# FACILITATING BIM-BASED SUSTAINABILITY ANALYSIS AND COMMUNICATION IN BUILDING DESIGN PROCESS

**Maria A. Zanni[1], Robby Soetanto[2] and Kirti Ruikar[3]**

School of Civil and Building Engineering,
Loughborough University, Leicestershire, United Kingdom, LE11 3TU
E-mail: [1] M.A.Zanni@lboro.ac.uk
[2] R.Soetanto@lboro.ac.uk
[3] k.d.ruikar@lboro.ac.uk

## ABSTRACT

Population growth and resource scarcity has created unprecedented demand of sustainable buildings around the world. During design and construction processes, meeting this demand is considered an extremely challenging task, at least due to following several reasons. Firstly, the long-term sustainability of a building is difficult to define, let alone assess. Although there are standard assessment methods (e.g. BREEAM, LEED) and specific client requirements, each participant of the process may have different views and approaches to sustainability owing to their disciplinary practices and experiences. Secondly, although the most critical time to make decisions on a building's sustainable features is during the early stages of design, building performance analysis (for relatively easy to agree and accurately predict performance criteria, such as energy efficiency) is usually performed after the design and construction documents are produced. This practice results in lost opportunities to maximise the sustainability of building design and technology options. Thirdly, it is widely documented that the sustainability progress in the AEC/FM industry has been hampered by fragmentation, low innovation, adversarial relationships and slow adoption of Information Communication Technologies. The emergence of Building Information Modelling (BIM) has promised an accelerated progress of sustainable building development. BIM promotes integration among building professionals and improves design goals by allowing multi-disciplinary information to be integrated within a single model. This creates an opportunity to conduct the analysis throughout the design process, concurrently with the production of the design documents. Despite these expected benefits, the practice of using BIM for sustainability has not been widely embedded within the AEC/FM industry. In order to achieve a step change in current processes for optimal results, there is a need to define requirements of the process, tools, systems and stakeholders responsibilities of conducting sustainability assessment during the design stages of a building. To align with the industry practice, this should be based on the recently developed BIM Overlay to the RIBA Outline Plan of Work which offers a response to the UK Government's commitment to have all projects utilising BIM from 2016. This paper presents a comprehensive literature review along with a conceptual model based on the RIBA Plan of Work 2013. The model describes the main stages of the sustainability design process and the key inputs and outputs of each stage.

## 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 & Thesseling, 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 et al., 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 & Thesseling, 2009; Azhar et al., 2008).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 (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. 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).

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.

## NEED FOR BIM-ENABLED SUSTAINABILITY ASSESSMENT

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., 2009; Bazjanac, 2008; Che et al. 2010); some BIM related frameworks are also based on the international assessment rating systems (Biswas & Krishnamurti, 2009; Wong & Fan, 2012; Nofera & Korkmaz, 2010; Lützkendorf & Lorenz, 2006; Sinou & Kyvelou, 2006; Ghosh et al., 2011) and others have created tools that are integrated into building information modelling (Schlueter & Thesseling, 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 & Thesseling, 2009).

### The role of the building simulation tools

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 capabilities 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, 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).

Kryegiel 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 modelling (reducing energy needs and analysing 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 & Nies, 2008).

A survey that examined the users' preferences (Attia et al., 2009) has identified the following software as preferable for the early design phases as well as for the conceptual design and development phase: 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 technological enablers of collaborative design

A major enabler to achieve integration of sustainability assessment 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 format. 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.

BIM has been also recognised for achieving the development and implementation of Computer Integrated Environments (CIE) in construction (Aouad et al., 1998). For the communication of that 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 processing power of computers, server capacity, networks and internet connection are additional aspects that need to be considered to achieve integration. 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 (Wilkinson, 2005). 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.

## The human aspect of collaboration technology

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 & Korkmaz, 2010). Several authors have acknowledged the significance of managing decision-making process when diverse experts have conflicting proposals (Plume & Mitchell, 2007).

Communication problems can be addressed 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 & Neff, 2011).

