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EXPLORING THE POTENTIAL OF BIM-INTEGRATED SUSTAINABILITY ASSESSMENT IN AEC

Maria A. Zanni*, Robby Soetanto† and Kirti Ruikar‡

*Research Student, School of Civil and Building Engineering,
Loughborough University, Leicestershire, United Kingdom, LE11 3TU
e-mail: M.A.Zanni@lboro.ac.uk
Web page: http://www.lboro.ac.uk/departments/cv/staff/students/421.html

† Lecturer in Construction Management, Loughborough University, School of Civil and Building Engineering,
Loughborough University, Leicestershire, United Kingdom, LE11 3TU
e-mail: R.Soetanto@lboro.ac.uk
Web page: http://www.lboro.ac.uk/departments/cv/staff/profile/356.html

‡ Lecturer in Architectural Engineering, School of Civil and Building Engineering,
Loughborough University, Leicestershire, United Kingdom, LE11 3TU
e-mail: k.d.ruikar@lboro.ac.uk
Web page: http://www.lboro.ac.uk/departments/cv/staff/profile/189.html

Abstract. *Worldwide, the need for designing and constructing more sustainable buildings is constantly growing. Although the most critical time to make decisions on a building's sustainable features is during the early stages of design, building performance analysis is usually performed after the design and construction documents are produced. This practice results in lost opportunities to maximise the use of energy efficient building design and technology options. Along with that, it is widely documented that productivity in the AEC/FM industry has been hampered by fragmentation, low innovation, adversarial relationships and slow adoption of Information Communication Technologies.*

Building Information Modelling (BIM) can promote integration among building professionals and improve design goals by allowing multi-disciplinary information to be integrated within one model. This creates an opportunity to conduct the analysis throughout the design process, concurrently with the production of the design documents. Despite the expected benefits of BIM and sustainable performance analysis, their practices have not been widely embedded within the UK AEC/FM industry. In order to achieve the change in current processes for optimal results, there is a need to define a number of aspects. These include the drivers, actions, good practices, impacts and benefits of sustainability analysis integration in the BIM-collaborative processes on one hand, and the barriers, limitations and deficiencies of current practice on the other.

This paper is an early contribution to this ongoing research to improve the way of conducting BIM-based sustainability analysis and communicating the results among the various AEC participants. This can be achieved by automating and standarising the decision making process at the pre-construction stage. The findings indicate that there is no single tool that can be utilised to assess the full range of criteria required for achieving sustainability. It is also demonstrated how the capabilities of BIM-related sustainability software can be used to predict a number of the BREEAM rating system categories criteria.

Key words: *Sustainability, BIM, building simulation, integration, collaboration, BREEAM*

1 INTRODUCTION

Currently, sustainable performance of buildings has become a major concern among AEC (Architecture, Engineering and Construction) professionals for a variety of reasons. Those include the growing awareness concerning the impact of construction on environmental deterioration which has also led to a number of measures such as building legislation and assessment in addition to a number of national and regional drivers and targets (Schlueter et al. 2009).

In order to address this issue, many countries and international organisations have initiated rating systems to assess sustainable construction. Some examples are United Kingdom's BREEAM (Building Research Establishment's Environmental Assessment Method), United States' LEED (Leadership in Energy and Environmental Design), Australia's GREEN STAR and Japan's CASBEE (Comprehensive Assessment System for Building Environmental Efficiency). Most of these systems take into account similar sustainable criteria such as energy consumption, material use, water efficiency and indoor visual and thermal comfort (Azhar 2011).

Sustainable analysis tools can aid professionals predict a building's performance from the early stages of design and significantly ameliorate both quality and cost during its life cycle. A number of studies have emphasised the importance of early informed decision making before and during the design process (Schlueter et al. 2009, Azhar 2011, Azhar et al. 2008).

