BIM-based Business Process Model to support systematic deep renovation of buildings

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Abstract

The European Union (EU) has adopted a wide range of 2030 targets and policy objectives to improve the energy efficiency of existing building retrofits. Building Information Modeling (BIM) is a tool which can facilitate energy-driven refurbishments, achieving a high-quality sustainability rating in a short period of time. However, while various BIM procedures are well established and widely used for new constructions, this is not often the case when it comes to retrofit projects. This paper outlines a BIM-based Business Process Model (BPM) to support Energy Service Companies' during the process of a building's refurbishment and thus narrows the gap between the expected and actual energy performance of the building.

Introduction

It has been found that buildings are responsible for 40% of EU's energy consumption (Yang *et al.*, 2016). More than 40% of these buildings were built before 1960 (Dunphy *et al.*, 2014), (M. Economidou *et al.*, 2011) and more than 80% before 1990 (Artola *et al.*, 2016). The current renovation rate of existing buildings is low, with only about 1- 2% of the building stock renovated each year (Meeus *et al.*, 2012), (Kivimaa and Martiskainen, 2017); although it is estimated that renovation accounts for 57% of all construction activity (Artola *et al.*, 2016). Thus, to increase the level of confidence in potential retrofit benefits undertaken by building owners, more practical case studies are required (Ma *et al.*, 2012), (Thyer *et al.*, 2018). A significant amount of scholars (Ardente *et al.*, 2011), (Hestnes, 2012) affirm that renovation practices and technologies are key to improving the performance of the existing buildings stock that combine energy reduction measures and low carbon technologies (Si *et al.*, 2016), (Boermans *et al.*, 2012) from the perspective of sustainable development (Xu *et al.*, 2015). According to (Krieske and Egnor, 2014), (Hong *et al.*, 2015), (Tan *et al.*, 2016) the building upgrade can range from simple and more affordable cost options such as replacing electrical fixtures, installing thermal sheathing, replacing doors or windows joints, to more complex options such as retrofitting heating systems, ventilation and air-conditioning systems

Research (Alajmi, 2012), (Torregrossa, 2015) demonstrate that the combination of simple and sophisticated retrofits often leads to major energy savings. These can lead up to

45% in reduction of building's energy consumption. Additionally, Parker *et al.* (2001) highlights a correlation between the energy saving that can be achieved taking advantage of these technologies for particular year of construction. For example, 12% for houses built in the 1990s and 25-30% for houses built before the 1940s.

However, according to Hou *et al.* (2016), while basic measures such as the retrofit of the lighting and air conditioning system and the operation optimisation are more affordable and could be done without subsidy, often the retrofit of the envelope needs policy incentives. Therefore, governmental retrofit guidelines and utility incentive programs (DCENR, 2014) are starting to promote retrofit activities in the building sectors which encourage the achievement of the sustainability goals (Lee *et al.*, 2015), (Moschetti and Brattebø, 2016).

For instance, Sirr *et al.* (2015) correlates the possible financing and funding schema for a proposed set of renovation options, taking into account the overall cost and the potential savings that could be achieved through the refurbishment works. However, the achievement of the savings is closely related to the specific building characteristics such as the dimensions, the location and the envelope and system's properties (Hong and Yan, 2014). In fact, Ma *et al.* (2012) affirms that identifying the most effective retrofit action remains the main challenge. The financial limitations are not the only factor that prevents the implementation of such practices. In fact, many authors (Gillingham and Palmery, 2014), (Jaffe and Stavins, 1994) in the last 30 years have started to conduct research on the "efficiency gap" as it is known the existing gap between the optimal energy efficiency improvements and the realised improvements.

Later, in the 2000s, Sorrell *et al.* (2000) would name this gap as the barriers that prevent the renovation process in the constructions sector. Systematic studies of energy efficiency barriers are typically based on barriers taxonomies. Blumstein *et al.* (1980) in the 1980s developed this concept dividing the barriers under 6 categories: misplaced incentives, lack of information, regulation, market structure, financing and customs. Subsequently, several authors started to develop different classification schemes such as Sorrell *et al.* (2000) who simplified the division in 3 categories (economic, behavioural and organisational) but including subdivisions or Cagno *et al.* (2013) who developed a barrier taxonomy able to evaluate the differences between

perceived and real barriers, the effect of the barriers on decision-making processes, and the interactions among barriers. Reddy (2013) then divided the categories in micro, meso and macro taxonomy, starting from the barriers that can happen at the lowest level (for instance at the design stage unique to a particular project) to the macro-barriers that arise at the highest level (state, market and civil society). More recent researches such as (Chai and Yeo, 2012) and (Kangas *et al.*, 2018) start to focus on the classification of these barriers using a more actor oriented approach.