The most important issue remains; people need to learn how to share more so that they can move from "creative isolation" to meaningful collaboration assisted by the new technology. This can only be achieved by changing the existing individual working patterns (Wilkinson, 2005).

## Defining the collaborative design process

In the light of the new RIBA Plan of Work 2013, an IDEF0 (Integration DEFinition language 0) model has been created to map the BIM-based sustainable design process (Draft Federal Information Processing Standards Publication 183 1993 December 21). The model is using the ICOM (Input, Control, Output, and Mechanism) code presented in Figure 1. Each side of the function box has a standard meaning in terms of box/arrow relationships. The side of the box with which an arrow interfaces reflects an arrows role. Arrows entering the left side of the box are inputs. Inputs are transformed or consumed by the function to produce outputs. Arrows entering the box on the top are controls. Controls specify the conditions required for the function to produce correct outputs. Arrows leaving a box on the right side are outputs. Outputs are the data or objects produced by the function. Arrows connected to the bottom side of the box present mechanisms. Upward pointing arrows identify some of the means that support the execution of the function. Other means may be inherited from the parent box. Mechanism arrows that point downward are call arrows. Call arrows enable the sharing of detail between models (linking them together) or between portions of the same model.

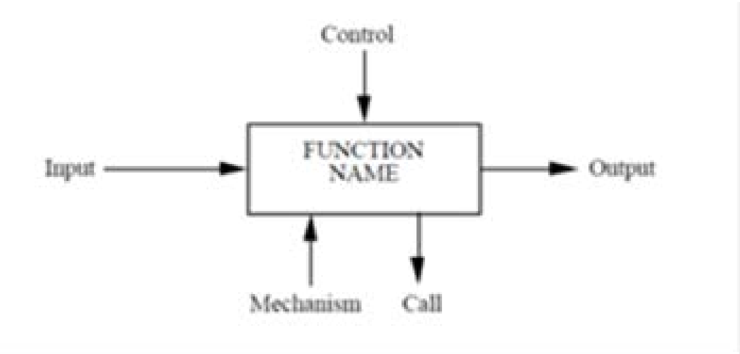


Figure 1: Positions of Arrows and Their Roles

The Parent Diagramme (A-0) presented in Figure 2 is the top-level context diagramme that describes the main Inputs, Outputs, Controls and Mechanisms that facilitate BIM-enabled Sustainable Design. The child diagramme (A0) is always in the scope of the top-level diagramme. The single function that is represented on the Parent Diagramme (A-0) is decomposed into its major sub-functions in the Child Diagramme (A0). The numbered arrows of A-0 diagramme correspond to the boundary arrows of its Child Diagramme (A0) as they are indicated in Figure 3.The letters I, C, O or M identify the arrow as an Input, Control, Output or Mechanism on the Parent box (0). These boundary arrows of the top-level diagramme can be found at any stage at the decomposition diagramme. For example, The Planning Application (O2 arrow) is one of the main outcomes of the Design Process shown in Figure 2; in Figure 3 it is shown as an output of phase 3, Developed Design, before the end of the whole process. Furthermore, the outcome of one stage can be either input or control for the next stage of the process. As you can see in Figure 3, the Final Project Brief that is an outcome of the Concept Design Development stage (A2 level) is a control for the preparation of the Developed Design (A3 level); that is because it is not altered but the process while it guides it to happen.

In order to understand the interrelationships between the people, process and tools the boxes in Figure 3, each box of the Child Diagramme (levels A1, A2, A3, A3, A4 and A5) needs further decomposition to lower-level diagrammes. Although this generic process outlines the main stages of the process, still it does not offer a comprehensive way on the inter-related practical elements and their relationships between them. For that to happen there is the also need for clearer definition of the elements described;

Sustainability Aspirations (I3 arrow) for example have to acquire a more specific meaning regarding its context (BREEAM assessment, Code for Sustainable Homes, or other specific client requirements). Additionally, the term “Project Team” becomes much more meaningful when tasks for each individual are specified; as an example, the thermal analysis is usually performed by the M&E engineer at the design development phase. Moreover, the level of detail of the information needed as well as the selection of software, the way of communication between stakeholders and the interaction with the client and users need further definition and clarification. For that reason this model needs to be further analysed to its sub-processes in order to fully comprehend how the existing workflows can be optimised with the use of the available technology and the selection of the most suitable tools and people for the project.