Traditionally, the RIBA Plan of Work (1964) is architect-lead while the structural engineer, mechanical engineer, contractor, client and project manager have supplementary roles in the design process. A number of studies have noted that building design is a multi-disciplinary process that requires contribution from a wide range of specialists, the AEC industry is hampered by fragmentation (Charalambous et al. , Bouchlaghem et al. 2005) resulting in poor outturn performance and the need for extensive modifications afterwards. In order to move towards the future of collaborative design the roles need to be re-defined and changed. An Integrated Design Team (IDT) that contributes throughout the whole life-cycle of a facility is the target.

Building Information Modelling (BIM) is considered to be one way to address the deep rooted fragmentation problem in the AEC industry by being a computer intelligible approach to exchange building information in design between disciplines (Sacks et al. 2010). This is considered to be the one step forward towards the long term vision of Integrated Project Delivery (IPD). Moreover, it offers the possibility to manage project information throughout the whole life-cycle of the building from cradle-to-grave.

Following the recommendations by the BIM Working Group, the government has mandate the use of fully collaborative 3D BIM for its projects by 2016 (BIS 2011). BIM can be the answer to the need for increased productivity and low margins that lead to significant time and cost savings. As a result, the number of people that are aware and currently using BIM rose from 13% to 31% from 2010 to 2011(NBS 2012).

So as to make one step forward towards sustainable development (SD) assisted by the new technological improvements (software, hardware and networks) and adapt to this technological evolution, there is the need to specify the process of sustainable performance analysis within BIM-collaboration. The challenge that this incorporation faces is the effective orchestration and co-ordination of all the available elements which are necessary to achieve optimum results. This paper is intended to identify the main elements that will constitute effective sustainable assessment within the design process.

2 NEED FOR SUSTAINABILITY ASSESSMENT IN BIM

The NBS Sustainability Survey 2012 (NBS 2012) illustrates some very interesting results concerning the current state, attributes and practices of construction professionals in the UK. Their roles concerning sustainability are green product selection, Client Advisor on sustainability, energy calculations, project assessment, managing corporate sustainability, Green Deal Advisor, none or other. It showed that even if more than 50% acknowledged the importance of all three aspects of sustainability (environmental, economic and social) and followed a sustainability policy, a very small number of them offer an environmental assessment service. It is apparent that the simplistic Green Overlay to the RIBA Outline Plan of Work (RIBA 2011) along with the BIM Overlay that are currently widely adopted need clarification concerning the sub-processes of sustainable design.

Although a lot of research has been done concerning BIM collaborative design and the efficient use of BIM technology, there is little known about the incorporation of sustainable performance analysis into these processes. Some recent research studies have resulted in producing conceptual frameworks to test interoperability and capabilities of common simulation tools (Azhar et al. 2008, Azhar et al. 2009a, Azhar et al. 2009b, SuperBuildings 2011, Moakher et al. 2012, Bazjanac 2008, Bazjanac 2008, Che et al. 2010, Hetherington et al. 2011, Hamza et al. 2007, Magent et al. 2010, Lee et al. 2007, Maile et al. 2007); some BIM related frameworks are also based on the international assessment rating systems (Biswas et al. 2009, Biswas et al. 2008, Wong et al. 2012, Nofera et al. 2010, Lützkendorf et al. 2006, Sinou et al. 2006, Ghosh et al. 2011) and others have created tools that are integrated into building information modelling (Schlueter et al. 2009, Welle et al. 2011, Feng et al. 2012, Huber et al. 2011, Mahdavi et al. 2001).

Despite these efforts, there is still no comprehensive and structured process to assist professionals to perform sustainability analysis from the early stages of design so as to harness the talents of all building professionals' disciplines and achieve optimum results. The importance of incorporating all disciplines from the early stages of design is widely acknowledged and documented (Bouchlaghem et al. 2005) along with how crucial early decisions are in order to achieve sustainability in the resulting design outcome (Schlueter et al. 2009).

