Exploiting BIM in Energy Efficient Refurbishment:
A paradigm of future opportunities

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ABSTRACT: This paper focuses on the potential for adopting Building Information Modelling (BIM) through the refurbishment process, to achieve energy efficient buildings. This paper critically reviews generic building refurbishment challenges in retrofit processes. High energy efficiency in the refurbishment process is confronted by both technical and social challenges. Extant literature highlights the importance of decision making at an early design stage. This paper explores how the potential of BIM may be integrated at an early stage and how this new technology can be brought into the refurbishment process. The possibility of exploiting new concepts (application of generative and parametric design for generation and change management) throughout the early refurbishment process is introduced as an evaluation method within this paper. There is a significant knowledge gap in the literature concerning the veracity of findings to date, which explicitly identify the support mechanisms needed to exploit the opportunities presented with new refurbishment methods.
Keywords: Refurbishment process, BIM, Generative and parametric design, Refurbishment design, Sustainable architecture

INTRODUCTION

Between 40% and 50% of energy consumption and CO_2 emission in European countries are related to the building stock. According to Sunikka (1) energy efficient refurbishment in the domestic sector offers a considerable opportunity to reduce global energy consumption and mitigate environmental degradation. According to recent estimates 75% of existing residential building will still exist in 2050 in the UK (2). Therefore, to achieve the climate change target in the UK and reduce 80% of greenhouse gas emissions by 2050, it is necessary to enhance through refurbishment the energy efficient of the UK housing stock (3). This paper critically reviews generic building refurbishment challenges in retrofit processes and recent technological advancements to enhance these processes. The possibility of using BIM in Architectural, Engineering, and Construction (AEC) projects has previously been explored in several studies (3-5). Accordingly, this paper explores how the potential of BIM may be integrated at an early stage and how this new technology can be brought into the refurbishment process to develop a systematic approach to make correct decisions at the early stages of retrofitting.

The first part of this paper presents a general background about BIM and sustainable refurbishment processes. It is followed to critically review generic building refurbishment challenges and outline main challenges in retrofit processes. Modern refurbishment technological opportunities are presented embracing: virtual reality (VR) in refurbishment, generative and parametric design; and BIM's benefits for refurbishment through case studies. Thereafter, to overcome challenges in refurbishment projects, these potentials are linked to the identified barriers. These issues are utilised to propose the conceptual framework based upon modern refurbishment technologies (Figure 1) which adopts the aforementioned new technologies in the conventional procedure (6).

WHAT IS BIM?

As construction projects increase in complexity, alternative modern methods of construction and design increase in popularity. Suermann (7) pointed out that designers, construction managers and contractors, who have the ability to accomplish tasks more efficiently than ever before, have used BIM. Furthermore, clients increasingly require BIM services from designers and contractors. In the UK, for example, the government, the largest procurement client of building and infrastructure developments, has already given a mandate as to how BIM should be used. According to the Government Construction Strategy on BIM, it will require fully collaborative BIM level 2 (with all project and asset information, documentation and data being electronic) as a minimum by 2016 (8).

There are many definitions of what BIM is and in many ways it depends on the point of view of what is being sought to be gained from the approach. There are two common definitions. In the UK, the Construction Project Information Committee (CPIC) has defined BIM as:

