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EXPLOITING BIM IN ENERGY EFFICIENT DOMESTIC RETROFIT: EVALUATION OF BENEFITS AND BARRIERS

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Abstract: Energy efficient retrofit of the building stock is an important and contemporary issue in the built environment. Building Information Modelling (BIM) can offer a comprehensive and integrating platform for construction projects, as has been demonstrated for many large-scale schemes, mostly in new buildings but sometime also in retrofit projects. This research focuses on the potential of adopting BIM through a smaller scale activity of residential retrofit to achieve energy efficient housing. Although many strategies and technologies have been developed during the last decades, retrofit processes are still confronted by technical, economic and social challenges.

This paper investigates how BIM may be integrated all the way through the residential retrofit process and how new digital technology can be engaged. The potential strengths and weaknesses of BIM implementation in retrofitting are identified. This paper is part of an on-going research study and the outcomes from this research will be used to develop a framework which enables informed decisions to be made in retrofitting schemes, and which actively engages BIM into the retrofit process to support automation at retrofitting stages.

Keywords: Retrofit Process, BIM, Energy Efficiency, Domestic Buildings.

1. INTRODUCTION

In the UK, approximately 50% of primary energy consumption is related to the demands of the built environment. At the same time, the rate of renewal of the building stock is typically very low – around 1% per annum. Hence, retrofitting and energy upgrading of the existing building stocks offer significant opportunities to reduce total building energy consumption. The UK government set a climate change target of an 80% reduction in total greenhouse gas emissions (compared to 1990 levels) by 2050. It is estimated that around 70 to 80% of the UK's domestic building stock will still exist in 2050 , so to meet the UK's climate change target and mitigate the consequent environmental degradation, energy efficient retrofit of domestic stock are critical (Crosbie & Baker, 2010; TRCCG (Three Regions Climate Change Group), 2008) . A great number of strategies and technologies have been developed in recent years. However, the retrofit process is still confronted by technical, economic and social challenges. This paper investigates how Building Information Modelling (BIM) may be integrated at all stages of the retrofit process and how this new digital technology can be engaged. The potential strengths and weaknesses of BIM implementation in retrofitting are identified.

The first part of this research critically reviews generic building retrofit challenges and outlines the main issues in the retrofit process. Secondly, BIM is critically reviewed, including its applications and capabilities throughout the retrofit process. Finally, in order to explore the potential significance of BIM in retrofit, several structured and semi-structured interviews have been conducted with built environment experts.

2. CHALLENGES IN RETROFIT PROCESS

Retrofitting existing buildings refer to all measures and implication of new products, systems and facilities in order to reduce the energy consumption. The terms of retrofit cannot be used in the same way as for the refurbishment or renovation that seeks to enhance a building from an aesthetical point of view regardless of any reduction of energy usage (Baeli, 2013). Also, although reducing carbon dioxide emissions is crucial, all functional factors, such as thermal comfort, should be considered throughout the process. A lack of knowledge and understanding of how a building works have left those involved on projects with challenges due to the utilization of ill-judged measures (Marianne & Roger, 2013).

2.1. RETROFIT PROCESS IN THE UK

The UK domestic stock is one of the oldest in Europe. Almost 13 million dwellings were built before 1960 and it is estimated that over 70% of the housing stock will still exist in 2050, including 4.7 million of the least energy efficient homes built before 1919 (Baeli, 2013). In the retrofit process improving energy efficiency, creating greater comfort and extending the life of building, together with other inseparable dimensions, including social, ecological economic and technical, should be reconciled. To execute energy efficient building retrofit, appropriate decisions should be taken from the inception of the project. Hence, sustainable principles should be taken into account from the conceptualisation through to completion (Martinaitis et al., 2004; Mickaityte et al., 2008) Retrofitting of existing buildings has encountered many challenges and opportunities. These challenges are classified and outlined below.