Another issue is that the method can be simplistic in an attempt to describe a more dynamic process of events. Many of those tasks between stages 3, 4 and 5 (Developed, Technical and Specialist Design) happen concurrently and not in a linear way. Despite that fact, there are some specific steps that should be followed like the mandatory Information Exchanges at the end of each stage (Government Gateway) and for that reason the need for a more structured process is revealed. Those steps and workflows can be defined and thus automated; this can be used as a guide for practitioners through the design process.

Finally, a level of flexibility is essential in the process in order to be incorporated; it is acknowledged that the successful incorporation of the above elements into practice depends 80% on tackling with people and process issues and only 20% on resolving technology aspects (Wilkinson, 2005). Workflow management is essential in that way to streamline the process, to support key project processes and help individuals manage their own responsibilities and deliverables required of them. The IDEF0 diagramme will become more meaningful when the business process, the documents, information and tasks, are passed from one participant to another for action according to a set of procedural rules.

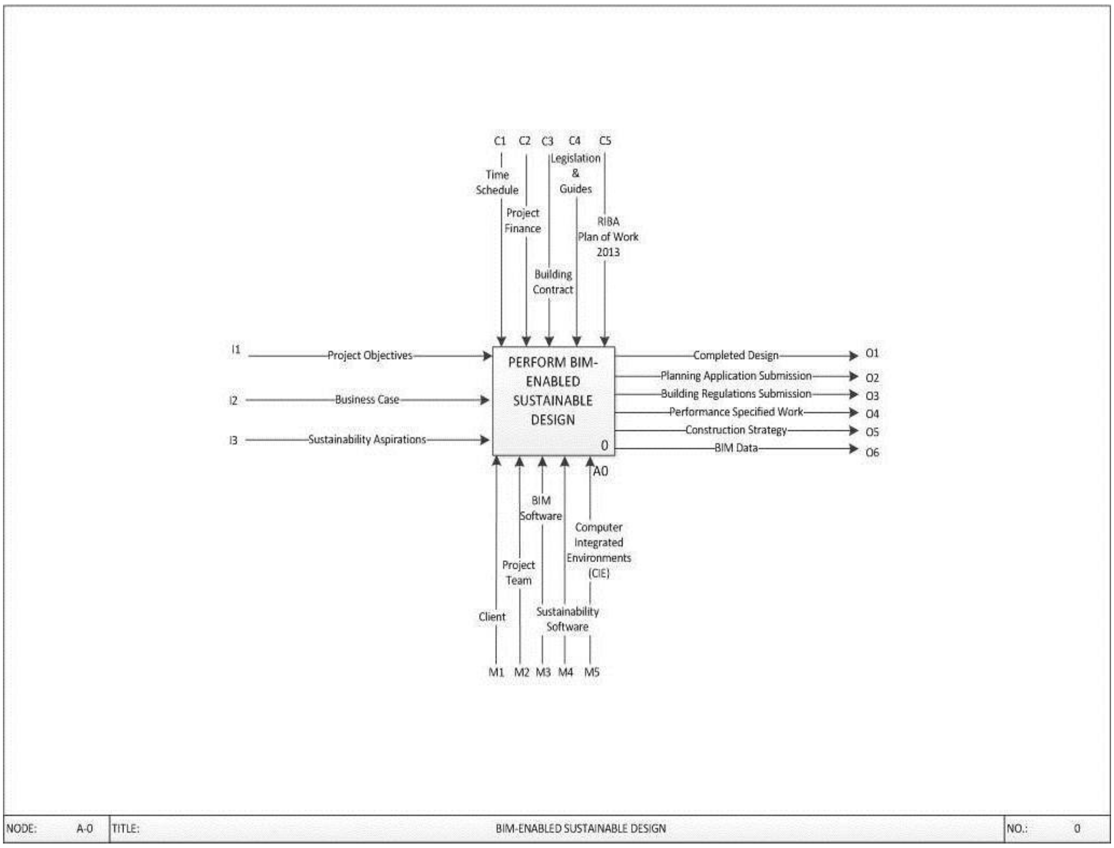


Figure 2: Parent Diagramme (top-level)

