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Using BIM to Increase the Efficiency of Energy-Driven Retrofitting Projects

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USING BIM TO INCREASE THE EFFICIENCY OF ENERGY-DRIVEN RETROFITTING PROJECTS

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Abstract
The building sector is responsible for nearly 40% of global energy consumption. Many existing buildings have poor thermal insulation and low energy performance, hindering sustainability goals. Energy-driven building retrofitting could address this issue and implementing Building Information Modelling (BIM) in retrofitting can reduce process time, costs, and waste associated with such undertakings. Yet, there is a lack of research and insufficient guidance for implementing BIM in energy-driven retrofitting. A BIM framework is presented to enhance decision-making processes during retrofitting. The aims of this study were to (1) identify BIM technologies and methodologies that could address existing barriers and improve efficiency in green retrofitting, (2) evaluate two BIM frameworks previously adopted in retrofitting projects, and (3) provide a set of recommendations. A comprehensive literature review was conducted to benchmark current retrofitting strategies and measures and identify the opportunities for implementing BIM. Then, a comparative analysis was conducted using two published case studies, to evaluate the BIM frameworks adopted in the research. The comparison provided an understanding of cases where BIM modelling and analysis tools were adopted, and costs and energy savings subsequently accrued; this facilitated the identification of the market's most cost-effective and energy-efficient retrofitting package at the time of publication.

Keywords: *Building Information Modelling, Retrofitting, Energy Analysis, Building Performance*

Resumen
El sector de la construcción es responsable de casi el 40% del consumo mundial de energía. Muchos edificios existentes tienen un aislamiento térmico deficiente y un bajo rendimiento energético, lo que dificulta alcanzar los objetivos de sostenibilidad. La rehabilitación energética podría abordar este problema, y la implementación del Modelado de Información de Construcción (BIM) puede reducir el tiempo de los procesos, así como sus costos y los residuos asociados. Sin embargo, falta investigación y orientación suficiente para aumentar la eficiencia energética de los edificios con el uso de BIM. Los objetivos de este estudio fueron (1) identificar tecnologías y metodologías BIM para superar las barreras existentes y mejorar la eficiencia en las rehabilitaciones de forma ecológica, (2) evaluar dos marcos BIM adoptados previamente en proyectos de modernización y (3) proporcionar un conjunto de recomendaciones. Se llevó a cabo una revisión exhaustiva del estado del arte para comparar las estrategias y medidas de modernización actuales e identificar las oportunidades para implementar BIM. Posteriormente, se realizó un análisis comparativo utilizando los dos casos de estudio publicados, para evaluar los marcos BIM en los que se basa la investigación. La comparación proporcionó una comprensión de los casos en los que se adoptaron herramientas de análisis y modelado BIM; esto facilitó la identificación del paquete de rehabilitación más rentable y energéticamente eficiente del mercado en el momento de la publicación.

Palabras clave: *Modelado de Información de Construcción (BIM), rehabilitación, sostenibilidad, análisis energético, rendimiento de los edificios*

Introduction

Climate change is predicted to affect the planet unless significant changes are implemented; it is already impacting human and natural systems (Hoegh-Guldberg et al., 2018). Most climate change global frameworks target the construction industry as it contributes to significant energy consumption and CO2 emissions (Amini Toosi et al., 2020). The 2021 GLOBAL STATUS REPORT (2021) indicates the building sector is responsible for 36% of global final energy consumption, with operational emissions accounting for 28%. The Report reveals that CO2 emissions from the building industry have spiked upward in recent years, and the industry is not on track to achieve the goals of the Paris Agreement. Efficient designs and energy-driven retrofitting are essential for meeting 2050 decarbonization targets (Lim et al., 2021). Energy efficiency policies have emerged since the 1970s (Economidou et al., 2020), but 42% of non-residential and 38% of residential buildings were built before this (RICS, 2020). Most do not meet current energy performance guidelines. There is a pressing need to upgrade the existing building stock, with only 0.2% of existing buildings in the EU being retrofitted to meet the current performance guidelines (EC, 2020). A large proportion of these will be demolished or will need to be retrofitted to limit energy consumption (Vilches, 2017).