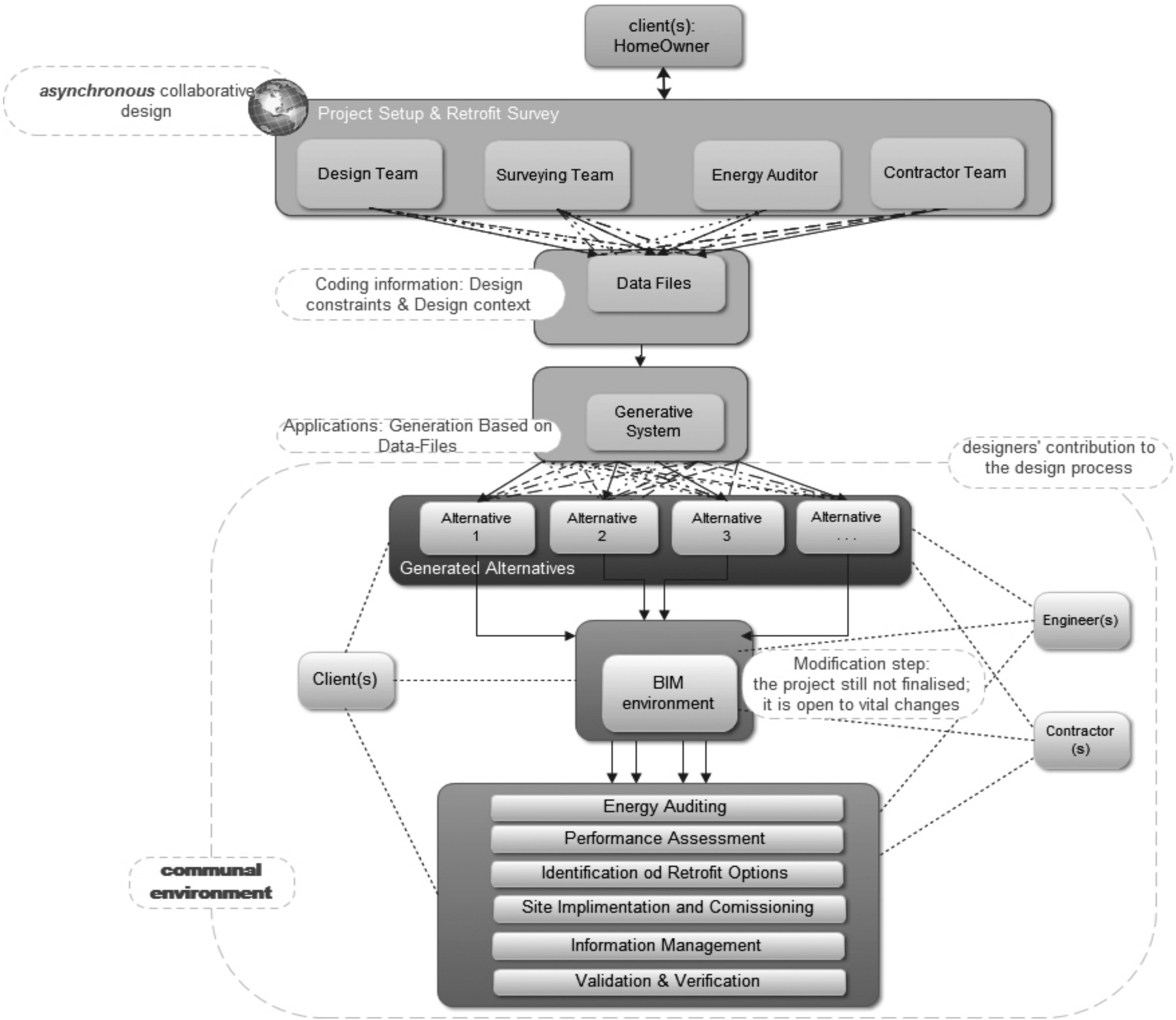

Figure 1 Conceptual framework

"*...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*" (9).

In the USA, the National BIM Standard has defined BIM as "*a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward*"(10).

The Building Information Model is primarily a 3D digital representation of a facility and its core characteristics. It consists of intelligent structural components, which includes data attributes and parametric rules for each object. For instance, a window of certain materials, shape and dimensions is parametrically related and hosted by a wall. Furthermore, BIM provides constant and coordinated views and representations of the digital model including reliable and updated data and for each view. BIM is increasingly becoming a better-known established collaboration process in the design and construction process of buildings.