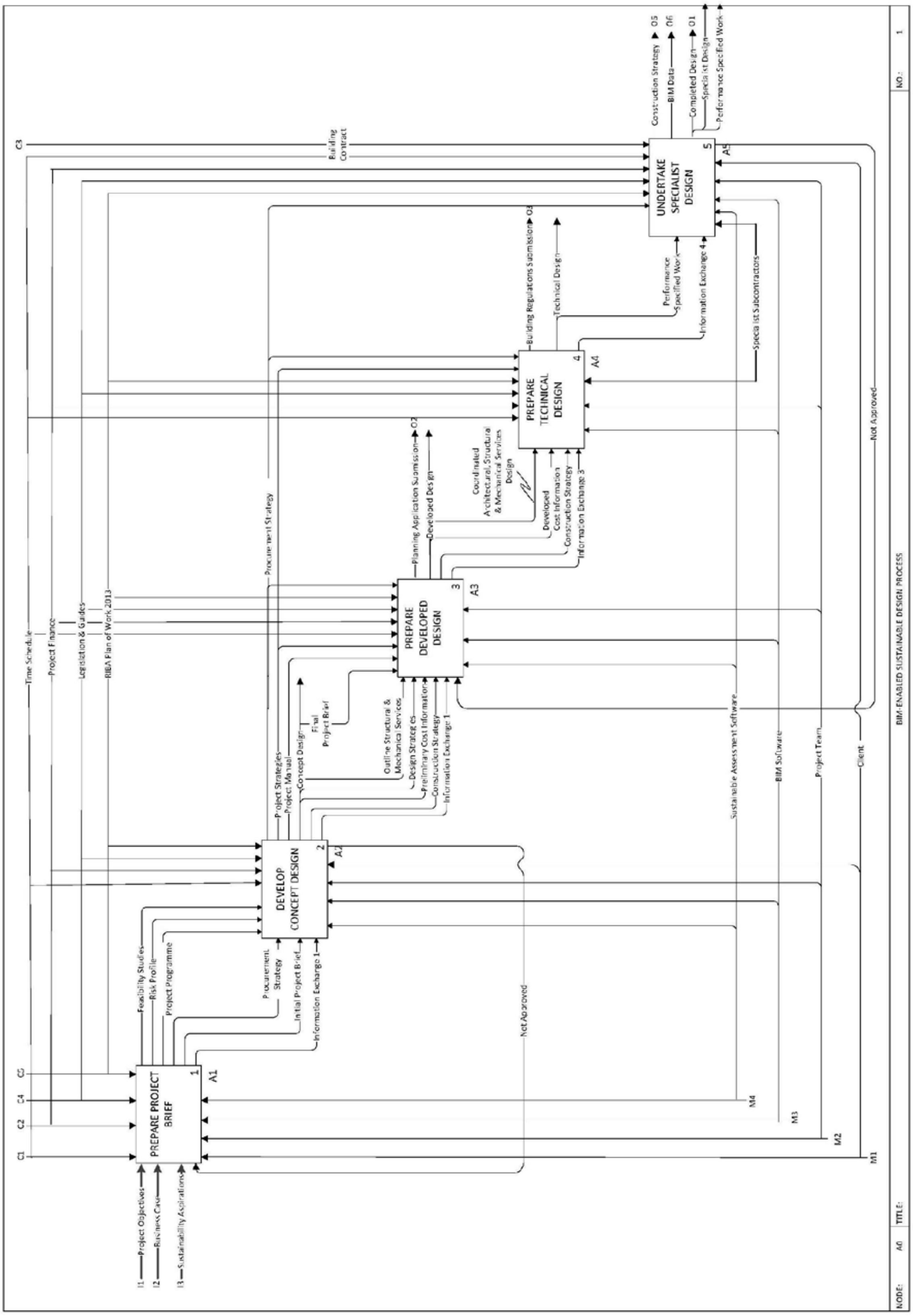


Figure 3: Child Diagramme (decomposition)

