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BUILDING INFORMATION MODELLING ENERGY PERFORMANCE ASSESSMENT ON DOMESTIC DWELLINGS: A COMPARATIVE STUDY

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Building Information Modelling (BIM) is growing in pace, not only in design and construction stages, but also in the analysis of facilities throughout their life cycle. With this continued growth and utilisation of the BIM processes, there comes the possibility to adopt such procedures to measure accurately the energy efficiency of buildings; and therefore, their energy usage. To this end, the aim of this research is to investigate if the introduction of BIM Energy Performance Assessment in the form of software analysis provides accurate results, when compared with actual energy consumption recorded. Through selective criterion sampling, three domestic case studies are scrutinised, with baseline figures taken from existing energy providers, the results scrutinised and compared with calculations provided from two separate BIM energy analysis software packages. Of the numerous software packages available, criterion sampling is used to select two of the most prominent platforms available on the market today. The two packages selected for scrutiny are Integrated Environmental Solutions - Virtual Environment (IES-VE) and Autodesk's Green Building Studio (GBS). The results indicate that IES-VE estimated the energy use in region of ±8% in two out of three case studies, while GBS estimated usage approximately ±5%. The findings indicate that the introduction of BIM energy performance assessment, using proprietary software analysis, is a viable alternative to manual calculations of building energy use, mainly due to the accuracy and speed of assessing, even the most complex models. Given the surge in accurate and detailed BIM models and the importance placed on the continued monitoring and control of buildings energy use within today’s environmentally conscious society, this provides an alternative means by which to assess accurately a buildings energy usage, in a quick and cost effective manner.

Keywords: building performance, green buildings, modelling.

INTRODUCTION

Building Information Modelling (BIM) is not a new process, having originated within the petrochemical sector under various aliases; but it was not until 1962 that Douglas C. Englebarts, in a report on ‘Augmenting Human Intellect’, that the phrase first emerged (Englebarts 1962). In the context of the built environment, the concept of

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BIM began to gain traction through the emergence of visual representation and accompanying programming environment. However, it is only in the last ten to fifteen years that BIM has begun to thrive in the construction sector, mainly under the premise of increasing the collaborative working environment. With the United Kingdom (UK) Government mandate of April 2016 for stage two BIM implementation fast approaching, the construction industry is continuing to upskill and develop the necessary competencies and processes required to meet this directive.

BIM is documented as an essential tool for the integration and amalgamation of intelligent and informative models, based on underlying information, integrated within a common data environment. Azhar (2011) outlines numerous benefits, including increased collaboration, accurate modelling, and increased appreciation of the inherent design process. However, in the context of analysing existing structures, this ability has yet to be introduced and maximised within the construction sector in any meaningful manner. Interestingly, Laine *et al*. (2007) outline that there are benefits derived in thermal performance management in building design and suggest that this process should also include operation. Crosbie *et al*. (2010) also advocates energy profiling of both new and existing buildings, while Schlueter and Thesseling (2009) advocate energy performance assessment in early design stages. However, these and other researchers fail to consider addressing energy analysis, using case studies, to measure the actuality within the built environment, specifically in a domestic construction context.

To this end, the aim of the paper is to investigate, by using three individual domestic case studies, the accuracy of BIM Energy Performance Assessment in the form of software analysis, when compared with actual energy consumption recorded. The research design applied in this instance is founded on the analytical review of three case studies using a variety of software packages. The results will help to identify the most accurate form of energy performance assessment method; thus helping practitioners in their selection and application of energy assessment, both in design and maintenance. It will also aid an academic audience in the appreciation and importance of accurate energy performance assessment, while also spurring additional research streams within the subject in context.

BUILDING INFORMATION MODELLING AND ENERGY ANALYSIS IN BUILDINGS

Since the introduction of 'Our Common Future' and the idea of sustainability, many of the world's governments have begun placing sustainability targets on its industries. The European Union legislative body introduced these targets and regulations in an attempt to limit the allowable energy consumption of buildings (Department of Communications 2009). This creates performance based building energy targets, which have resulted in clients and the architectural, engineering and construction sectors working together, to create carbon efficiency in the built environment. To facilitate this, technology has been developed and adapted to ensure that the targets for energy savings and carbon dioxide emissions can be achieved through efficiency in building design (Motawa and Carter 2012).