SUSTAINABLE REFURBISHMENT PROCESS

Sustainable retrofit processes not only improve the energy efficiency of a building but also enhances the building's condition and, as a consequence, increase the building's value (11). The expectations of sustainable refurbishment projects are:

- Improve energy efficiency
- Offer greater comfort

- Extent lifecycle of building
- Reduce greenhouse gas emission.

Further pillars of sustainability should be reconciled in the retrofit process. According to Mickaityte et al. (12) these dimension include social, ecological economic, design, and technical. These dimensions are inseparably related to each other and achieving the optimal result depend upon the how these dimensions can be contemplated as an integrated approach (12). One of the challenging issues during the retrofit process is finding an approach that improves collaboration and integration during this process.

CHALLENGES IN RETROFIT PROCESS

According to a CPI report that surveyed 2000 homeowners regarding thermal efficiency refurbishment, several challenges were outlined (13). One of the biggest concerns for homeowners relate to the quality of refurbishment measures. Uncertainty about the quality of materials' labelling, standards and services cause anxiety for them. Also, throughout all stages of refurbishment identifying the possible options and through it making the correct decisions, as well as lack of a comprehensive approach for these measures are perceived as major challenges. Furthermore, one of the critical barriers is the financial issues and uncertainty over the matter of the payback period of energy saving from refurbishment. To overcome these barriers one aspects of exploiting BIM in retrofit is facilities management. By harnessing the description and performance data of assets to the model, clients are enabled to manage and maintain their mechanical, electrical and plumping (MEP) services and evaluate the impact of maintenance and refurbishment work on them (14). In addition to this capability, creating a prototype of building with high quality rendering visualisation, as well as comparing different options through parameterisation, ensures stakeholders about the quality of retrofit measures and making the correct decision. A significant motivation for retrofit projects is investment payback. The BIM model's capability to embody cost information allows designers, homeowners and contractors to carry out option appraisals more precisely at the initial stages.

According to Crosbie and Baker (2) 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 refurbishment, it is critical to understand why and how inhabitants react to these measures. Based on the Crosbie and Baker's research (2) , aesthetic features of building and influence on inhabitants' lifecycle are considered as two key issues demonstrating why users react to these measures. Some of the problems that experienced in their research are:

- Technical challenges
- Insufficient levels of residents' knowledge
- Communication problems with contractors or organization

Hence, to implement new technologies, the communication methods with contractors and clients should be reconsidered; residents should have comprehensive knowledge about what is happening in the refurbishment process. Moreover, post occupancy evaluation and maintenance should be considered to ensure inhabitants do not encounter technical problems. One of the critical challenges that make occupants dissatisfied arises when problems with technologies cannot be resolved 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 refurbishment and protect them against post-occupancy difficulties (2).

As the decision making process progresses, saving on energy bills and achieving thermal comfort exceed all other features in importance. Consequently, raising the awareness of these advantages may boost the thermal efficiency of refurbishment projects. Also, aesthetic features of the refurbished building are considered as a major trigger to plan for the refurbishment. Pursuing users' interests by providing them with 3D high quality rendering of building at the early stages in BIM may assure homeowners about the quality of refurbishment measures, high potential on energy saving, and aesthetic features at the same time (13).

IMPORTANCE OF THE DECISION MAKING AT THE EARLY STAGE OF RETROFITTING

To execute energy efficient building refurbishment, appropriate decisions should be taken from the outset of the project. Hence, sustainable principles should be taken into account since the conceptualisation through the accomplishment. According to Mickaityte and Zavadskas (12) the character of information should alter depending upon the phase of decision making. These types of information are classified in to four groups (12):

- *Data and information collection as well as problem formulation.*
- *Decision modelling phase.*
- *Decision selection phase.*

- *Implementation phase*

There are three types of factors influencing the effectiveness of decision making:

- Macro environment: technical, social, economic, political exert a major influence on refurbishment efficiency.
- Micro environment: information system, financial issues, innovative technologies use and supply, depreciation of building, premises quality, facilities management.
- Diverse group of stakeholders during the decision making process: refurbishment decision is made by different participating embraced inhabitants, contractors, subcontractors, engineers and architects.

