Challenges in Energy Analysis of BIM based Building Projects During Early Design Phase

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Abstract

The challenges presented by excessive energy use in the built environment have been well documented and proven by many academic and national research over the past 20 years. These are mainly manifested in climate change direct and indirect impacts on health and well-being, as well as irreversible damage caused on a global scale. As a consequence, a variety of physical and voluntary approaches have been taken at international levels to limit the impacts caused. However, the problems associated with the built environment is quite complex as energy consumption and carbon emission of buildings have been increasing for several decades.

Effective reduction in energy consumption within the AEC (Architecture Engineering and Construction) sector needs a detailed understanding of where energy is used, and carbon associated with it on a building. With the advancement of Building Information Modelling (BIM) applications in AEC sector, integration of building energy analysis with BIM has received much interest of researchers and governments at present. As a result, number of researches have been conducted in order to integrate Life cycle energy analysis with BIM. However, what has lagged behind is the effective integration of whole life cycle energy analysis and applying digital analysis prediction of energy consumption as a tool within BIM frameworks.

Therefore, this paper attempted to investigate the challenges and difficulties faced in using existing life cycle energy analysis tools during early design phase of BIM based projects. The findings revealed that complexity and time-consuming nature of mapping life cycle input data, interoperability with BIM and determining an adequate granularity and development process for building BIM model as key challenges. Accordingly, the study suggests the necessity of an effective, accurate and complete energy analysis tool which can be integrated into BIM based projects during their early design phase.

Keywords: Building Energy Modelling, Life Cycle Energy Analysis, Early Design Stage

1. Introduction

The building sector is considered as a major energy consumer as well as a major culprit for the increasing presence of atmospheric carbon. In the UK, almost 40% of energy consumption and carbon emissions come from the operation of buildings (MHCLG, 2014). Therefore, awareness on optimizing of energy consumption and carbon reduction in buildings has been increased over the last years, making the energy performance of buildings legislation (England and Wales) more stringent. As explained by MHCLG (2014), even small changes in energy performance and the way each building is occupied will have a significant effect in reducing total energy consumption.

A building within its lifetime consumes not only the operational energy but also the embodied energy. Operational energy is the energy required to run a building by operating processes such as heating and cooling, lighting, ventilating and appliances; whereas embodied energy of a building is the energy consumed by all the processes associated with its production i.e. extract raw resources, process materials, assemble product components, transport between each step, construction, maintenance and repair, deconstruction and disposal (Ibn-Mohammed et al., 2013). Therefore, optimization of energy consumption of buildings requires equal attention on both operational and embodied energy.

Building energy analysis is the main drive towards energy optimization. It enables a deeper understanding of the likely effects of the changes in building design and occupation which affect the energy performance of buildings (BRE, n.d). An energy analysis can be performed during building design, construction, and/or operation stage. However, according to the Energy Performance of Buildings Regulation (2012), it emphasizes that energy modelling should be carried out at an early stage of the design process of new buildings in which more opportunities are available to optimize the energy consumption by further improving the design and construction.

During the last decade, Building Information Modelling (BIM) had significant growth within Architecture, Engineering and Construction (AEC) industry enabling to improve decision making and performance across the building and infrastructure lifecycle (Gokuc and Arditi, 2017). Incorporating energy analysis into BIM during design stage would certainly provide many benefits including giving more room to create alternative options which optimize the whole building life cycle energy consumption. Number of researches have been carried out integrating embodied and operational energy assessment with BIM in isolation platforms, but limited research contributions were found integrating whole building life cycle energy analysis (operational and embodied) with BIM during early design stage to optimize the total energy consumption (Shadram and Mukkavaara, 2018). Accordingly, this study explores the challenges in using existing tools for whole buildings life cycle energy analysis during early design phase of BIM based projects.

This paper is organized into six main sections; section 1 briefly introduces the aim of this study, section 2 presents the methods adopted to conduct the study, this is followed by benefits of BIM based energy analysis during early design stage of buildings are discussed under under Section 3, section 4 explains existing building energy analysis tools. The challenges in using existing tools for energy analysis during early design phase of BIM based projects are discussed in section 5. In the end, the section 6 draws the conclusions and future work.