## CONCLUSION

This paper presented the drivers, technologies, tools, processes, project participants and other factors of BIM-based sustainable assessment into collaborative design. In order to achieve the effective integration of the above elements for leaner design, the sub-processes need to be clarified. Defining the above processes will accelerate and streamline the design process as well as encourage the adoption of this new collaborative philosophy widely into the construction industry. By following the same principle to specify the workflows and interactions between stakeholders and tools, practitioners will make informed choices. The outlined process presented will be the ground for the development of an automated software tool that supports re-engineering of the existing processes and assists decision making for sustainable design.

## REFERENCES

Anumba, C., Ugwu, O., Newnham, L. & Thorpe, A. 2002, "Collaborative design of structures using intelligent agents", *Automation in Construction*, vol. 11, no. 1, pp. 89-103.

Aouad, G., Hinks, J., Cooper, R., Sheat, D., Kagioglou, M. & Sexton, M. 1998, "Map for a generic design and construction process protocol.", *Journal of Construction Procurement*, .

Attia, S., Beltrán, L., De Herde, A. & Hensen, J. 2009, "Architect friendly: a comparison of ten different building performance simulation tools", *Proceedings of IBPSA '09 Buildings Simulation Conference*, pp. 204.

Azhar, S. 2011, "Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry", *Leadership and Management in Engineering*, vol. 11, pp. 241.

Azhar, S., Brown, J. & Farooqui, R. 2009, "BIM-based sustainability analysis: An evaluation of building performance analysis software", *Proceedings of the 45th ASC Annual Conference*, pp. 1.

Azhar, S., Hein, M. & Sketo, B. 2008, "Building information modeling (BIM): Benefits, risks and challenges", *Proceedings of the 44th ASC Annual Conference*, pp. 2.

Azhar, S., Nadeem, A., Mok, J.Y. & Leung, B.H. 2008, "Building information modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects", *Proc., First International Conference on Construction in Developing Countries*, pp. 435.

Azhar, S., Carlton, W.A., Olsen, D. & Ahmad, I. 2011, "Building information modeling for sustainable design and LEED ® rating analysis", *Automation in Construction*, vol. 20, no. 2, pp. 217-224.

Bazjanac, V. 2008, "IFC BIM-based methodology for semi-automated building energy performance simulation", *Proc.of CIB-W78*, .

Biswas, T. & Krishnamurti, R. 2009, "Framework for Supporting Sustainable Design", *School of Architecture*, , pp. 46.

Bouchlaghem, D., Shang, H., Anumba, C.J., Cen, M., Miles, J. & Taylor, M. 2005, "ICT-enabled collaborative working environment for concurrent conceptual design", *Architectural Engineering and Design Management*, vol. 1, no. 4, pp. 261-280.

Cerovsek, T. 2011, "A review and outlook for a 'Building Information Model'(BIM): A multi-standpoint framework for technological development", *Advanced engineering informatics*, vol. 25, no. 2, pp. 224-244.

Charalambous, G., Demian, P., Yeomans, S., Thorpe, T., Peters, C. & Doughty, N. "BIM and Online Collaboration Platforms–An investigation into emerging requirements", .

Che, L., Gao, Z., Chen, D. & Nguyen, T.H. 2010, "Using building information modeling for measuring the efficiency of building energy performance", *Paper 83), Proceedings of the International Conference on Computing in Civil and Building Engineering (ICCCBE), Nottingham*, pp. 165.