2.2. QUALITY OF RETROFIT MEASURES

According to a Climate Policy Initiative (CPI) study that surveyed 2000 users in domestic stock, one of the major challenges to retrofit is attributed to the quality of retrofit measures (Novikova, Vieider, Neuhoff, & Amecke, 2011). On the one hand, occupants are concerned about the quality of retrofit measures, services, standards and labelling of materials; on the other hand, designers and contractors are faced with a lack of a comprehensive approach to help identify possible options and, thereby, assure clients to make a correct decision to achieve energy efficient retrofit. Occupants should be provided with informed advice through improving the communication and collaboration of the designer, contractors and users to broaden the understanding of project and enhance energy performance. The systems and subsystems in buildings are interactive and different retrofit approaches may effect on associated systems due to a high level of interactions. Although there are a great deal of technologies and approaches to achieve energy efficient retrofit, there is lack of a practical balanced approach to make the multi-objective decisions that are necessary to improve the energy performance. Different specific requirements of site and building, budget targets, building fabrics and diverse type of services make this decision a complex and multi-faceted one. All factors attributed to energy, social, environmental, economic, and technical issues should be contemplated in order to choose an optimal solution (Ma, Cooper, Daly, & Ledo, 2012). Uncertainties about the quality of theses retrofit measures, and confronting technical and social challenges to make a proper decision are considered as one of the main challenges in retrofit processes.

2.3. FINANCIAL ISSUES

One of the critical retrofit barriers is the financial one, with homeowners unwilling to pay for energy efficient retrofit measures due to issues such as the uncertainty over the payback period and primary cost benefits flowing to tenants rather than the homeowner (Tobias & Vavaroutsos, 2009). However, retrofitting domestic stocks offers considerable opportunities to improve the energy performance and thermal comfort, reduce maintenance costs, improve users' productivity, reduced CO_2 emissions and boost national energy security. By providing financial incentives from government and by harnessing the description and performance data of assets, clients can manage and maintain their mechanical, electrical and plumbing (MEP) services and make a proper decision about retrofit without any concern and uncertainty over the matter of payback period (Eastman, Teicholz, Sacks, & Liston, 2011). Also, a financial evaluation of the whole lifecycle cost of various retrofit approaches, by comparing their performance, should be given priority to assure home owners about the payback period of their measures and to demonstrate the financial benefits of different retrofit approaches (Ma et al., 2012).

2.4. INSUFFICIENT LEVELS OF RESIDENTS' KNOWLEDGE

One of the social barriers to achieving energy efficient retrofit is the lack of occupants' knowledge. According to a survey (Crosbie & Baker, 2010) the improvement in technological issues and state of the art approaches cannot be effective without the cooperation of building occupants. If occupants are not willing to engage with the installation and utilisation of energy efficient heating or lighting effectively then the expected efficiencies cannot be achieved, regardless of how much these energy efficient measures hypothetically could be energy saving. Therefore, to boost the uptake of energy efficient retrofit, it is critical to enhance users' knowledge about the benefits taken from energy efficient retrofit measures. It is necessary to understand why and how inhabitants react to these measures.

In addition, one the challenges for occupants, designers and contractors is the lack of appropriate communication and collaboration approaches amongst those involved in the project.

Misunderstandings by homeowners due to insufficient levels of knowledge about the building, and the lack of a comprehensive method at the early stages of retrofit, are considered as social obstacles that are accompanied by technical challenges. In order to avoid misunderstanding by occupants due to their insufficient level of knowledge, designers and contractors should be able to clarify their decisions in a way that helps occupants fully appreciate the potential options. However, due to the lack of a comprehensive method at the early stages of retrofit occupants are not able to 'walk through' the virtual model and challenges arise for users to make a decision on optimal solutions. Hence, to implement new technologies, the communication methods between contractors and clients should be reconsidered; residents should have a comprehensive knowledge about what is happening in the retrofit process. Moreover, post occupancy evaluation (POE) and maintenance should be considered to ensure inhabitants do not encounter technical problems. One of the critical challenges that makes occupants dissatisfied arises when problems with technologies cannot be resolved even over a long period of time. There is an urgent need to contemplate a systematic approach to make stakeholders informed about the potential benefits of retrofit and protect them against post-occupancy difficulties (Crosbie & Baker, 2010).

3. BUILDING INFORMATION MODELLING

Building Information Modelling (BIM) is defined by the Construction Project Information Committee (CPIC) as "*...digital representation of physical and facility characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition*" (RIBA, 2012).