2. Method

The purpose of this paper was to investigate the challenges in using existing LCEA(life cycle energy analysis) tools during design phase of BIM based projects. Accordingly, the paper followed a systematic literature review. The search results limited to last 10 years period and thus, related books, journal articles, government publications, web sites, newspaper articles, and other published reports were referred.

3. Benefits of Energy Analysis of BIM based Buildings During Early Design Stage

In the building industry, the concept of BIM has gained increasing acceptance over the last years, increasing collaboration among building design and construction project members (Eastman et al, 2011; Schlueter and Thesseling, 2009). According to the US National Institute of Building Sciences Facilities Information Council (2010), "BIM is a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition".

In the traditional project delivery method, the work of architects, structural engineers, MEP engineers, contractors, and various other building consultants occurs in relative isolation to one another. However, BIM-based project delivery method, information available to the various parties can all be shared and integrated around a central building information model (Azhar, et.al., 2011). In addition, immersive virtual environments (IVEs) combine pre-construction mock-up that presents a sense of real space to the future users and building information models that allow for testing of different design alternatives (Heydarian et al., 2015).

In conventional energy modelling approach, traditionally created 2D drawings were used to create an independent model in an energy modelling tool (US GSA, 2015). This may lead to misinterpretation of the drawings, inconsistencies, simplified model, and large amount of time needed to create an energy model (Reeves, Olbina and Issa, 2015). In contrast, BIM-based energy analysis assists to automate this process and create consistent and more complex energy models which provide faster and accurate results compared to the traditional methods (Azhar et.al., 2011; US GSA, 2015). In BIM-based project delivery, energy analysis can be integrated into building design, construction, and operation/maintenance more efficiently as energy performance is analyzed using the central BIM model without having to recreate building geometry in certain energy analysis platforms (i.e., gbXML-enabled tools). According to US-GSA (2015), use of BIM -based energy analysis provides several benefits including: more accurate and complete energy performance analysis in early design stages, improved lifecycle cost analysis, and more opportunities for monitoring actual building performance during the operation phase. In addition to them, it will assist to assess the energy benefits of various design alternatives and thus help designers and owners make better decisions related to materials and products selection that have low environmental impact (Donn, Selkowitz and Bordass, 2012).

4. Existing Building Energy Analysis Tools

Most of the important decisions related to energy efficiency are made early in the design process as more energy savings can be achieved later on in the project (Cemesova, et al., 2015). And importantly, Energy performance regulation (2012) mentions that energy modelling should be carried out at an early stage of the design process of new buildings, in order to inform further development of the design and construction. As a result, number of tools have been developed to support the operational and embodied energy estimation and analysis process. The below two sections describe such existing operational and life cycle energy analysis tools.

4.1 Operational energy analysis tools

Operational energy analysis is an assessment of the overall building energy performance (BEP) and also known as building energy modelling (BEM). There are various existing BEM tools available for the use of architect and building services engineers in order to evaluate the design decision during the preconstruction design stages in informing building design performance analysis and validation (Hyun, Marjanovic-Halburd and Raslan, 2015). These tools can be used during conceptual and early design stage in order to:

1. Understand climate and weather of the project location
2. Inform the massing and orientation phase
3. Design and selection of materials for building fabric
4. Simulate the energy use of building services (Zanni, 2016 and Reeves, Olbina and Issa, 2015)

Table 1 summarises the existing BEM tools that can be used to above purposes during early design stage of a building development.

Table 1: Operational Energy Analysis Tools

Purpose	Design/ Energy variables	BEM tools
Climate and weather	Daylight availability Solar access/intensity Wind direction/intensity Temperature range Humidity	Autodesk Vasari Sefaira Autodesk Revit PHPP IES-VE EcoDesigner EDSL TAS Bentley Hevacomp TRNSYS

		Climate consultant
Massing and orientation	Overshadowing Building height and footprint Irradiance over building's planes Thermal performance Daylight Ventilation	Sefaira Autodesk Revit plug in IES-VE EnergyPlus eQuest PHPP iSBEM
Building fabric	Glazing and shading Daylighting Insulation properties of building skin: Solid and voids (U-Values and G-values) Airtightness (at 50 Pa) Ventilation and free cooling Overheating	IES-VE Sefaira EnergyPlus (engine) PHPP DesignBuilder (operated by energy plus) Open studio (operated by energy plus) EcoDesigner EDSL TAS Bentley Hevacomp TRNSYS EnergyPlus
Building services	Energy consumption Heating, cooling, and hot water Electric load IT and small power consumption Energy source Artificial lighting Occupation schedules	IES-VE Bentley Hevacomp Modelica Sefaira EnergyPlus (engine) DesignBuilder EcoDesigner EDSL TAS TRNSYS Assessment (SWERA) Solar Deployment System (SolarDS) Open studio (operated by energy plus)