With this technological development, BIM has emerged as one of the leading processes in which to assist in monitoring and controlling these energy consumption concerns. BIM is a digitally constructed representation of a building's design using intelligent and intuitive design founded on component construction. This digital representation, not only allows for 3D visualisation, but also incorporates a vast array of intellectual information, including precise building geometry, spatial attributes and, most importantly, element thermal properties; all of which is intended to support the stages of the project from design through to operation and decommissioning (Azhar 2011).

Azhar *et al*. (2011) suggest that BIM is fully capable of enhancing a buildings sustainability, but to date, this ability has yet to be maximised by the construction sector. As such, BIM has developed analytical support systems, which enable users to carry out energy efficiency analysis, of both new and existing buildings (Ryan and Sanquist 2012). This type of analysis is produced under the remit of the sixth dimension (6D), which is what is commonly referred to as the sustainability and life cycle dimension; thus forming part of the facilities management aspect within the overarching BIM process. Using BIM, even in this regard, has the potential to result in faster and more effective processes, controlled whole life costs and energy data, integrated planning and implementation; thus leading to a more competitive industry with long term sustainable growth and ultimately, better customer service (Arayici 2008).

As a tool for assessments, Krygiel and Nies (2008) suggests that BIM Energy Performance Assessment, which is also known as Energy Profiling, can be used to perform part of the life cycle analysis, by measuring and predicting building energy use, in both late design and operational phases. Ultimately, this mode of energy use assessment must be as accurate as possible, in order to produce reliable and usable results for the sector. According to Crosbie *et al*. (2010), energy performance assessment or energy profiling, typically involves the analysis of a buildings actual energy performance. This will ideally lead to the improvement of the energy performance of buildings through more informed design. Therefore, this energy performance assessment can potentially be applied as a more efficient and accurate alternative for manual calculations and associated assessment. The use of current manual calculations is partly driven by legislative pressure; a premise supported by Crosbie *et al*. (2010), who suggests that increasing energy prices and legislative regulations are causing a surge in interest in energy performance assessment, in both the commercial and domestic sector. Energy performance assessment can typically be applied in two phases; either individually or collectively. In the context of the design phase, this involves the building designers running energy simulations to analyse the buildings energy performance. Under the operational phase, assessment is based on actual energy consumption within the building and the results used to illustrate how building owners can improve their energy usage (Hellingsworth *et al*. 2002; Crosbie *et al*. 2010). With the continuing advancement of BIM being used for design stage energy profiling (Crosbie, *et al*., 2010), it is conceivable that it can be used for operational stage profiling. To date, this is only considered and incorporated within building management systems in the context of facilities management, with the merits of its application to existing buildings for energy use estimation, yet to be widely tested.

To this end, it is estimated that the overall effective use of BIM, specifically in the context of this paper, can be achieved through the integration of ‘tested’ simulation tools to improve accuracy of the simulations (O'Donnell *et al*. 2005; Krygiel and Nies 2008). Stadel *et al*. (2011) emphasise that BIM can be used for this purpose, as the parent modelling software in some cases, has convenient plug-ins, to calculate operational energy usage. The use of such an approach is further supported by Motawa and Carter (2012), who specified, that for energy analysis to be accurate, one must use the integrated energy analysis software available within the BIM design packages used.

It is conceivable that with the advancement of technology, BIM can assist in the establishment of higher standards of excellence in the future. This advancement could potentially aid in the achievement of the government targets and building regulations set out under BIM 2016 (Bynum *et al*., 2013). Bynum *et al*. (2013) also propose that through sustainable business practice, such as willingness to co-operate to achieve maximum collaboration, BIM will be maximised, and thus, it is conceivable that this will result in more efficient BIM operation and furthermore, a potential for highly accurate energy analyses.