Even though the efficient co-ordination of people, tools and mediums can lead to significant benefits in the quality and performance of buildings, there are many challenges to be faced. An integrated design process, interdisciplinary collaboration, complex design analysis, careful material and system optimisation are required to solve this problem (Nofera et al. 2010).

3 PROJECT AIM

The main aim of this ongoing research is to ameliorate the way of conducting sustainability assessment within BIM collaborative environment in order to achieve leaner and thus more efficient processes. The main concept is to clarify the sub-processes and create a framework that identifies the challenges that need to be overcome.

4 METHODS AND RESEARCH DESIGN

In this paper, a comprehensive literature review takes place so as to evaluate the current state of collaborative BIM-enabled sustainability assessment and identify the elements that need to be integrated. That serves to understand and define the impacts, drivers and benefits of sustainability analysis integration in the BIM-collaborative processes as well as identify the barriers and limitations of current practice and the need for change. Aspects such as people, process, technology, policy and information are reviewed and analysed. Moreover, a number of BIM related performance analysis software is also presented in relation to the BREEAM rating system.

5 ELEMENTS OF BIM-INTEGRATED SUSTAINABLE DESIGN

This section answers to a variety of questions in relation to BIM-based sustainability assessment (who, what and how). Firstly, the aspects that are considered to constitute sustainable design are discussed. Secondly, the sustainable analysis software that can be related to BIM is presented in relation to the minimum standards of the BREEAM rating system categories. That consists also of BIM software itself as sustainable way of working compared to the traditional methods. Thirdly, the means to communicate the sustainable information are discussed. ICT, OCP, interoperability, technology infrastructure and maturity are the technological enablers of BIM collaborative processes. Finally, the various stakeholders in the design process are identified.

5.1 Definition of sustainable development and aspects of sustainable design

The most widely accepted definition of sustainable development (SD) is given by the Brundtland Report (1987); it states that SD is the kind of development that satisfies the needs of the present generations without compromising the chance of future generations to satisfy theirs. The construction industry, as one of the main sectors of the national industry is expected to contribute more towards this direction (Nofera et al. 2010).

The three main pillars of sustainability (environmental, social and economic) can be further analysed in a variety of perspectives which are human well-being, climate change mitigation, environment protection, fossil fuel replacement, security of supply and living standards (Clarke 2012). All those perspectives are necessary to achieve sustainable design but sometimes they become conflicting.

Recent research has acknowledged the complexity of the process of ecological design and identified the most important clusters of eco-determinants to be the following: (i) design aspects and strategies, (ii) environmental impacts, (iii) design environmental strategies, (iv) social aspects, (v) site analysis and (vi) economy (Vakili-Ardebili et al. 2010).

Kriegel and Nies (2008) indicate that BIM can aid in the following aspects of sustainable design: (i) building orientation (selecting a good orientation can reduce energy costs), (ii) building massing (to analyse building form and optimise the building envelope), (iii) daylighting analysis, (iv) water harvesting (reducing water needs in a building), (v) energy modeling (reducing energy needs and analyzing renewable energy options can contribute to low energy costs), (vi) sustainable materials (reducing material needs and using recycled materials), (vii) site and logistics management (to reduce waste and carbon footprints) (Krygiel et al. 2008).

All these factors are considered to be necessary in the quest towards sustainability and should be taken into consideration during the design of a high performance facility. This task can be challenging since many times there is a conflict between them which leads to the need for a holistic point of view from the early stages of design. However, BIM combined with a range of sustainability performance analysis software that support interoperability standards can manage the sustainable information through a building’s life cycle. A dynamic procedure is essential in order to assess and re-assess those aspects during the design process.

5.2 BIM software and building simulation tools

A main difference between assessment and rating tools is that the former can provide evidence of quantitative performance while the latter determine performance of a building in a more simplistic way such as rating with stars (Ding 2008). For that reason simulation tools can produce a more informed and detailed analysis by giving exact numbers which can be translated in the more simplistic version of the BREEAM assesment (BREEAM 2012) (oustanding, excellent, very good, good and pass) and this way they can help to predict a facility’s rating from a very early design stage.