Source: Zanni, 2016 and Reeves, Olbina and Issa, 2015

In the UK , only few tools such as IES-VE, DesignBuilder and EnergyPlus engine are approved and compliant for the high accuracy as they are accredited by UK's National calculation method (NCM) (BRE, no date). But, still the use of those tools are reported to be non-user friendly specially for architects, too complex and require high detailed input, beside it is not compatible to the architects' iterative working need for exploring multiple alternatives at early stage that requires manageable input (Arayici et al., 2018).

4.2 Life cycle energy analysis tools including embodied energy

Numerous studies in the last ten years have been conducted for general BIM-LCA integration and estimation of embodied energy in particular. Table 2 presents few such tools which can be used to estimate life cycle energy including embodied energy during early design stage of a building. The required input and system boundaries of each tools are also summarised in the table.

Table 2: Life Cycle Energy Analysis Tools

Tool	Input required	System boundary and region of database
Tally (Kieran Timberlake, 2014)	**Automatic Quantity take-off from model:** Only required to assign the unit of material calculation/ Material take off options (Length, area, volume) **Automated family identification:** All objects are automatically available in the interface according to modelled families. **Required material mapping:** Required the material mapping of the existing materials to the material library database in the program.	**Allow cradle to grave system boundary.** Usually user rely on industry average transportation and construction impact. Ignores construction details and asks for lump sum value. -Material database used is German database GABi and filtered to North America market and manufacturers.
One Click LCA (One Click LCA, n.d)	**Import open standard BIM schema file either IFC or gbxml and file additional project information.** Similar to tally.	**Allow cradle to grave system boundary.** -complies with European standards and has template for North American Market as well -Have different schemes for use in UK and international schemes as well
Athena **Impact Estimator** (Bowick, O 'connor and Meil, 2010)	- **manual entry of project material take-off** - **Assembly information** (geometry, assembly/material choice, loading) - **Operational energy information** (annual operating energy) - **Building information** (location, life expectancy, occupancy type, floor area, height)	High detailed tool with high range of LCA scoping according to: 1. Object of assessment eg. Core and shell 2. System boundary, Life cycle activities To according include scenario for database Suitable for Canadian and US regions.
etool LCD (Hermon and Higgins, 2015)	Similar to Athena IE	Similar to Athena IE, but have different schemes for use in the UK and international European and US schemes as well

Ms Excel and data base such as ICE, Gabie, US LCI	-Manual entry of material quantities that can be -Manual search through data base to get coefficients of the embodied energy values for excel calculations.	**Flexible method** as User can determine the system boundary. Level of complexity is also determined by the user.

5. Challenges in Using Existing Tools for Whole Life Cycle Energy Analysis of BIM based Projects During Early Design Phase

BIM facilitates energy efficient design within the energy consumption assessment throughout the entire life cycle of buildings (Häkkinen and Kiviniemi,2008). However, there are many challenges in using tools mentioned in Table 2 for assessing whole life cycle energy during early design stage of BIM based projects due to lack of interoperability of existing tools, lack of input data during early design stage and difficulty in determining an adequate granularity and development process for building BIM models.

5.1 Complexity and Time-Consuming Nature of Mapping Life Cycle Input Data

The complexity and time-consuming nature of mapping the life cycle input data with building material quantities is one of the main challenges confronted using existing tools (Soust-Verdaguer, Llatas and García-Martínez, 2017). The multiple manual input required to match the sustainability data with the material properties database question the practicality of use due to the need for long modelling time and high susceptibility in errors during transfer. A study done by Jarde and Abdulla, 2012, accessed the embodied energy and carbon for two different alternatives of houses, the first is mud-brick and second is cement block. The manual calculation presented in the study to estimate the embodied energy and carbon for two alternatives reflects the complexity and time consumption required to compare results, which highly affect the uptake of this approach by architects in early design.