Using Building Information Modelling (BIM) to develop sustainable buildings has proven successful in recent years (Sanhudo et al. 2021). BIM adoption can potentially reduce process time, costs, and waste, but adopting BIM in retrofitting projects is still relatively new (Lim et al. 2021). Guidance and recommendations for implementing BIM in energy-driven retrofitting are in short supply. There is a clear need for further research on achieving green retrofits efficiently by adopting BIM (Chong et al., 2017). This study helps close the gap by investigating how to implement BIM tools and methodologies to make energy-driven retrofitting more efficient and providing recommendations for BIM adoption.

1. Methodology

A comprehensive literature review was conducted. Involving databases such as Engineering Village, Science Direct, Emerald, and Google Scholar. Selected sources identified current energy standards and guidelines for energy-driven retrofitting, retrofit measures, role retrofit projects can play in reducing energy demands, current barriers and challenges, and BIM technologies and methodologies that can improve efficiency in retrofitting. Next, two existing retrofit case studies were determined to evaluate and compare effective BIM frameworks. These cases were selected for their differing BIM framework goals and the context of the case buildings, such as location, purpose, dimension, and age. Comparative analysis of the case studies along with the literature findings enabled recommendations for a BIM framework to enhance the decision-making process.

2. Literature Review

2.1. Building Retrofitting

Building retrofitting involves undertaking structural, architectural, mechanical, or electrical works to reduce the energy consumption and CO_2 emissions of an existing building (Bertone et al., 2018). The five main steps for retrofitting involve: (1) project setup and pre-retrofit survey, (2) energy audit and performance assessment, (3) identification of retrofit options, (4) site implementation and commissioning, and (5) validation & verification (Ma et al., 2012). Building owners may undertake such projects to extend a building's service life, enhance user comfort, increase the building's value, meet new energy standards (Amini Toosi et al., 2020), and decrease operational costs (Tom, 2016). Building retrofitting has the potential to help reduce the European Union energy consumption by 5-6%, as well as lower CO2 emissions by 5% (European Comission, 2019).

2.2. **Strategies, Standards, and Retrofit Measures**

Today, countries across the globe are creating and implementing strategies to meet such strict retrofitting targets. The European Green Deal aims to cut carbon emissions by 2050 while achieving economic growth through effective resource use (Vilches, 2019). In 2020, the Renovation Wave Strategy was published by the Commission to double the rates of energy-driven retrofitting in the coming decades (European Comission, 2019). The Global Roadmap for Buildings and Construction 2020-2050 describes key policies and timelines for building retrofitting and aims to improve the retrofit rate by 30% by 2030 and 50% by 2040 (GlobalABC/IEA/UNEPM, 2020).

Further initiatives include Europe's Building Energy Rating (BER) system, which indicates a building's energy performance, including theoretical energy use and carbon dioxide emissions, rated from G (highest) to A1 (lowest) [16]. Directive 2010/21/EU of the European Parliament states that by 2020 all new buildings must be Nearly Zero Energy Buildings (NZEB) at an A2 BER (New Energy Efficiency and Ventilation Standards for Major Renovations to Buildings, 2021).

To target savings regarding energy-driven retrofitting, one can focus on improving the thermal envelope with various techniques to ameliorate the building performance by amending the building shell. These can include upgrading the windows and insulation of the wall and improving the airtightness of the building. After the energy demand is lowered, the building's services can be upgraded to provide more efficient temperature control (Sustainable Traditional Buildings Alliance, 2020).

In 2014 on a local level, the National Standards Authority of Ireland and others developed a Standard Recommendation (S.R.54) to guide energy retrofitting (National Standars Authority, 2014). It addresses the retrofit of the building envelope and services and provides technical guidance for each. It also provides technical information and recommendations for planning and installing retrofitting measures related to the walls, roofs, floors, ventilation, heating and and lighting.

