being and humans' existence [24]. Furthermore, it may be explicit that sustainability integrates the following three related components: environmental, economic, and social.

According to Patel et al. [25] the introduction of BIM to project design optimization and delivery are significant efforts in reducing the use of energy and material. BIM and sustainable integrated analysis tools can be applied to the building performance assessment and the selection of best solutions which can help to reduce consumption of resources such as water, materials wastage and energy in the project delivery process. In other words, it concerns the two aspect of sustainability that are environmental and

economic. Lee [26] also observed in the review of their studies that BIM application is mostly used in the early stage of building life cycles, mostly during the design and construction phases, and fewer BIM application in later stages of the building life cycle. Among those who use BIM for sustainability practices, 77% of the designer and engineer during design/preconstruction stage and 11% during the post construction stage.

4. BIM utilisation for IEQ in Building

In order to achieve a sustainable form, the harmonisation between the four IEQ parameters mentioned above, the surrounding and natural environment must be established. To achieve this, it is pertinent to consider the overall comfort condition (acoustic, ventilation, daylighting and thermal) as well as energy efficiency in building. However, Soltani [27] stated that despite the importance of IEQ, that concerns with safety and wellbeing of the people, not much literature is available unlike environmental aspect of sustainability such as energy consumption, greenhouse gas, and water efficiency. The only work that used BIM for IEQ is study by Al-Suhaili et al. [28] that developed a frame work for assessing the IEQ of educational buildings in Saudi Arabia. The framework was claimed suitable to be used as a tool to determine the IEQ and able in comparing the measure IEQ parameters data with the standard value.

5. Discussions

IEQ is one of the key elements of sustainability in building that prolong life of people. IEQ come under the social aspect of sustainability including safety, well-being and convenience of the occupant. The available literature reveal that little studies have been done on a social aspect of sustainability such as the health and well-being of humans. Studies on indoor environmental quality in the last decade have focused mainly on thermal comfort [29-35], acoustic comfort [36-38], ventilation [39] and energy efficiency [40-42]. Most of IEQ studies only focused on the assessment of occupant's satisfaction on IEQ parameters in the building without investigating on how to improve the IEQ of a building through green retrofitting, in order to reduce the building negative environmental impact and increase its benefits. It was also observed that BIM application is mostly used in the early stage of building life cycles, mostly during the design and construction phases, with fewer BIM application in later stages of the building life cycle as mentioned by [26] . Most green BIM research have focus on energy consumption and total greenhouse gas emission. The only work on IEQ using BIM was study by (41) for the development of a frame work for assessing the IEQ of educational buildings. However, the author study does not cover on the improvement of IEQ of the education building in order to fulfilling the standard limits. The author only proposed a framework that can be used to detect the immediate and future threats. While the study by [27] and [43] focus on economic and environmental aspects of the sustainability leaving out the social aspect of it.

6. Conclusion

The utilization of BIM as tool assessment for IEQ in building was reviewed through recent and past literatures. The IEQ important parameters and utilisation of BIM in sustainable building were discussed. Several conclusions can be drawn from the review as follow:

- IEQ studies only focused on the assessment of occupant's satisfaction
- There is no study on retrofitting aiming for improvement of IEQ
- Most of the studies using BIM are directed towards the environmental benefits of sustainability such as energy consumption, Carbon dioxide emission, and waste reduction
- there are little research efforts on utilising of BIM on IEQ for benefit of health and well-being of the human. Health and well-being of occupants is very paramount, there is therefore need for research in this area.

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