However, Crosbie *et al*. (2010) and Motawa *et al*. (2012) criticise its use in this fashion, as they believe that the current energy analysis software applications available through BIM, are based on estimated values and assumptions of operational use, much like the manual energy performance assessment techniques. This in turn, has the potential to result in inaccurate energy use estimates. Ryan and Sanquist (2012), found that the largely unpredictable nature of occupancy could result in errors and thus, produce inaccurate data. Subsequently, research by these and other practitioners demonstrate that the accuracy of building energy profiling software may not be accurate in every instance. As a result, and for the purposes of this study, the accuracy in a domestic context must be determined, in order for both the industry and academic sectors to ascertain the future value within this practice.

RESEARCH DESIGN

In order to address the aim of investigating the accuracy of BIM Energy Performance Assessment in a domestic context, it is essential to, firstly, identify potential case studies to measure the actual performance of modelled structures and secondly, to identify potential software packages to utilise as part of the review process.

Firstly, in the context of the case studies identification and selection process, in order to minimise interoperability issues when exporting models into the respective energy analysis software, a relatively simple structure is selected - a domestic building. Ten case studies are identified based on adopting a criterion sampling method, where the properties in question have to be meet a set of predetermined conditions. Firstly and most importantly, each case study must be a domestic, detached unit. Additionally, each of the case studies must have the consent of the homeowner, have access to at least twelve months of utility bills and have access to the premises to survey the respective buildings to assist the modelling of the structures. Of the ten potential case studies identified using this method, random sampling is then introduced to shortlist and ascertain three random case studies for inclusion in the research. This process reduces the possibility of researcher bias in the identification and selection of the case studies for inclusion in the research. Additionally, through triangulation of the case study data, it is possible to identify and document trends that are beyond chance alone. Subsequently, three domestic dwellings are selected; case study I is a detached single storey dwelling built in the late 1940's / early 1950’s, case study II is a two storey semi-detached dwelling built in the late 1970's / early 1980’s, and case study III is a detached two storey dwelling built in 2005.

Each of these structures is surveyed and modelled using Autodesk Revit. This software package is selected as it allows for structured creation of the models while also having the capability to incorporate occupancy and energy usage data through its

MEP (Mechanical, Electrical and Plumbing) provisions. This software platform also supports the export of gbXML format, which is supported by most energy analysis software packages. Finally, this software also accommodates supporting add-on capability with the selected energy analysis software, which further mitigates the potential for interoperability issues to emerge during the transfer and examination of the respective structures.

Secondly, with regard to the analytical software packages considered for this study, both Integrated Environmental Solutions – Virtual Environment or IES-VE and Autodesk's Green Building Studio or GBS, utilising the default analysis in both cases, are shortlisted for consideration. Both packages are selected due to their integrated functionality with Autodesk Revit, while providing functionality that will simulate and asses the energy requirements of each of the nominated dwellings. Originally, a third option in the form of Autodesk Ecotect Analysis is considered; however, it is intended to be used in conjunction with GBS to provide additional functionality. This additional functionality is not required for the current study; therefore Autodesk Ecotect was omitted from the study.

To ensure consistency within the research and supporting analysis, each case study follows a specific vein, as detailed in Figure 1.