2.3. **Retrofitting Barriers**

Despite improvements, barriers to retrofitting still limit progress. Gholami (2017) identified obstacles and challenges of energy-efficient retrofit, such as

- Financial, including long payback periods and uncertainty about the cost-effectiveness of retrofitting measures applied during a project.
- Technical, including difficulty in assessing the actual thermal performance of the building envelope, sometimes due to the late adoption of building performance tools.
- Lack of demand and homeowner knowledge about potential advantages of energy efficiency retrofits

Other barriers to entry for homeowners include project budget, risk of not fully achieving predicted energy savings, and uncertainty regarding cost savings (Nikman Lee et al., 2020). This has presented the opportunity for BIM to enter the market.

2.4. **Building Information Modelling (BIM)**

BIM is a collaborative process supported by technologies, processes, and policies that interact with one another (Succar, 2009). Implementing such processes enables efficient project data management capture throughout a building life cycle (Sanhudo et al., 2018), by using analysis tools, authoring tools, and a collaboration platform (Lim et al. 2021). Authoring tools create a data-rich 3D model that captures information throughout the construction and design process, whereas analysis tools help input information into the model (Moakher, 2012). When paired with the BIM model, energy analysis and simulation tools enable seamless building performance evaluation (Moakher, 2012). Implementing BIM in the planning and design stage can help the decision process meet sustainability requirements; however, there is a need for improved interoperability between BIM software and energy analysis tools (Chong et al., 2017).

BIM modelling software allows the creation of a pre-retrofit model into which information can be integrated. Software used for this purpose includes Autodesk Revit, ArchiCAD, and Telka (Xu et al., 2021). Most existing buildings only have outdated 2D paper-based plan drawings, which limit evaluation and prediction processes. The 3D point clouds obtained from the surveying techniques must be converted into a digital model using commercial software. Creating a digital twin of an existing building facilitates more accurate visualization and collaboration (Göcer et al. 2016)

Further benefits include the ability to perform optimization and document decisions along the process. A 3D building model works as data storage and offers enhanced transparency between stakeholders and clients. Authoring software, such as Revit's phasing tool, provides the possibility to attribute phases to the model components, allowing the user to capture each stage of the renovation and store information throughout the building lifecycle (Sanhudo et al., 2018).

Further advantages include enhanced decision-making process and visualization, reduced costs and mistakes (Volk et al., 2014). Communication and collaboration may also be improved, as BIM is a multi-disciplinary collaborative working methodology. BIM processes and standards support using a Common Data Environment (CDE), a cloud-based data storage, allowing users to work simultaneously on models and files across multiple disciplines and stakeholders (Mondrup et al., 2012).

For a BIM process to be implemented successfully then, it must follow a recognised strategy such as that outlined in ISO 19650, which is a standard for managing information over the whole life cycle of a building. These standards set collaboration goals, project milestones, and deliverable strategies. The key requirements include establishing a CDE and having the lead appointed party create a BIM Execution Plan (BEP). The BEP provides evidence of the delivery team's capability to meet the Exchange Information Requirements (EIR). The EIR defines the modelling requirements for each stage of the project. Energy-focused projects such as building retrofitting can benefit from implementing BEPs and the creation of EIRs (UK BIM Framework, 2019).

2.5. **Analysis Tools**

Potential costs and energy savings are the most important factors in persuading consumers to undertake such projects (European Comission, 2019). Once a model of the existing construction is available, the building energy efficiency can be studied based on the information on the building geometry, construction materials, thermal bridges, etc. Data relating to the building and its surroundings (e.g., HVAC systems, weather and the simulation can be captured and shared through the model (Kamel and Memari, 2018). Simulation software can predict energy use and building performance based on the data collected from the as-built, and can identify potential retrofitting measures to implement. This is valuable for evaluating and comparing various retrofit scenarios.