Therefore, it has been decided that the overall structure of the barrier categories utilised in this paper follows the report published by the European Parliament (Artola *et al.*, 2016) and the barriers within these categories are principally based on the systematic literature review that has been done so far. According to our findings the main perceived barriers, as shown in Figure 1, are split between the absence of financial subsidies, that can help the owner to cover the initial up-front cost, the absence of expertise in the renovation sector and the lack of interest in energy efficiency's interventions due to several reasons such as the low energy prices, the uncertainty of the cost-effective savings and the dearth of an agreement between landlord/tenant.

Figure 1. Barriers that prevent the renovation of buildings

To each barrier, a driver can be associated to incentive the achievement of the sustainable targets such as financial and tax incentive, mandatory building codes, information campaigns, technical skills development and voluntary/negotiated agreements (Torregrossa, 2015), (Artola *et al.*, 2016). In the meantime, there has been a growing number of interest in the use of Building Information Modelling (BIM) in the construction sector, due to the many benefits and resource savings that this process seems capable of achieving during the whole project life-cycle (LC) (Succar, 2009), (Autodesk, 2014). BIM is an intelligent model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage construction project across the project LC (*What is BIM?* / NBS, 2018).

Khaddaj and Srour, (2016) affirm that BIM can facilitate energy-driven refurbishments achieving sustainability ratings in shorter period of times.

But, while the BIM procedures are well established for new constructions such as 61% of reduced errors, 20-30% of reduced construction costs and 20% reduced project

duration (McGraw Hill Constuction, 2014), (*BIM and LCM*, 2018) there is a little maturity in deploying BIM to retrofit existing buildings (Volk *et al.*, 2014), (Chong *et al.*, 2017).

There are many reasons for this, ranging from the non-availability of building documentation in BIM format (since in Europe more than 80% of the buildings are built before 1990 (Gholami *et al.*, 2015)), to the inadequate project experience and the lack of available skilled personnel (Ku and Taiebat, 2011), (Ghaffarianhoseini *et al.*, 2017), culminating in the incompatibility in exchange information between different software applications (Migilinskas *et al.*, 2013), (Gu and London, 2010). Holzer *et al.* (2007) affirms that exactly this incapability seems to be the main barrier to the BIM implementation on the different project LC phases.

Both (Eadie *et al.*, 2013) and (Marzouk, *et al.*, 2012) agree that to efficiently implement a BIM process through the project LC, a detailed planning must be performed. The development of such a plan, the BIM Execution Plan (BEP) (*BIM Project Execution Planning Guide*, 2017) is set out in (*British Standard Institution*, 2013) as "the plan prepared by the suppliers to explain how the information modelling aspects of a project will be carried out".

The BEP will detail the project deliverables stipulated by the contract and the information exchange requirements detailed in a BIM protocol, such as the latest CIC BIM Protocol established in 2018 (CIC, 2018).

The planning guide (*BIM Project Execution Planning Guide*, 2017) is composed of four main procedure tasks to:

1. identify the proper BIM goals and uses;
2. plan the BIM execution process throughout a business process model (BPM);
3. outline the information exchange between the BIM deliverables;
4. develop the project infrastructure.