5.2 Interoperability of existing tools with BIM

The other challenge is the lack of interoperability between BIM model and LCA tools which limited the role of BIM model. Table 3 summarises the interoperability with BIM and complexity of life cycle energy analysis tools identified in Table 2.

Table 3: Interoperability and complexity of existing Life Cycle Energy Analysis Tools

Tool	Interoperability with BIM environment and complexity
Within BIM Environment	
Tally (Kieran Timberlake, 2014)	**Plugin limited only for Revit** - It is plug in within Revit architecture or structure model - Depends on the granularity and detail of BIM model LOD **Deal with 3 detailed levels:** - Schematic design: showing building components weighting

	- Design option comparison: comparing reports but the after mapping of materials once and executing the results report are available in the BIM model - Complete LCA **Closed commercial product:** Limited customized development or update for the inventory data and not flexible to other system boundaries.
One Click LCA (One Click LCA, n.d)	**Can be used with wide range of software not limited to one** - Web based interface software (IFC can be plugin in Revit, IES-VE, Graphisoft ArchiCAD, tekla structures etc.)
On separate platform- BIM model can just be used for material take-off	
Athena Impact Estimator (Bowick, O 'connor and Meil, 2010)	- Manual entry of material quantity information and required high experienced LCA individual to complete information module about product, construction installation, use, end of life. - Very complicated for the use of screening and simplified LCA that is suitable for early design conceptual phases
etoolLCD (Hermon and Higgins, 2015)	- Manual entry of all Material, Assembly and operational inputs - Have simplified scheme
Ms Excel and data base such as ICE, Gabie, US LCI	- Results are not connected to the BIM model - Level of complexity is flexible and can be designed to suite the conceptual design stage - High possibility of errors - Doesn't allow iterative process as it will be impractical and time consuming - Reliability is not assured and validation is required

5.3 Determining an adequate granularity and development process for building BIM model

The third challenge is determining an adequate granularity and development process for building BIM model. Lee et al., 2015 proposed a framework for automated LCA within BIM model without data exchange. This framework utilizes the use of parametric modelling and inter-object data relationship which associate embedded impact factors of the materials in Revit family (∗. rfa) file. After preparing Revit family for each building element by using a family writer tool, the file is used by the modeller in the BIM authoring tool (Revit). This requires a development of model of LOD 300 or higher in addition to the need for high skilled modeller to use the developed built in family. Another effort in automating calculation of LCA impact factors without exchange of data is proposed by Jrade and Jalaei, 2013. Similar to Lee et al., 2015, the provided framework which adds unique keynote i.e. parameter in each Revit material family. Manual preparation of the material library is required before use by filling keynotes for the plenty potential materials. Despite, these studies provided automatic calculation within BIM environment with no exchange of files between different platforms, the method provide complex and impractical use in the industry current state. This is reasoned by the current lack of ready to use material library and requirement for high skilled modeller of the use of detailed built-in family.

6. Conclusions and Future Work

The finding of the systematic and mapping analysis of available methods in energy analysis tools, reveals that while tools do exist for sustainability purposes, they are currently standalone and not fully compatible with existing BIM frameworks. In order for the construction industry to fully utilize benefits of energy and carbon predictions at early stages in a project, and allow for different options in terms of material selections in order to make more informed decisions in relations to life cycle analysis, more needs to be done on a technical and operational levels. The research for this paper has highlighted that while ready off the shelf tools exist, they are limited by commercial and technical boundaries making them unacceptable to most design and construction professional and attractive only to sustainable minded developers and clients. The main outcomes and conclusions can be summarized as follows:

- Greater collaboration and input are needed amongst stakeholders adopting BIM strategies and development of bottom up approaches to appreciate the importance of energy and carbon within developments.
- Early support and predication are key to achieving energy targets and thus CO2 reductions. The Climate Change Act (2008) also pushes for tough measures, establishing that the UK must reduce emissions by 80% from 1990 levels by 2050. If BIM has been proposed as policy for change and efficiency it must incorporate energy elements and targets.
- LCA and energy predication can be linked to long term Facilities Management (FM), so making a case for energy analysis at earlier stages set the agenda for long term carbon strategy

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Suggestions for future work which are part of the study is to produce a definitive methodology for evaluating the life-cycle of buildings through the lens of BIM and whole energy and carbon emissions The outputs of this research will assist government, developers and planners to compare and contrast options at early design phases.

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