BIM-based performance simulation software is diverse and can reduce building energy consumption (Habibi, 2021). The energy model can be imported into simulation interfaces and engines such as OpenStudio, IES-VE, EnergyPlus, etc., which can be complemented using plug-ins, allowing the user to analyse shadows, solar access, daylight, etc. However, some of these packages have poor interoperability with BIM software, and further development of exchange format files is needed (Carvalho et al., 2020).

Performance simulation software can save time and costs while reducing human error (Kamel and Memari, 2018). Such technologies can facilitate the presentation and storage of data output and organize energy-related information for a building. Research indicates that creating and using a data-rich 3D model offers a better understanding of the process on-site, limiting disruption for occupants of the buildings during energy efficiency retrofits (Chaves et al,. 2017)

While BIM has gained significant traction within the retrofit sector, some ongoing concerns remain. These include weak interoperability between BIM and energy performance tools and uncertainty regarding captured data can lead to inaccurate decision-making processes (Succar, 2009). Other barriers involve BIM maturity, i.e., further development is required regarding the construction and management phases (Elagiry et al., 2019).

3. Comparison of Case Studies

A comparative analysis between two retrofitting case studies where BIM frameworks were developed and implemented was undertaken to explore the literature review findings. Table 1 provides an overview of both the cases selected for analysis. Case A (Hu, 2018) was conducted with a building in the United States to demonstrate a proposed BIM framework and evaluate multiple retrofitting packages. The University of Maryland building was constructed in 1972 and underwent several major renovations. Case B (D'Angelo et al., 2019) was a residential house constructed in 1998 in Ireland's Aran Islands, with a renovation performed in 2008. Neither case had a BIM model available before the case study.

Table 1. Case studies for comparison

Title	Case A: Optimized Renovation Strategies of Education Building – a novel BIM/BPM/BEM framework	Case B: BIM-based Business Process Model To Support Systematic Deep Renovation Of Buildings
Author	Ming Hu	D'Angelo et al.
Year	2018	2019
Country	University of Maryland, US	Galway, Ireland - Madrid, Spain - Pavia, Italy
Case study overview	Educational Building 1972 US Notes: Several renovations No existing BIM model available	Residential House 1998 Aran Islands, Co. Galway, Ireland Notes: Renovated in 2008, No existing BIM model available
Process and phases	***BIM-BPM-BEM Process*** 3 Phases: • BIM: Model and prepare for data extraction • BPM: Energy Analysis and measures • BEM: Environmental impact and package	***BIM-based Business Process Model (BPM)*** 3 Phases: • Pre-energy modelling • Energy modelling stage • Renovation option stage

The following comparative analysis identifies key aspects of each and discusses primary differences.

3.1. Aim of Framework and BIM Adoption

The two cases had similar motivating factors, including using a BIM framework, but the framework was further developed in Case B. The framework for Case A was created to help the decision-makers identify the most energy-efficient and cost-effective strategies for retrofit while minimizing adverse long-term environmental impact. Case B aim to effectively assess design costs and increase the effectiveness of the design sustainability goals; the use of BIM was supported by the goal to improve communication, on-site coordination, and efficiency.

For Case A, the main indicators in identifying the best strategy were the energy-saving potential, carbon emission reduction potential, construction feasibility, initial costs, and annual cost savings. In Case B, the key indicators were broken down further to include aspects such as the payback period, discomfort time, and capital investments.

3.2. **BIM Process Breakdown and Phases**

Hu developed a "BIM-BPM-BEM Process" for Case A, which involves three stages, each defined by one of the acronyms from the framework's title.

- Phase 1 – Building Information Modelling (BIM) aims to compile data on existing building conditions and generate a 3D model (which was not previously available) to identify opportunities for improvement. Methods for acquiring information include field measurement, construction document review, etc.
- Phase 2 – Building Performance Model (BPM), where some retrofitting packages were compared based on the performance simulations associated with various retrofit measures.
- Phase 3 – Building Environment Model (BEM) to identify the best retrofit package by comparing the quality of outputs related to environmental impact.