According to Suermann (Suermann, 2009) the designers, contactors and engineers who have used BIM in their projects accomplish tasks more effectively in comparison with their project without using BIM. The desire for utilizing BIM services has increased and designers and contractors have been asked for BIM services by clients. Increasing the complexity of construction projects have enhanced the popularity of alternative modern approaches to design and construction. In the UK, for instance, the government, has already given a mandate to implement fully collaborative BIM level 2 (with all project and asset information, documentation and data being electronic) as a minimum by 2016 (Hall, 2011; RIBA, 2012). BIM represents a virtual building over the whole lifecycle as data-rich digital building models. BIM consists of intelligent objects with 3D models, including geometric or non-geometric attributes with topological or functional data and parametric rules for each component (ISO, 2010). These features can be used through the entire whole life cycle to enhance the project delivery and decision making process through extraction and analysis of information based upon requirements of various clients and users to provide a comprehensive definition of BIM as modelling, repository of functional and environmental data, collaboration, integration, schedule of performance, cost estimation and facility management (Succar, 2009). Constant and coordinated views and representations of the digital model, including reliable and updated data, can be easily interrelated with specification, procurement information and processes (Khemlani, 2007). To implement BIM, defining the aims and scope of works are essential to enjoy all the benefits of BIM's implementation and, as a result, assemblies, systems, geometric and functional data can be shown in a relative scale.

3.1. REVIEW BIM FOR EXISTING BUILDINGS

To exploit BIM in the retrofit process the condition of the building related to type of house structure, age and ownership should be considered due to the influence of these differing frameworks, required level of details and its functionalities based upon the need of users. The benefits of BIM application in new buildings are confirmed by involved parties in projects such as high rendering visualization, improved collaboration, clash detection, and implementation of lean construction (Gray et al., 2013; Gu & London, 2010). However, the application of BIM in existing building is confronted other challenges and potentials. BIM's potentials in existing buildings embrace quality control of retrofit measures and services, retrofitting planning, operation and maintenance, energy analysis, cost calculation and life cycle assessment (Rebekka et al., 2014).

BIM applications in new buildings create lifecycle stages from outset to demolition. BIM implementation in existing buildings is almost reverse engineering processes and recaptures building data. More than 80% of domestic stocks were constructed before 1990 and there is no pre-existing BIM for these buildings (Arayici, 2008). The application of BIM in existing buildings has faced different challenges. Incomplete information of residential buildings mainly brings about inefficient management in the retrofit process. Although a great number of data capturing technique have been developed during last years to recapture building information, the required level of detail, cost, time and environmental aspects are not combined in one technique. In order to capture accurate data and effective project management, a combination of several capturing techniques are required which confront involved parties in projects with time and cost restrictions (Akbarnezhad et al., 2012; El-Omari & Moselhi, 2008).

3.1.1. CHALLENGES TO IMPLEMENTATION

The obstacles to implement BIM in retrofit process were explored through critical review of literature and they are as follows: One of the main challenges is associated to the BIM data Standard. The Construction Operations Building Information Exchange (COBie) standard is a formal scheme to organize data and it provides a standardized level of detail for materials, maintenance information, serial numbers, location, tag, and performance data (East et al., 2013). However, it does not include architectural information, such as walls, roofs, stairs and slabs, which are crucial for energy efficient retrofit processes. Also, lack of automation processes to capture data averts collaborated team to exploit BIM. The accuracy of information is essential to BIM for any type of function. Involved parties in retrofit project are confronted with handling uncertain data that is not addressed in Building Information Modelling. These three major challenges represent major obstacles to the application of BIM in existing buildings.

3.1.2. BIM'S POTENTIALS

BIM is widely used for prototyping, visualisation, collaboration, energy simulation, comparing different design options, facility management and energy demand prediction. The capability of BIM to provide comprehensive visualisation can assist designers to communicate to residents in a more precise way by providing a walkthrough of the retrofitted dwelling. BIM could be offered as a solution for these types of social challenges to achieve a sustainable approach by providing digital prototypes of premises and making the process comprehensive for stakeholders and assure them about the quality of retrofit measures. By adding cost information to the model, designers and stakeholders are able to obtain more accurate quantity schedules and cost estimations. At the initial stage of a project stakeholders can be reassured over the matter of payback period. Accurate quantity information allows designers to convince homeowners through cost drivers and market trends accompanied by a robust plan of work. The clash detection tool in BIM reduces the construction time. Although capturing accurate data is time consuming, a considerable improvement in automation capturing is promised in the near future and, in general, BIM applications will reduce the time of construction in retrofit schemes (Rebekka et al., 2014).