From the wide range of building simulation tools that are available in the market now, there are a number of reports and studies that have tested both technical aspects such as interoperability with BIM (SuperBuildings 2011) and their capabilites in analysis (Crawley et al. 2008) while others have examined qualitative aspects like the users preferences concerning Usability and Information Management (UIM) of interface and the Integration of Intelligent design knowledge-Base (IIKB) (Azhar et al. 2011, Attia et al. 2009). Another important recommendation of those studies is that the users have to consider adopting a variety of tools which would support a wider range of simulations that a single tool cannot offer due to the lack of extensiveness (Crawley et al. 2008, Attia et al. 2009).

In view of the above, the tools presented in Table 1 have been chosen to explore their informing possibilities regarding the BREEAM sustainable categories. Table 1 presents the capabilities of seven (7) building simulation tools in addition to the sustainable features that the BIM Autodesk Revit software itself offers. The analytical names of the acronyms presented are: Green Building Studio (GBS), Energy 10 (E10), Home Energy Efficient Design (HEED), Design Builder (DB), Ecotect Analysis (ECOTECT), QUick Energy Simulation Tool (eQUEST) and Integrated Environmental Solutions Virtual Environment (IES VE). The categorisation between early design phases and conceptual design and development phase is based on a survey on the users’ preferences (Attia et al. 2009).

BIM-based sustainability analysis and the BREEAM rating system (SuperBuildings 2011, BREEAM 2012, Crawley et al. 2008, Azhar et al. 2011, Attia et al. 2009).

Relationship between BIM-based sustainability analysis & minimum standards by BREEAM rating level		Sustainable design related performance analysis software							
		BIM	Early design phases				Conceptual & design development phase		
Categories	Weighting & Credits	Revit	GBS	E10	HEED	DB	ECOTECT	eQUEST	IES VE
Management	**12%**								
Man 01 Sustainable procurement	1-2	X X							
Man 02 Responsible construction practices	0-2								
Man 03 Construction site	0-1	X							

impacts		X	X	X					
Man 04 Stakeholder participation									
Man 05 Life cycle cost and service life planning									
Health and Wellbeing	**15%**								
Hea 01 Visual comfort	Required					X	X		X
Hea 02 Indoor air quality			X		X	X	X	X	X
Hea 03 Thermal comfort			X	X	X	X	X	X	X
Hea 04 Water quality	Required								
Hea 05 Acoustic performance							X		
Hea 06 Safety and security									
Energy	**19%**								
Ene 01 Reduction of emissions	0-10		X	X	X		X	X	X
Ene 02 Energy monitoring									
Ene 03 External lighting	0-1			X			X	X	X
Ene 04 Low and zero carbon technologies	0-1		X	X			X	X	X
Ene 05 Energy efficient cold storage									
Ene 06 Energy efficient transportation systems									
Ene 07 Energy efficient laboratory systems									
Ene 08 Energy efficient equipment				X		X	X	X	X
Ene 09 Drying space									
Transport	**8%**								
Tra 01 Public transport accessibility									
Tra 02 Proximity to amenities									
Tra 03 Cyclist facilities									
Tra 04 Maximum car parking capacity									
Tra 05 Travel plan									
Water	**6%**								
Wat 01 Water consumption	0-2		X						X
Wat 02 Water monitoring									
Wat 03 Water leak detection and prevention	None – Criterion 1 only								
Wat 04 Water efficient equipment				X					
Materials	**12.5%**								
Mat 01 Life cycle impacts									
Mat 02 Hard landscaping and boundary protection									
Mat 03 Responsible sourcing of materials	Required	X							
Mat 04 Insulation		X		X	X		X	X	X
Mat 05 Designing for robustness									
Waste	**7.5%**								
Wst 01 Construction waste management	0-1								
Wst 02 Recycled aggregates	0-1								
Wst 03 Operational waste									
Wst 04 Speculative floor and ceiling finishes									
Land use and Ecology	**10%**								
LE 01 Site selection		X					X		