In Case B, D'Angelo et al. created a procedure of three stages, named differently than in Case A.

- Phase 1 – Pre-energy Modelling Stage, for modelling the building based on existing building conditions and data captured using data acquisition technologies. In contrast to Hu's framework, no energy analysis was performed at this point.
- Phase 2 – Energy Modelling Stage focuses on evaluating the existing building's performance and simulating proposed measures, like Case A.
- Phase 3 – Renovation Option Stage, where the retrofitting options were compared and analyzed, and the best package was identified.

The Cases have many similarities; Case B has divided the steps such that all the energy analysis and simulations were performed by the end of Phase 2. Therefore, Phase 3 focused solely on preparing the most efficient and cost-effective package. Case A focused deeper on environmental impacts when identifying the best retrofitting package. Neither framework includes a planning stage, during which the possibilities for implementing BIM would be diverse.

3.3. **BIM Methodologies**

Revit was used as the modelling tool in both Cases. Although the software for energy and environmental analysis differed, they were equivalent. However, Case A did not specify a Common Data Environment, so it must be assumed that no CDE was used.

Case A did not mention BIM methodologies involving a BEP, any collaborative BIM platform such as a CDE, or any use of BIM standards. In contrast, Case B described step-by-step the creation of a BEP for building retrofitting projects. A BEP was not, however, included in the BIM framework. Case B used Zutec as a BIM platform to share information, presenting a standardised approach

3.4. **Findings and Conclusion**

The two Cases reported using the same standards and achieved similar findings. Both concluded that the energy and environmental impact models offered a clear indication of costs and energy savings to determine the best retrofitting measures and package to use. Hu observed the importance of interoperability between the building modelling and energy analysis software during the process. Similarities between the Cases, including positive results obtained from both frameworks suggest that the two methodologies have good foundations.

The main differences between Case A and B can be found in the BIM framework phase breakdown and differing focus. Defining the phases was more judicious in Case B, where the 3 phases each have a distinct purpose. In Case A, the stages were not organized to the same degree, and there was the scarce implementation of BIM methodologies and practices. Notably, the BIM framework in both Cases omitted any planning stage.

4. **Results**

An optimized BIM framework, illustrated in Table 2, has been developed based on key findings. This new framework aims to enhance decision-making processes for building retrofitting. It describes the steps from the planning phase to the package option stage. Some BIM methodologies and technologies are suggested for each of the corresponding phases. The list of BIM tools is non-exhaustive and is only meant to provide examples and guidance. Further investigation may be required to fully explore the available options in the market.

Table 2. Proposed BIM Framework

	1	2	3	4
Phases	Planning	Energy-Driven BIM Modelling	Energy Analysis	Retrofitting package options
Steps	• Define goals and preliminary scope • Definition of LOD • Identify CDE • Identify modelling and simulation software	• Acquire information and data from existing building • Create BIM model • Prepare model for data extraction	• Create energy analysis and impact on environment model • Evaluate existing building's performance • Perform simulation of proposed measures	• Combine best measures to create retrofit scenarios • Identify best packages based on: cost-effectiveness, energy efficiency, environmental impact
Suggested BIM Tools	• Create BEP • CDE: BIM 360, Zutec	• Data Acquisition: laser scanning, photogrammetry, infrared thermography • Modelling software: Revit	• Energy Modelling software: IES-VE, Sefaira, etc. • Environmental impact and life cycle assessments: Tally • Bill of quantities: Revit	

4.1. **Phase 1: Planning**

A BEP, established in Phase 1, is prepared in line with the building retrofitting standards.The project deliverables will be determined for each phase of the process and will consider costs, time, and quality of construction. The roles and responsibilities of each stakeholder will be identified, along with relationships among them. This phase will allow decision-makers to identify opportunities for implementing BIM in the following phases in line with the project goals. The BEP will also guide the adoption of BIM software in the project. Interoperability between BIM software adopted in the following phases must be considered to ensure a smooth translation from the modelling software (Habibi, 2021). The LOD will also be defined in this phase. LOD 300 is sufficient for modelling a building for retrofitting, as it encompasses the material specification and HVAC systems (AlizadehKharazi et al., 2020).