Existing literature highlights the importance of the decision making at the early stages of the process. Hence, exploiting BIM in the initial stages and considering factors influencing the effectiveness of decision making could be a potential benefit of BIM for retrofit projects.

VIRTUAL REALITY (VR) IN REFURBISHMENT

Regenbrecht and Donath (15) defined VR as a component of communication which takes place in a computer generated 'synthetic' space, which embeds humans as an integral part of the system. They described the tangible components of a VR system as a congruent set of hardware and software with actors within a 3D or multi-dimensional input/output environment, where actors can simultaneously interact with other independent objects. According to the most popular definitions, a VR system usually includes a computer capable of real-time animation, controlled by a set of wired gloves and a position tracker, and using a head-mounted stereoscopic display for visual output.

Early studies which used VR in the AEC industry used it as an advanced visualisation medium. Since around 1990, VR has been widely used in the AEC industry as it provides an intuitive medium for designing 3D models which can be spontaneously manipulated and collaboratively used in order to reveal various phases of a building's construction (16). The building industry has also used VR as a design application to provide joint visualisation for improving construction processes. However, expectations of VR have been changed during the current decade. According to Sampaio et al. (17), it is increasingly important to incorporate VR 3D visualisation and decision support systems with interactive interfaces in order to perform real-time interactive visual exploration tasks. This thinking supports the position that a collaborative VR is a 3D immersive space in which 3D models are linked to databases which carry characteristics. This premise has also been followed through other lines of thought, especially in construction planning and management by relating 3D models to time parameters (18) in order to design 4D models which are controlled through an interactive and multi-access database. In similar studies, 4D VR models have been used to improve many aspects and phases of construction projects by: 1) providing better communication among partners (19); 2) enhancing design creativity(20); 3) improving coordination (21); 4) aligning directly with construction processes (18); 5) integrating with Building Information Models (BIM) to enhance data integration.

BIM'S POTENTIAL IN REFURBISHMENT PROCESS

Amongst different parametric tools, BIM is largely accepted and recommended by the majority of specialists. Mitigating the environmental degradation and improving the energy efficiency during the retrofit process can be encouraged by designers and contractors through exploiting BIM (22). BIM is widely used for prototyping, visualisation, collaboration, energy simulation, comparing different design options, solar study, and energy demand prediction. Frequently, parametric tools during the refurbishment process are exploited for visualization, coordination and energy simulation. Due to the capability of BIM-based software for providing high quality rendering and comprehensive visualisation, it is utilised for presenting to stakeholders. Hence, clients and stakeholders with different levels of knowledge obtain a better understanding of projects through providing the walkthrough for them. As mentioned before, insufficient levels of residents' knowledge and inappropriate communication with contractors or organisation are considered as challenging issues to implement high-energy efficient retrofit projects. BIM could be offered as a solution for these types of social challenges to achieve sustainable approach by providing digital prototype of premise and make the process comprehensive for stakeholders.

To obtain very effective use of BIM, it should be applied from the initial stages of a project, although it can be used during any stage for facility management, maintenance and operation. Furthermore, BIM software can assist in providing certificates for building environmental performance like BREEAM. Also, it can save time to compare various design options and explore the optimal solution among possible ones, as well as simulation (energy simulation, solar studies and so forth) at the same time. As a consequence, there is no need for multiform software for simulation and comparative studies (23).

One of the considerable potentials for retrofit projects through BIM is the prediction of the energy performance of different alternatives by generating models. Extant literatures indicate that the energy simulation plays a major role in analysing the performance of refurbishment projects. So, exploiting BIM and providing early integration of energy simulation in thermal efficient retrofit could improve the efficiencies of retrofit processes (24). Sheth (25) has explored the limitations and benefits of BIM in retrofit projects. Although the potential benefits of utilizing BIM have been explored in various projects, it imposes some difficulties for adopting BIM at the early stages of refurbishment. The substantial benefits and important limitations are (25):

Merits: data rich 3D modelling; intelligent model based process; parametric design; shared knowledge resource for context, material, etc.; easier collaboration amongst contributors involved in the process; appropriate set of data for different levels of participators from various disciplines; facilitating underlying issues for sustainable design; integrated simulation at early phase of process and comparison different possible options; and reduction in construction time by utilization of clash detection tools at early stage to prevent errors in site.