Crawley, D.B., Hand, J.W., Kummert, M. & Griffith, B.T. 2008, "Contrasting the capabilities of building energy performance simulation programs", *Building and Environment*, vol. 43, no. 4, pp. 661-673.

Dossick, C.S. & Neff, G. 2011, "Messy talk and clean technology: communication, problem-solving and collaboration using Building Information Modelling", *The Engineering Project Organization Journal*, vol. 1, no. 2, pp. 83-93.

Draft Federal Information Processing Standards Publication 183 1993 December 21, *INTEGRATION DEFINITION FOR FUNCTION MODELING (IDEF0)*.

Feng, C., Mustaklem, O. & Chen, Y. 2012, "The BIM-based information integration sphere for construction projects", *Proceedings of the 28th ISARC Conference, Seoul, Korea*, pp. 156.

Ghosh, S., Negahban, S., Kwak, Y.H. & Skibniewski, M.J. 2011, "Impact of sustainability on integration and interoperability between BIM and ERP-A governance framework", *Technology Management Conference (ITMC), 2011 IEEE International*IEEE, , pp. 187.

Huber, D., Akinci, B., Oliver, A., Anil, E., Okorn, B. & Xiong, X. 2011, "Methods for automatically modeling and representing as-built building information models", *Proc., NSF CMMI Research Innovation Conference*.

Krygiel, E. & Nies, B. 2008, *Green BIM: successful sustainable design with building information modeling,* Sybex.

Lützkendorf, T. & Lorenz, D.P. 2006, "Using an integrated performance approach in building assessment tools", *Building Research & Information,* vol. 34, no. 4, pp. 334-356.

Mahdavi, A., Brahme, R. & Gupta, S. 2001, "Performance-based computational design via differential modeling and two-staged mapping", *Proceedings of the CAAD Futures Conference. Eindhoven, The Netherlands*, pp. 667.

Nofera, W. & Korkmaz, S. 2010, "Design Process Integration for Sustainable, High Performance Buildings", *Proceedings Editors,* .

Plume, J. & Mitchell, J. 2007, "Collaborative design using a shared IFC building model—Learning from experience", *Automation in Construction,* vol. 16, no. 1, pp. 28-36.

Ruikar, K., Anumba, C. & Carrillo, P. 2006, "VERDICT—An e-readiness assessment application for construction companies", *Automation in Construction,* vol. 15, no. 1, pp. 98-110.

Sacks, R., Koskela, L., Dave, B.A. & Owen, R. 2010, "Interaction of lean and building information modeling in construction", *Journal of Construction Engineering and Management,* vol. 136, no. 9, pp. 968-980.

Schlueter, A. & Thesseling, F. 2009, "Building information model based energy/exergy performance assessment in early design stages", *Automation in Construction,* vol. 18, no. 2, pp. 153-163.

Sinou, M. & Kyvelou, S. 2006, "Present and future of building performance assessment tools", *Management of Environmental Quality: An International Journal,* vol. 17, no. 5, pp. 570-586.

SuperBuildings 2011, *Deliverable 3.3: Needs, levels and potentials of integrating SB assesssment and benchmarking with BIMs*.

Welle, B., Haymaker, J. & Rogers, Z. 2011, "ThermalOpt: A Methodology for BIM-Based Passive Thermal Multidisciplinary Design Optimization", *Center for Integrated Facility Engineering Technical Report,* , no. 200.

Wilkinson, P. 2005, *Construction Collaboration Technologies: An Extranet Evolution,* Taylor & Francis.

Wong, K.A. & Fan, Q. 2012, "Building Information Modelling (BIM) for Sustainable Building Design", *Facilities,* vol. 31, no. 3/4, pp. 3-3.

**Reference**:
Zanni, M.A., Soetanto, R. and Ruikar, K. (2013) Facilitating BIM-based sustainability analysis and communication in building design process. *Proceedings of the 6th Civil Engineering Conference in Asia Region (CECAR6) - Embracing the Future through Sustainability*, 20-22 August, Jakarta, Indonesia.