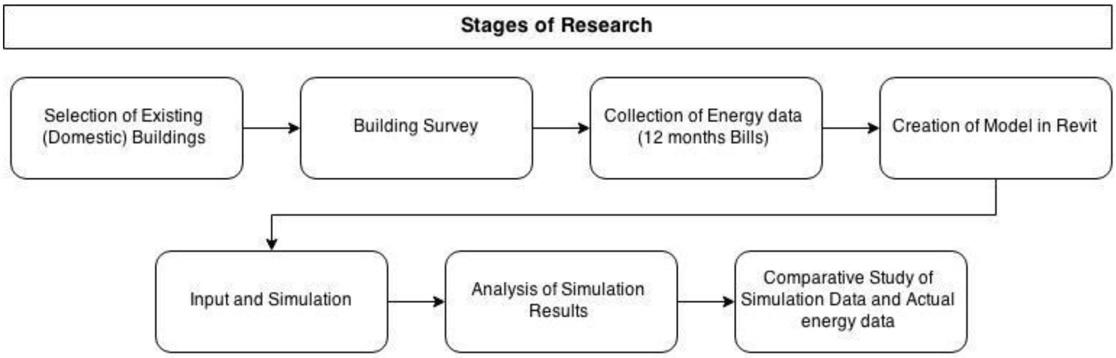


Figure 8: Research Flow Chart

Once each of the three case studies are modelled and analysed using the respective tools identified, the results are quantified using an energy comparison spreadsheet. This spreadsheet is created to compare and contrast the results and calculate percentage differences, in each case, while also comparing the results against the baseline. The baseline is calculated from the existing utility bills from each of the respective domestic units; thus providing an insight into the actuality of the case studies in question. This then provides the ability to establish a percentage difference between the results compared and recorded to the baseline energy use acquired from the existing energy bills from the respective dwellings. Given that a percentage is used to establish the accuracy of the models and their underlying energy outputs, a margin of error is applied. In light of this, previous research by Maamari *et al*. (2006) and Reeves *et al*. (2012) highlight that computer simulations are deemed accurate where results are produced within ±15% of the control test. Therefore, in the context of this paper, results that emerge within this range of the existing baseline are deemed accurate.

RESULTS AND ANALYSIS

As outlined, three case studies are carried out, detailing the baseline energy use over an eighteen-month period and the two BIM Energy Performance Assessment simulations results compared. The result of the analysis is displayed in table 1. Given the results, particularly in case study I, it would appear that the simulations proved promising. However, geometrical issues are encountered in the attic space of case study II, which prevented the simulation from being carried out until that space was removed. This issue is encountered in GBS, and therefore the results produced by GBS in this instance are based on the building minus one bedroom. In light of this, the results from case study II are not considered appropriate and as a result, are omitted from the study. Further detailed research is ongoing at the time of writing, where this anomaly is revisited and contingency measures introduced to eliminate this issue within the analysis.

Table 1: Case study analysis results

Case Study 1

Case study 1 results

	Total kWh
Baseline	19,928.61
GBS	13,953.50
IES	15,380.00

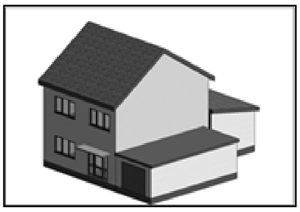
Case study 1 - % difference

	% Difference
Baseline	0%
GBS	-30%
IES	-23%

Case 1 - Heating & Electrical %

	Heating	Electrical
Baseline	-	-
GBS	-29%	-33%
IES	-8%	-93%

Case Study 2



Case study 2 results

	Total kWh
Baseline	16,916.55
GBS	17,313.33
IES	17,809.80

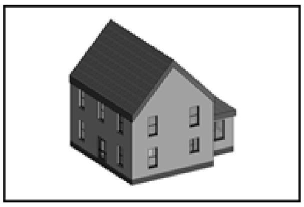
Case study 2 - % difference

	% Difference
Baseline	-
GBS	2%
IES	5%

Case 2 - Heating & Electrical % Difference

	Heating	Electrical
Baseline	-	-
GBS	-5%	15%
IES	52%	-73%

Case Study 3



Case study 3 results

	Total kWh
Baseline	21,539.46
GBS	34,904.11
IES	30,369.70

Case study 3 - % difference

	% Difference
Baseline	-
GBS	62%
IES	41%

Case 3 - Heating & Electrical % Difference

	Heating	Electrical
Baseline	-	-
GBS	28%	171%
IES	8%	145%

COMPARATIVE DISCUSSION

Based on the results outlined in Figure 1, in the majority of cases, all estimates are far beyond the acceptable ±15% percentage difference prescribed to ascertain that the results are accurate when compared with existing utility bills. Following the breakdown of the data, it is determined the reason for the widely varying estimates is due to the lack of electrical appliance data. This could have been achieved through accurate input of Watts (W) or Kilowatts (kW) used by the total number of appliances in a dwelling, that is, televisions, washing machines, etc. Therefore, the result produced by GBS, where electricity is estimated within the acceptable percentage difference at 15%, is not considered valid, as the electrical appliance data and its use is not known.