Nowadays, the benefits of using a BPM to represent complex processes are well recognised in the marketing sector. This is because they allow to align business execution and operation activities with strategy (*Importance of BPM for Your Business*, 2018), (Ioannidis *et al.*, 2012). BPM also improves the efficiency of the procedure as the simulation allows the analysis and the understanding of the flow and its optimisation, increasing the productivity of the resources by limiting the risks and costs (Joncheere *et al.*, 2014), (Bandara *et al.*, 2005). An additional advantage includes the improvement of the communication process. In fact, using the same language every actor has a clear idea of his/her role and his/her responsibility, avoiding all the issues linked to misunderstanding and personal interpretation (*5 Key Benefits of BPM*, 2018). BPM also allows an understanding of the existing processes, detecting the inefficiencies and improving them in a re-engineering process (Jarzabek and Ling, 1996), enabling the process agility to change processes quickly to take advantage of challenges and new business opportunities. So, using the BPM it is possible to represent the whole retrofit process in a simple understandable mechanism by technicians and

Table 1. Potential BIM uses associated to each goal

Priority	Goal description	Potential BIM uses
High	Assess Cost associated with design changes: compare money spent/saved vs. quantitative benefit of design change	Cost Estimation Existing Conditions Modeling
High	Increase Effectiveness of Design: Increase efficiency of structural system, lighting/electrical system, and mechanical system	Design reviews Engineering analysis Existing conditions Modeling LEED evaluation
High	Interdisciplinary Design Coordination: Effectively implement BIM through open communication and periodical design reviews	Design reviews 3D coordination Record Modeling
High	Increase Effectiveness of Sustainability Goals: Increase thermal and lighting efficiency through implementations	Engineering analysis LEED evaluation Daylight integration
Med	Improve on-site coordination and efficiency	Site utilization planning 4D modeling Space Management and Tracking
Med	Value engineering and life cycle cost evaluations	Cost estimation Engineering analysis LEED evaluation

at the same time making it possible to handle the complexity characteristic of the business process. The objective of this paper is to understand the barriers that prevent the deployment of retrofitting existing buildings and thus, propose a methodology to overcome some of these barriers. This paper is organised in two parts. Firstly, in the Methods section reports the core of the study, a BPM that clearly explain the retrofit workflow. In doing this, automatizing the current process using the benefits of the BIM adoption. Secondly, in the Results section, the proposed methodology has been applied in an Irish case study. The paper concludes with a discussion that summarises the findings of the paper and the importance of further developments.

Methods

The first step developing the BEP is to identify the different tasks that can benefit from the integration of BIM throughout the building LC phases, based on the project requirements. Thus, a list of project goals, related to renovating existing buildings, has been outlined in order of priority. The main project goals that have been discovered so far, have been divided in environmental benefits such as energy savings and greenhouse gas (GHG) emission reduction to social benefits such as health benefits, tenant's satisfaction, energy bill savings and added property value.

Table 1 shows the potential BIM uses that have been associated to each goal. Once the BIM uses have been identified, the overall BIM execution process has been performed throughout a BPM. This becomes useful in showing the development of the retrofitting procedure and to highlight the interaction between the BIM uses and their concatenation inside the project. Then, the detailed process maps related to each BIM use have been carried out. Focused attention has been placed on the process map of the Engineering Analysis as shown in Figure 2.

This is because the use of BIM recurs more often within the project goals 'retrofit. One of the challenges has been to maintain the level of detail general enough in order to

not standardise it but keep it suitable for different requirements as suggested by (Berard *et al.*, 2013). Furthermore, the procedure has followed the framework for the organization of project information of the ISO 22263 (ISO 22263, 2015). Hence, the project LC phases have been highlighted in: *inception, brief, design, production and demolition*. Finally, the project planning guidance has been followed (Pacific Northwest National Laboratory; PECL, 2011) to effectively plan and implement performance improvements through deep retrofit works in cold climate zones.

The Business Process Modeling and Notations (BPMN) v2.0 (OMG, 2011) is an established modeling language and has been used to represent the overall process. The process is composed essentially by the standard graphical notation typical of the flow chart symbols:

- a start and an end event;
- several activities that represent the work that has to be done by a particular responsible party;
- the gateways to control the divergence and convergence of the sequence flows;
- the sequence flow to show the order in which the activates are going to be completed;
- the message flow to represent which data is needed to be sent and received between the actors in order to not interrupt the flow.

The procedure is organised in 3 different stages: the pre-energy modeling phase, the modeling phase and the renovation option stage.