Demerits: collection of reliable data as a prerequisite at early stage; consumption more time to draft accurate modelling; lack of comprehensive scheme to clarify the responsibilities of different disciplines; lack of widespread accepted BIM based tools for implementing sustainability; and lack of experts and professionals to implement cash detection.

BIM'S BENEFITS FOR REFURBISHMENT - CASE STUDIES

Exploiting BIM is potentially beneficial for retrofit projects. Although it is widely used for new construction projects, there are some excellent examples of utilising BIM in refurbishment projects. In two recent projects, the Sydney Opera House and Manchester's Grade II listed Central Library, it was exploited for Facilities Management (FM) and substantial improvement in the energy efficiency of the whole process. Benefits of BIM's implementation in these case studies embrace reducing the required materials' volume, avoiding remedial works, reducing the materials wastage and embodied carbon, optimisation of construction time; and it adds some benefits to the retrofit process through visual decision making, controlling and monitoring the whole life-cycle and environmental impacts. Hence, these best practice case studies demonstrate that the exploitation of BIM can improve the energy efficiency of retrofit process (26,27).

GENERATIVE AND PARAMETRIC DESIGN

The application of generative design is proposed for the generation of alternatives based on existing 'data-files', including the current situation of the building, design requirements, site-data etc. It is advocated that this approach could enhance the refurbishment process and outcome by assisting designers through iterative generation of alternatives and parameterisation for change management during later design and construction stages. Several researchers have highlighted the benefits of using generative design (28) in the design process; this research offers this method for the early stages of the refurbishment process.

DISCUSSIONS & CONCLUSION

This paper is part of an ongoing research study to develop a systematic approach to make correct decisions at the initial stages of retrofitting through evaluating a framework of barriers. It focuses on existing academic literature to critically review generic building refurbishment challenges and, also, to explore how the potential of BIM may be integrated at the early stages of retrofit to overcome challenges. Most energy consumption in the construction sector is related to existing buildings; hence, energy efficient refurbishment and extending the life of existing building stock offers a considerable opportunity to reduce global energy consumption and carbon emission (22). Although many strategies and technologies have been developed during the last decades, further developments of existing approaches and tools are required to make them suitable for the existing building stock. This paper outlines several challenges in retrofit process embracing: uncertainty about the quality of refurbishment measures; lack of comprehensive approaches to evaluate various possible options and identifying the optimal solution amongst them; financial issues and uncertainty in the matter of the payback period of energy saving from refurbishment payment; technical challenges; insufficient levels of residents' knowledge; and communication problems with contractors or organizations. BIM's potential to overcome these challenges is explored. Energy simulations are not frequently taken into account during retrofit projects. BIM based tools provide this benefit for retrofit projects at the early phases of retrofit projects (25). Gathering information for energy simulation performance of the existing stock can be easier in comparison with new buildings. Accuracy levels of assumptions for retrofit projects are higher than for new build. For instance, lighting requirements and the quality of the indoor environment is based upon the design team's experience; however, these issues are assumed in new construction and could have dramatic impacts upon the completion of a project. Prototyping of the project in data rich 3D modelling may be used as a trigger to motivate homeowners to have energy efficient retrofit through demonstrating the aesthetics features of the projects.

The exploitation of the virtual reality with generative and parametric design is recommended through the refurbishment process. Extant literature indicates that a framework is lacking to exploit BIM in retrofit projects. By proposing a systematic method, architects and householders can gain comprehensive knowledge about the process and potential benefits of BIM in retrofit projects.

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