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Building information modeling for energy retrofitting – A review

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ABSTRACT

Building Information Modeling (BIM), as a rising technology in the Architecture, Engineering and Construction (AEC) industry, has been applied to various research topics from project planning, structural design, facility management, among others. Furthermore, with the increasing demand for energy efficiency, the AEC industry requires an expeditious energy retrofit of the existing building stock to successfully achieve the 2020 Energy Strategy targets.

As such, this article seeks to survey the recent developments in the energy efficiency of buildings, combining energy retrofitting and the technological capabilities of BIM, providing a critical exposition in both engineering and energy domains. The result is a thorough review of the work done by other authors in relevant fields, comprising the entire spectrum from on-site data acquisition, through the generation of Building Energy Models (BEM), data transfer to energy analysis software and, finally, the identification of major issues throughout this process. Additionally, a BIM-based methodology centered on the acquired knowledge is presented.

Solutions for as-built data acquisition such as laser scanning and infrared thermography, and on-site energy tests that benefit the acquisition of energy-related data are explored. The most predominant BIM software regarding not only energy analysis but also model development is examined. In addition, interoperability restrictions between BIM and energy analysis software are addressed using the Industry Foundation Classes (IFC) and Green Building Extensible Markup Language (gbXML) schemes.

Lastly, the article argues the future innovations in this subject, predicting future trends and challenges for the industry.

1. Introduction

Increasing energy efficiency and reducing energy consumption are some of the main research objectives in the AEC Industry [1,2]. In recent years, these goals have been backed by international strategies, such as the 2020 Climate & Energy Package, which aims for a 20% increase in energy efficiency and a 20% reduction in CO_2 emissions, based on 1990 values. Amidst these goals, a 26% reduction on energy use is set for buildings until 2020. This roughly equals to a 10% reduction in energy use in European countries, since the building sector is responsible for approximately 40% of the total energy consumption in these countries [3]. As such, despite the recent advances in technology regarding new constructions, the retrofitting of the existing building stock has not only to be considered if the above-mentioned goals are to be accomplished [4,5] but also presents itself as one of the most efficient solutions to do so [6–8].

Despite this, AEC professionals are faced with many challenges when tackling retrofitting. Such challenges are primarily due to the wide range of purposes behind retrofitting projects, which require the intervention of various stakeholders and professionals [9]. Consequently, retrofitting is slowly being implemented for various reasons such as [10–12]:

- intervention of different stakeholders along multiple stages of the building life;
- complexity surrounding the deterioration and aging of building

Abbreviations: AEC, Architecture, Engineering and Construction; BEM, Building Energy Model; BIM, Building Information Modeling; COBIM, Common BIM Requirements; COMBINE, Computer Models for the Building Industry in Europe; gbXML, Green Building Extensible Markup Language; GUI, graphical user interface; IBDE, Integrated Building Design Environment; ICADS, Intelligent Computer-Aided Design System; IFC, Industry Foundation Classes; LOD, Levels of Development; NBS, National Building Specification; STEP, Standard for the Exchange of Product; XML, Extensible Markup Language

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Table 1
Methods applied on research for retrofitting energy efficiency.

Method	Articles
Statistical approach	[22–24]
Artificial neural networks	[25–28]
Computational models	[29,30]
Simulation software	[31–33]

systems;
- potential building usage during the retrofitting process;
- and lack of knowledge regarding the financial benefits of retrofitting.

Focusing on the first two above-mentioned reasons, the need to gather data in multiple formats that is possibly outdated or even incomplete, from multiple stakeholders, creates obstacles that may hinder the design team ability to propose solutions for retrofitting [8,13]. As such, building retrofitting becomes considerably more challenging than constructing new green buildings [10,14]. However, and although there is a growing demand for answers to these impediments, research regarding retrofitting methodologies and their respective results is still a difficult process [6,12,15,16].

Despite this, retrofitting research on "energy efficiency" has become very prominent when concerning short-term benefits [17–21]. As seen in [9], Göçer et al. identified various studies as part of four major groups shown in Table 1.