The pre-energy modeling phase

The pre-energy modelling phase starts with dependence on the availability of the BIM model. If a BIM model of the building already exists, it can be used for the energy simulation by the mechanical engineers after the required checks and updates. However, if the model is not available, a model is developed based on sketches, data collection, building study and other surveys that are recognised to be one of the most time-consuming step (Berard *et al.*, 2013). Hence, in the last few years many

Figure 2. BPM of the Energy analysis phase using BIM

data capture techniques such as the laser scanning and the photogrammetry are spreading to speed up the data gathering (Alizadehsalehi *et al.*, 2015), (Laing *et al.*, 2014).

The energy modeling stage

Once the model is ready, the energy modeling stage begins. The model is thus calibrated through comparison of simulated and actual data with close attention paid to standards of acceptability margins such as the ASHRAE Guidelines 14 (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2018).

The renovation option stage

The latest stage is the development of the retrofit options. Depending on the features of the building, a list of different retrofit packages is analysed. These packages can include envelope adjustment, system updates, or both. A list is prepared, and the model is updated. Then, the various options need to be compared and the most-effective solution is selected based on a multi-criteria decision making (MDCM) technique (Contreras *et al.*, 2017). This technique considers all the economical, environment, social and technical aspect. In fact, while some key performance indicators (KPIs) are well developed such as the environmental energy demand and the GHG reduction and there is no scepticism in the marketplace about the benefits, the others indicators are not yet well established (Carlson and Pressnail, 2018). For instance, to only consider the most common KPI such as the financial up-front cost (CAPEX) or the simple payback period (PBP) results in neglecting social aspects such as the impact on thermal comfort.

Results

The pilot case is a residential house of 110 m² located on the largest of the Aran Islands, Inis Mór, Co. Galway, constructed in 1998 and renovated in 2008 (Figure 3).

The construction consists of two types of external walls, the old one is a 4 x 2 m timber frame plus 100 mm of wool glass insulation, while the newer construction has further 50 mm of insulation. During the renovation works in 2008, the owner decided to: replace the old lamps with a LED lighting system (A1); to upgrade all the windows and roof lights with a timber-framed with double-glazed (B1); to add the 50 mm of insulation in the external old walls (B2); and to insulate the roof with a 150 mm rigid foam (B3).

Figure 3. Dwelling as it is of the residential house

An existent BIM model of the house was not available, so a detailed site survey was carried out. This included a site visit and a detailed interview with the homeowner. Once the data became accessible (building fabric, occupancy schedule, weather data, energy consumption and utility bills of the last 2 years), a Revit BIM model was developed (Revit Autodesk, 2018). In addition to this, all information was stored on Zutec (Building Knowledge - Zutec, 2018) an online BIM platform, to archive data for energy modeling and sharing information between the actors.

The BIM model was then exported as a gbxml file into the IES-VE software (Integrated Environmental Solutions, 2018) to conduct the energy analysis. The energetic model

was calibrated following the Raftery methodology (Raftery *et al.*, 2011) using the ASHRAE Guidelines 14 providing a NMBE of 0.21% (<5%) and a CV (RMSE) of 7.57% (<20%). Furthermore, as suggested by the International Performance Measurements and Verification Protocol (IPMVP) (Efficiency Valuation Organization, 2016), a comparison in terms of monthly deviation between the simulated energy consumption and the utility bills have been carried out. The monthly deviation values, as shown in Figure 4, are within the 15% boundary recommended by IPMVP.

Figure 4. Energy monthly deviation based on the IES-VE model

In order to estimate which retrofit intervention has been the most profitable, a back-casting simulation has been carried out as described by the IPMVP. This methodology analyses the building at its original conditions and the energy consumption at these conditions is calculated. The annual savings of each retrofit can then, be evaluated through each renovation package. Thus, the four retrofit packages related to the envelope and the lighting system, and their combinations, were simulated in the original model of 1998.

The Annual Energy consumptions and the Annual Savings have been calculated through the IES-VE model (Table 2), the Annual Electricity Cost and Annual Bill Savings have been evaluated, considering the electricity tariff of 0.1497€/kWh (Compare Electricity Prices, 2018).

The Cost Investment has been calculated based on the bills of quantities generated by Revit and the quotes of

Table 2. Summary of the retrofit scenarios' results.