4. DATA COLLECTION: STRUCTURED AND SEMI-STRUCTURED INTERVIEWS

These interviews were conducted through snowball sampling from April 2013 to July 2014. It was conducted through face-to-face, Skype and telephone interviews to obtain knowledge from nine experts throughout the world in United Kingdom, Finland and Norway. The interview was developed as a part of a research project that aims to evaluate, through discussion with experts, the barriers, opportunities and practical challenges of BIM applications in the retrofit process. The findings will be used to develop a framework to enable informed decisions to be made at the early stage of a retrofitting scheme through exploiting BIM. Through snowball sampling, interviewees were selected from diverse background to obtain fully understanding of the benefits and challenges to implement BIM in retrofit process. Their backgrounds and experiences are as follow: technical director for data performance consultancy; Green Deal manager; architects; physics and use this background to make sure that model are delivered properly from architects to collaborated team; BIM coordinator; civil engineer; structure engineer; and business development director.

4.1. COLLECTING DATA THROUGH SNOW BALL SAMPLING TECHNIQUE

Snow ball sampling is used as an approach to reach a target group for exploratory research through conducting structured and semi-structured interviews. Snow ball or chain referral sampling has been widely used in qualitative researches as a technique to obtain data from extended associations through people who share and know of others enjoying specific ranges of knowledge and skills which are of interest to the research (Patrick & Dan, 1981). Snow ball sampling assists researchers in the circumstance where there is no list or sources for locating participants of specific population of specific knowledge and interest. Just considering that the number of people who are familiar with BIM in retrofitting residential building (no obvious source for finding participants of this specific matter) is too limited and so snow ball sampling can be a useful technique to build up a network of professional contacts. Building up a network of initial contacts and connections and locating correct target areas have a profound impact on the success and accuracy of the sampling results and is essential to find credible relevant people for inclusion in the study (Patton, 2001; Rowland & John, 2004).

4.2. APPLIED METHOD FOR INTERVIEWS: ANALYSIS IN NVIVO 10

Nvivo is a computer software packages that can be used for the evaluation, interpretation and analysis of qualitative data (Nvivo, 2014). Nvivo 10 was used in this study to analyse structured and unstructured interviews in order to organise and analyse the qualitative data more efficiently and to identify potential avenues for further research (Garry W et al., 2007). Conducted unstructured and semi-structured interviews were analysed effectively in Nvivo through analytical coding data, reviewing and exploring coding by coding query and a classification scheme that paves the ways for identification, exploration and retrieval of qualitative data (Garry W et al., 2007). However, after running the query process it is still the researchers who are responsible for interpreting and analysing the data. In order to analyse the interviews, all relevant concepts and processes are coded and then categorized and classified. The connections between them are described and through defining a hierarchy amongst the categories, results and interpretations of results can be concluded.

5. DISSCUSSION: INTERVIEW ANALYSIS

Interviewees were asked about their experience regarding BIM's challenges and benefits to exploit in retrofit process; technical issues; their experience to enjoy benefits of BIM in their projects; and suggestion to improve the energy efficiency of retrofit process through BIM.

Challenges to implement BIM: One of the main challenges to implement BIM at early stages is related to energy performance simulation tools to capture data. The building energy performance simulated based upon the SAP calculations having standard occupancy and usage pattern which are typical values of quantities , however in real life cases they are varied substantially within dwellings of similar size and type. So, capturing data techniques should be improved to be beneficial to exploit BIM in retrofit process. Also, James Nicholas, architect in John Mc Call Company who strive to implement BIM in their company trough bottom-up approach were faced challenges to implement BIM due to incapable interoperability, lack of clients' demands for non-governmental Organisation (NGO) projects and legal issues surrounding BIM.

Technical issue: Based upon Graham Cavanag and John Lorimor's opinions, who implement BIM in Manchester central library through collaborating in three-dimensional coordination, fully understanding of phasing and possibility of measures were obtained. As Graham mentioned, "*Predominantly one of the major benefits of BIM implementation has been related to the lower ground floor which has been heavily serviced at very early of program. It was critical at the conception of project to understand that we have to leave clear spaces for construction to go on. Without understanding the certain elements of services at early stage we would never completed on time.*" The federated model allowed collaboration amongst many different users that they have different levels of coordination. Also, Ground Penetrating Radar (GPR) which is one of method used in archaeological geophysics utilised in Manchester Central Library. GPR can be used in any types of construction for thermal design in building. These accurate surveys save money and time for the project. In addition to GPR, laser scanning applied in this project and the point cloud was imported directly to Revit and export to IFC. Laser scanning cost money upfront, however having a model which shows all of the variations in the buildings save time and money for the onsite construction process.