The BEP will also reflect the information exchange requirements. Case B used Zutec as an online data storage and exchange platform, but several other effective open collaboration tools exist. The choice of a CDE, which will be used throughout the project, will also be done in this first phase.

4.2. **Phase 2: Pre-energy Modelling**

This phase aims to collect all the data concerning the existing building to create a 3D model appropriate for the energy analysis phase. The data is collected via site visits, field measurements, interviews, and a review of building history and construction documents. Data acquisition tools such as laser scanning, photogrammetry, infrared thermography, etc., can contribute to identifying information on the building fabric (such as materials, textures, and thermal bridges). If there is no available model of the existing building, the BIM model can be created based on the information collected. Some modelling tools gives the possibility to hold all the building information, including the building envelope's composition and the building performance, within the model. Finally, the model is prepared for data extraction for the next phase.

4.2. **Phase 3: Energy Analysis**

In this phase, the energy model will be created to evaluate the existing building's performance, allowing the decision-makers to identify improvement opportunities in energy uses. Energy simulations can then be done based on the retrofitting techniques chosen. IES-VE, Design Builder and Sefaira, are example of energy analysis tools which can be used for this stage and translate easily to, and from, Revit. (Mahmoud et al., 2020).

The energy model will then be used to assess the impact of environmental and global warming by applying different measures. As can be seen, this stage reflects Case B, as the total energy and environmental impact analysis is done before the final stage. There are multiple available BIM tools to perform such analysis, and they can be used after the implementation of the retrofit measures, during the post measurement and verification stage.

4.3. **Phase 4: Retrofitting Package Options**

This final phase aims to identify the best retrofitting package prepared in the previous phase. A detailed cost-benefit analysis should be designed considering the initial costs, payback period, and annual savings. Some modelling software such as Revit can be used to generate the bill of quantities to calculate the cost investments. Energy analysis software can assist to calculate energy and cost savings (D'Angelo et al., 2019). The scenarios should be compared based on cost-effectiveness, energy-saving potential, carbon emission reduction potential, and construction feasibility, considering disruption to the users.

The scenarios should align with the current and future needs of the occupants and take in consideration the future improvement opportunities. Finally, the best packages are prepared to be presented to the homeowners, for them to choose among the alternatives and make informed decisions.

5. Conclusions and implications

This research aimed to review the current guidelines, standards, and barriers in building retrofitting and examine how BIM can be implemented to improve efficiency. The paper presented BIM tools that can improve efficiency when adopted in retrofits, including analysis tools, authoring tools, and collaboration platforms. An optimized BIM framework reflecting key findings was presented to utilize BIM's capabilities to develop an efficient decision-making process. The framework outlines four phases, from planning to retrofitting package options, and suggests BIM methodologies and technologies for each of these phases.

The pre-energy modelling phase aims to collect data to create a 3D model appropriate for the energy analysis phase. The energy analysis phase evaluates the building's performance and assesses the impact of environmental and global warming. Finally, the retrofitting package options phase identifies the best retrofitting package through a detailed cost-benefit analysis, considering various factors.

The implementation of the framework could benefit the decision-makers. Adopting BIM from the planning phase would allow to identify the opportunities for implementing the tools and methodologies throughout the project, aligning with the goals and deliverables. The subsequent phases offer clear indications regarding the costs, energy savings, and environmental impact, through the various BIM technologies.

The complexity of building systems and the variability in building design and construction make it challenging to identify the most effective retrofitting strategies for different buildings. Therefore, the need for further research on evaluating the best retrofitting options and scenarios with BIM is critical to advancing sustainable building practices and achieving global climate goals.

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