Despite these issues, it is determined that, due to the wide variation of the electrical data, no viable conclusion could be achieved. Therefore, the electrical estimations have to be omitted from the overall results of the study. Regardless of these findings, the remaining heating energy category still presented practical results as shown in table 2. The results from the electrical data are to be revisited and deliberated further in an alternative piece of research, focusing on electrical energy performance measurement. Once the data relating to the electrical aspects are revisited, the results will be subsequently published in a paper and subsequent separate study focusing on this aspect of the research. However, this does not affect the results relating to heating, as in all of the case studies herein, heating is provided by means of solid fuel, oil or gas. Therefore, the results relating to heating are both relevant and accurate.

Table 2: Percentage differences in heating results of case studies

	Case Study I	Case Study II	Case Study III
Baseline	-	-	-
IES	-8%	52%	8%
GBS	-29%	-5%	28%

It is determined that the heating estimation and simulation results produced by GBS are outside the acceptable ±15% in two of the three case studies (+28% and -29%). However in the context of IES-VE, in two of the three case studies, the simulation presented promising results of -8% and +8% respectively, with only one beyond the acceptable threshold (+52%).

CONCLUSION

With the emergence of BIM throughout the construction sector, in conjunction with the need to take more effective control of our built environment energy usage, there is a need to link these aspects collectively. The literature clearly illustrates the need for greater energy efficiency driven by government targets (Department of Communications, Energy and Natural Resources, 2014; Bynum, *et al*., 2013; Hellingsworth, *et al*., 2002). Additionally, clear evidence is provided to demonstrate that BIM could aid this need for greater energy efficiency through BIM Energy Performance Assessment capability.

To address this dearth in knowledge and application in context, an initial case study analysis of three domestic units is undertaken using Integrated Environmental Solutions – Virtual Environment (IES-VE) and Autodesk's Green Building Studio (GBS) with the models produced in Autodesk Revit. The study confirms the accuracy of one of the BIM Energy Performance Assessment tools, by comparing the estimated annual energy data produced by GBS and IES-VE in comparison to the calculated baseline use. In this context, the BIM Energy Performance Assessment tools are considered accurate, only if it they meet the percentage difference criteria of within ±15% (Maamari *et al*. 2006). Through the use of three case studies it can be confirmed that one of the two BIM tools is accurate in the majority of cases (two from three instances measured) in terms of heating prediction. However, even though the estimates could be construed as accurate overall, when they are broken down, the values merely averaged out to obtain a random estimate that was only accurate by chance. The study concludes that IES-VE is the more accurate of the two BIM assessment tools surveyed. The results produced by IES-VE in terms of heating estimations, can be confirmed accurate in two instances (case studies I and III).

It is found that, in the majority of cases, the electrical estimates through IES-VE and GBS are all either significantly over or underestimated (>15%), as a result of insufficient electrical appliance data. Therefore, this data is not included in the comparison. This also suggests that BIM Energy Performance Assessment may not be sufficiently robust to provide overall energy estimates for domestic dwellings, as it may not be possible to accurately estimate both the potential number and energy use of the electrical appliances in the building. This indicates that using BIM Energy Performance Assessment in isolation may not be feasible without considering the inclusion of appliances within the design. Therefore, for the purpose of this paper, the electrical data is not considered nor discussed in detail, but the subject of further investigation, with the emphasis on the heating data and the results provided. In relation to the results reported on heating, these figures remain unaffected, as heating in all of the case studies is provided outside of electrical means.

Furthermore, this is combined with the variable nature of occupancy schedules in different rooms of the building, which may not be possible to accurately predict (Ryan and Sanquist 2012). Due to this, further research is ongoing on the aspect of obtaining more complete data using a larger sample size and more detailed modelling techniques, to mitigate such anomalies within the dataset. This includes the acquisition and inclusion of further case studies including various domestic dwellings beyond detached units, to address the limitations that are evident in the selection of a single domestic style.

However, despite this, when all heating estimation values and percentage differences of both the simulation results and measured data are compared, it concludes that IES-VE is the more accurate heating energy estimation method for these domestic buildings, when compared with GBS. These findings can be used by those designing and working within the context of domestic construction sector, to assist in making informative decisions; however, due to the preliminary nature of the study, it is not possible to conclude by stating that the results herein should be adopted without question, but simply provide another level of scrutiny in the energy performance assessment measures adopted.

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