Retrofit	Annual Energy consumption [kWh]	Annual Savings [%]	Annual Electricity Cost [€]	Annual Bill Savings [€/year]	Cost Investment [€]	Capital Investment [€]	Payback Period [year]	Discomfort hours [%]	Most cost-effective option
1998	17332.44	-	2594.67		-	-	-	12.9	
A1	15496.46	10.59	2319.82	245.73	520	520	2	12.9	√
B1	16606.17	4.19	2485.94	104.17	17100	17100	164	12.6	
B2	17027	1.76	2548.94	44.92	4222.06	1822.06	41	12.5	
B3	16198.55	6.54	2424.92	158.64	2842.6	2442.6	15	4.8	√
A1+B3	14362.57	17.13	2150.08	368.41	3362.6	2962.6	8	4.8	
B1+B2	16248.89	6.25	2432.46	152.07	21322.06	18922.06	124	10.9	
B2+B3	15126.53	12.73	2264.44	288.20	7064.66	4264.66	15	4.2	
B1+B3	15612.72	9.92	2337.22	231.90	19942.6	19542.6	84	4.6	
A1+B1+B2	14412.91	16.84	2157.61	363.43	21842.06	19442.06	53	10.9	
A1+B2+B3	13290.55	23.32	1989.60	463.97	7584.66	4784.66	10	4.2	√
A1+B1+B3	13776.74	20.51	2062.38	423.09	20462.6	20062.6	47	4.6	
B1+B2+B3	14363.51	17.13	2150.22	368.32	24164.66	21364.66	58	2.4	
As it is	12527.48	27.72	1875.36	519.89	24684.66	21884.66	42	2.4	

Irish construction companies. The Capital Investment is the cost of the retrofit measures minus the existing grants available in Ireland (SEAI, 2018). The Payback Period is the length of time required to recover the cost of an investment and has been calculated by dividing the Capital Investment per the Annual Bill Savings.

Moreover, this study includes an indoor thermal comfort analysis of the original building and all the retrofit scenarios. For this analysis, a comfort index (IES-VE, 2013) is utilised in evaluating the thermal comfort of each space. This analysis is performed only during occupied hours and considers all rooms are naturally ventilated.

This index is based on a scale from 0-very cold to 13-very hot, where the comfort threshold is from 6 to 8. The percentage of the discomfort hours is calculated dividing the total hours of the occupied rooms by the total hours outside the comfort range (0-5 and 9-13).

Discussion

According to the results shown in Table 2 the most economical package has been the updating of the lighting system (A1) with a payback period of 2 years. In terms of comfort, the best retrofit has been the insulation of the roof (B3), leading from 12.9% to 4.8% hours of annual discomfort with a payback period of 15 years. The best package which optimises thermal and economic values is "A1+B2+B3". This package has a return of investment of 10 years compared to the current retrofit of 42 years. These results present a discomfort rate of 4.2%, which only increases the current rate by 1.8%.

Furthermore, according to the outcomes we can assume that the envelope retrofits B1 and B2 were very expensive and, interestingly, didn't improve the occupancy comfort. Thus, they could have been avoided.

Conclusion

This paper investigated a systematic methodology for retrofits of existing buildings for energy efficiency and sustainability. A BPM for Engineering Analysis has been presented in order to evaluate the most cost-effective retrofit strategies in an Irish residential house using the benefits of BIM.

A BIM model has been created using the software Revit and has been exported into IES-VE through a gbxml file. The model was then calibrated using the ASHRAE guidelines 14 comparing the energy bills and the simulated energy consumption of the year 2017.

Using the automatic generation of the bills of quantity in Revit BIM it was possible to estimate the capital investment of a series of proposed retrofits and, adding the energy consumption for each of those estimated in IES-VE, to calculate the annual savings and the payback period. To conclude, the application of the methodology presented in this paper leads to the most cost-effective retrofitting choice and considers important factors such as payback period and indoor thermal comfort.

The future work of the authors will focus on:

- quantification of time and resource gain from the application of the presented methodology, compared to a standard building retrofit workflow;
- automatization of the selection of the best retrofit solution for the building, using appropriate weighting factors and constraints, applied to the proposed KPIs;
- application of the methodology to a selection of diverse case studies in order to evaluate effectiveness and scalability of the methodology.

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