The aim of this article is to provide a comprehensive discussion concerning recent advances in the fields of BIM and energy retrofitting that helps achieve the previously mentioned energy goals. This can be accomplished by a clear, BIM-based methodology that enables a well-informed decision-making process regarding energy retrofitting projects and solutions. To do this, the article must comprise the whole process of energy retrofitting design, from data acquisition to building energy analysis. The study is prepared by reviewing and analyzing previous research in these fields. The focused research topics include geometric data acquisition, modeling automation and quality verification, data interoperability, authoring and energy-analysis software, among others.

As such, the document is planned as follows. Section 2 describes the applicability of BIM to energy retrofitting. Section 3 evaluates the main tools for as-built data acquisition. Section 4 establishes the link between acquired data and BEM, examining different software for BIM and energy analysis. Section 5 reports major data interoperability restrictions. In Section 6 conclusions are drawn. Finally, Section 7 discusses future work and expected trends.

2. As-is BIM

Most of the already mentioned challenges branch from the exhaustive documentation and analysis processes that the building has to endure before the rehabilitation process may begin. As such, a centralized database in which to store and examine all this information has to be created. To this end, BIM has the potential to streamline various steps in traditional energy modeling by organizing data such as building geometry, construction typology, and thermal properties [34,35]. In fact, as an emerging technology in the AEC industry [36], the ability for BIM to support information creation, exchange, and applications in the lifecycle of a building is firmly proven [37,38].

BIM is the creation and application of coordinated, reliable computable data regarding a building project. This data, which is typically parametric, may be applied in rapid design generation, planning and decision-making, document creation, cost estimation, among others [37–40]. As such, information stored in BIM contains both geometric descriptions and non-geometric attributes (i.e. semantically rich information) [37].

Furthermore, BIM is a set of technologies, policies and processes assimilated to enable the management of vital project data in a digital format through the course of a building life cycle [41]. The fact that it may be used to model buildings and sequentially perform multiple analysis, enables the energy performance prediction of various retrofitting measures in existing buildings [40]. This in turn enables the comparison between design alternatives, allowing for an improved final decision [42]. As such, BIM has the ability to support its users in attaining a more energy efficient building [43]. Moreover, energy analysis is commonly complex and expensive often causing it to be delayed until the final stages of the design process [43]. The consistent and interconnected information that makes a BIM model can be applied to ease building energy analysis in the initial design phases, enabling the study of more efficient design alternatives [40].

However, converting a substantial amount of dated energy-related data can be overwhelming [9]. Additionally, given the necessary precision retrofitting requires, typical BIM energy models (commonly based solely on project documentation) usually do not fulfill the requirements for retrofitting [5]. As such, to solve these problems, appropriate techniques have to be implemented for capturing, managing and visualizing all the required information.

For instance, as in most traditional energy models, in current BIM-based energy modeling practice, thermal properties are usually acquired from standard values for construction types. This usually does not diminish the energy analysis results since most building elements, when new, typically exhibit the same thermal properties as the ones stored in databases. However, when faced with existing buildings, such assumptions may be incorrect since these stored values do not account for diminished thermal resistances of building elements and materials due to deterioration [34,44]. These deviations have been studied by [45] and [14].

Therefore, solely relying on stored standard information, without questioning building elements deterioration, coupled with the lack of updates to material properties, may result in an inaccurate BIM-based energy simulation, causing ill predictions for the building energy performance and ultimately turning this method unreliable for retrofitting projects [34,46].

Despite this, it should be stressed that the ill modeling of as-is thermal properties is not the sole cause for result deviation in energy studies. In fact, many assumptions and simplifications are required to make the simulation tools inputs manageable, significantly altering the final result (i.e. averaging building operating schedules [47]).

Still, with this in mind, "accurate modeling of as-built conditions" is labeled as one of the primary challenges for BIM-based energy modeling [48] prompting many initiatives to tackle this problem. In Fig. 1 is possible to address a few of the areas this research is divided into.

3. Data acquisition

In recent years, for the generation of the as-built BIM, various methods to measure both on-site geometric and energy-related data have been studied. Geometric data helps create the building model, as well as support the information stored in it. Energy-related data represents the actual conditions of the construction [49]. By analyzing these methods a clear preference for non-destructive methods is noticeable, as disassembling or damaging the building during the operational phase is often an inviable task [46].

3.1. Geometric data

Regarding geometric data acquisition, the recent technological developments made it possible to generate 3D models to assess as-built conditions [49]. These technological developments enable the capture of the as-is building in detail, allowing for a more accurate BIM model