LE 02 Ecological value of site and protection of ecological features LE 03 Mitigating ecological impact LE 04 Enhancing site ecology LE 05 Long term impact on biodiversity	0-1			X			X	X	X
Pollution Pol 01 Impact of refrigerants Pol 02 NOx emissions Pol 03 Surface water run off Pol 04 Reduction of night time light pollution Pol 05 Noise attenuation	**10%**		X						X
Innovation Inn 01 Innovation	**10%** (additional)	X							X

Table 1 : Categories that BIM-based performance analysis aids to predict performance for a number of BREEAM sustainability factors.

5.3 Technological enablers for collaborative design

A major enabler to achieve integration of sustainability asssessment with BIM collaboration is interoperability. Interoperability is defined as the ability to manage and communicate electronic product and project data between collaborating firms; which means that data interoperability is the ability of different software to use common data formats (Charalambous et al.). One major interoperability standard is the Industry Foundation Classes (IFC). A number of schemes have also been developed for extracting the environmental data in a neutral format; the gbXML, ecoXML, IFCXML, greenbuildingXML, ecoXML are other interoperability standards that can enhance data integration.

For the communication of those information among different disciplines from the early design phase, the use of OCPs (Online Collaboration Platforms) is essential. OCPs enable both the synchronous and asynchronous collaboration that is needed in BIM collaborative processes (Anumba et al. 2002). The procesing power of computers, server capacity, networks and internet connection are additional aspects that need to be considered to achieve intergration. The existing technological maturity creates the need to rethink and redesign the traditional collaborative processes so as to enhance the centrality of information and exploit all the potential benefits of mobilisation and cloud computing. The use of this new technology will help transform the current perception of the industry by enabling the mapping of the collaborative processes and leading to the future Integrative Project Delivery (IPD) approach.

5.4 People perspectives and collaboration

It is documented that despite the obvious benefits of collaborative BIM-based sustainability analysis, its use is still not widely adopted; the e-readiness of construction companies to adopt new technologies is a major concern among researchers (Ruikar et al. 2006). Especially in the case of high performance buildings, the need to increase collaboration and coordination between structural, envelope, mechanical, electrical and architectural systems increases. This interaction requires attributes such as the early involvement of participants, team experience, levels and methods of communication and compatibility within project teams (Nofera et al. 2010). Several authors have acknowedged the significance of managing decision-making process when diverse experts have conflicting proposals (Plume et al. 2007).

Communication problems can be addresseed by providing an audit trail (how it is done) where except for the explicit knowledge (who did what when) also accounts for the tacit knowledge (why was it done) (Cerovsek 2011). A recent research revealed that the current capabilities of BIM are very limited concerning the "how" and absent concerning the "why" leading to inefficiency to solve the emerging problems that occurred during the design process (Dossick et al. 2011).

Currently, the new roles of all the stakeholders of the integrated design process are not yet been defined. For the integrated design of a sustainable building except of the traditionally involved participants of the RIBA Plan of Work (client, architect, structural engineer, mechanical and electrical engineer, contractor) the role of new ones have to be considered such as the Model Manager (of the BIM model) (RIBA 2012). Furthermore, several studies have focused on the importance of the occupant consensus in the design of a building; user behaviour and their perception of comfort can make a critical difference in the operation of a facility (Wei et al. 2011, Andersen et al. 2009).

6 CONCLUSION

This paper discussed the drivers, aspects and other factors of BIM-based sustainable assessment into collaborative design. The technology, tools and design participants were also presented. In order to achieve the effective integration of the above elements for leaner design, the sub-processes need to be clarified. The automation and standarisation of the above processes can accelerate and streamline the design process as well as encourage the adoption of the new technology widely into the construction industry.

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