BIM's benefits: Despite of general attitude that assumed BIM can be beneficial for big complex projects, Tiina Koppinen, business development director at Skanska Oy Company in Finland, have utilised and targeted BIM for residential construction. They believe through obtaining lessons and experience from small projects it can be exploited for complicated projects more appropriate, where may other issues need to be tackled. Moreover, in another case, Manchester central library, achieved BREEAM excellent through reassessment of the library functionality for this 80 year-old building, refreshing the building fabric and replacing the services (Lorimor, 2014). In addition, as suggested by John Lorimor, director in JLO innovation Ltd, occupied property is one the main concern for stakeholders and contractors during the retrofit process and although exploiting BIM in current situation due to the lack of automation in capturing data required more time, but it has speed up the retrofit process onsite. Evaluating different possible options and alternations through federated model can be used to assure stakeholders about the quality of retrofit measures such as aesthetics features of façade by putting outside insulation, thermal efficiency model.

Suggestions to improve BIM implementation**:** BIM necessarily cannot solve any problem or bring new creative ideas; however it allows novel innovative ideas to be communicated that associated members obtain fully understanding of project. Interviewees' suggestions are as follow: incorporating BIM into a more definitive EPC and set up open data resource at Land Registry through more accurate building energy performance simulation tools rather than SAP; developing more capable collaboration system; training the stakeholders, architects, contractors who are involved in project; financial incentives for NGO companies; and improving the automation in capturing data.

6. CONCLUSION

This paper is part of an on-going research study to develop a systematic approach to making correct decisions in residential retrofit projects. Generic building refurbishment challenges are critically reviewed and, also, BIM applications in retrofit process are analysed, including its use and capabilities throughout the retrofit process. In order to explore the potential of BIM in retrofit, several structured and semi-structured interviews have been conducted with built environment experts.

To meet the UK's climate change target and mitigate potential environmental degradation, energy efficient retrofit of the domestic stock will be necessary. Many technologies and approaches have been developed for new buildings, but these technologies need to be developed further to make them appropriate for existing buildings. Through critically reviewing relevant literature and conducting interviews by researcher, challenges in the retrofit process have been identified as follows: occupants' concerns about the quality of the retrofit measures; financial challenges; lack of occupants' knowledge; technical barriers; and lack of knowledge over the state of the art methods and platforms to collaborate and communicate amongst involved parties in a project. BIM's potential to address these challenges in the retrofit process includes: creating a prototype of building, as well as comparing different options; investment payback as a significant motivation for retrofit projects; providing the high quality rendering visualisation; motivating people to implement sustainable refurbishment at the initial stage; reduction in construction time by utilization of clash detection tools; and calculation of alternatives and optimizations. Generally, the potential of BIM in existing buildings embraces quality control retrofit measures and services, retrofitting planning, operation and maintenance, energy analysis, cost calculation and life cycle assessment. However, there are some challenges to implement BIM in the retrofit process, as discussed by several interviewees. BIM applications in new buildings involves the lifecycle stages from outset to demolition, The implementation of BIM in existing buildings is almost a reverse engineering process and tries to recapture building data. More than 80% of the UK's domestic stock was constructed before 1990 and there is no pre-existing BIM for these buildings. In order to capture accurate data and effective project management, a combination of several capturing techniques are required which confront involved parties in projects with time and cost restriction. Also, COBie provides a standardized level of details for materials and sustainability features; however, it does not include the architectural data required for energy efficient retrofit processes. Moreover, dealing with inaccurate and uncertain data is one of the major challenges. Since the accuracy of information is essential for BIM applications for any type of function uncertain data may lead to ineffective project management and a wasting of time and money. These technical challenges need to be addressed to apply BIM in their projects with time and cost justifications. The outcome of this on-going research will be utilized to develop a framework which enables informed decisions to be made in retrofitting schemes, and which actively engages BIM into the retrofit process to support automation of retrofit process.

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