Characteristics of Green BIM: Process and Information Management Requirements

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Abstract: In this paper, the authors explore the characteristics and requirements of digitally supported 'green' building design. Well planned, integrated and interdisciplinary digital design practices play a vital role in the iterative processes of sustainable building design. Unlike traditional ways of working, the management of design information and process integration in green building design involves a wider range and a larger number of consultants utilizing sophisticated environmental modelling and analysis systems. To understand the complexities surrounding information management in this context, the authors focus on issues relating to: 1) information exchange and model management, and 2) multidisciplinary design process coordination. Different aspects of sustainable design modelling methodologies are explored in relation to technology requirements, information exchange, and multi-disciplinary collaboration. Finally, the literature is synthesised in a conceptual roadmap framing the key factors identified by the study.

Keywords: Building information modeling, environmental sustainable design, information management, collaboration.

1. Introduction

The construction industry has long been aware of its contribution towards CO2 emissions and is now shifting towards more sustainable design solutions. Consequently, today's AEC projects (architectural, engineering and construction) often require the use of advanced information technology (IT) to address complex building system dependencies and interdisciplinary design development processes that meet expectations of environmentally sustainable design (ESD) and the information requirements of green building. The application of building information modelling (BIM) and associated collaboration technologies (e.g., XML schemas, iCloud, etc.) represents a paradigm shift. 'Green BIM' has thus been coined to describe the convergence of two key trends, green buildings and BIM. Green BIM is emerging as a new form of project design and delivery, where industry is still trying to grasp its implications. The required level of coordination between different organisations during Green BIM design processes depends on the complexity of the building [1]. Building development projects that employ ESD strategies and target maximum GBC (green building certification) credits arguably represent a higher order of complexity, particularly those utilising intelligent building systems. Further, in this context, integrated design processes and accreditation procedures often

increase the number of participating stakeholder organisations working in synchronous collaboration. Such projects have high levels of process, activity and task interdependencies, and consequently information exchange between collaborating design firms is arguably more complex.

Not surprisingly, the rate of adoption of BIM technologies on green building design projects has increased in recent years [2]. Properly adopted, BIM promotes buildings of higher quality, with faster project delivery and at lower cost [3]. Yet, whilst this methodology has facilitated innovations in sustainable design (see e.g., [2, 4]) and in optimising green building accreditation [5, 6] its full deployment is hindered by traditional work processes, business models, and industry fragmentation [7]. Green BIM must not only overcome the adverse effects of entrenched industry methods but also new ones such as incomplete implementations of the BIM methodology. Thus, the coordination of reciprocal design task interdependencies, the management of inter-organisational processes and the sharing of digital design information represent significant challenges [3].

This paper explores the characteristics and requirements of information management for Green BIM in a literature based study. Sect. 2 describes the main attributes of Green BIM. In Sect. 3, the paper presents the research related to information management including discipline specific modelling requirements for sustainable design and associated challenges to information exchange (Sect. 3.1), and multi-disciplinary collaboration across organisational boundaries and the challenges surrounding task interdependencies (Sect. 3.2). The authors discuss their characteristics and requirements in relation to methodologies for sustainable design modelling. In Sect. 4, the authors present the main elements of Green BIM, synthesising the literature into a conceptual roadmap that identifies the relationships between each factor. Sect. 5 provides conclusions and directions for future research.

2. What is Green BIM?

A variety of definitions of Green BIM exists in the literature, (e.g., [2, 4]). The authors define Green BIM as being based on three conceptual pillars: (1) ESD principles, (2) optimisation of GBC credits, and (3) integrated building systems and design processes supported by object-based modelling and analysis tools. The intention of ESD is to "eliminate negative environmental impact completely through skilful, sensitive design" [8]. According to its principle objectives, ESD should result in more comprehensive and assessable sustainable design solutions for the built environment. ESD methodologies target five key areas of sustainability relative to building type including 1) climate, culture and place, 2) reduction of resource consumption, 3) use of local resources, 4) efficient use of man-made systems, and 5) application of renewable energy systems. Furthermore, building systems integration is one of the main goals of ESD, and the complexity of such a task requires higher levels of process and stakeholder integration.

GBC systems such as Australia's Green Star [9] and the US LEED [10] system are generally hierarchically awarded credit-based systems assessing a range of criteria, including e.g., sustainable sites, water efficiency, energy use, and quality of

atmosphere, material resources, indoor environmental quality, and innovation in design ([9, 10]). To assess these criteria during the design stages it is necessary to model, simulate and analyse the virtual building. Object oriented or component based computer aided design (CAD) assists in the generation and coordination of semantically rich building information models. BIM technologies are able to provide more accurate and reliable building data, support inter-organisational collaboration, provide simulation and analysis, and accelerate production of documentation drawings [4, 5]. Azhar *et al.* [11] shows that more than half of GBC (LEED) credits can be facilitated by BIM technologies. A virtual prototype integrated with discipline specific information models can be used to simulate ESD alternatives and optimise the final solution. In this way, BIM facilitates multidisciplinary collaborative working activities between the design team members [12]; however it can increase the complexity of information management due to the amount of information generated and the complexities surrounding interoperability and the timing of information exchange [5, 13].

Green BIM therefore requires explicit, precise information for building system integration and evaluation. Theoretically, the methodologies and technical capabilities of Green BIM should enable major improvements to both design processes and products. However there are two key challenges surrounding Green BIM: (1) the involvement of a wider diversity of the design team members from different disciplines and organisations, and (2) the high level of interdependencies between processes, activities and tasks (e.g., a change in the facade materials creates a need to change the architectural design model, the structural design model and possibly also the mechanical, electrical and hydraulic models). Sodagar and Fieldson, [14] highlight the challenges of an integrated approach to sustainable design during tentative and iterative design processes. Involvement of a wider variety of the design team participants from the early project phases also means their potential continued participation through to project delivery [15]. Figure 1 illustrates the required participation of design disciplines and the timing of their involvement in a Green BIM project.

Fig. 1. Design team members in Green BIM project (Adapted from [18]).

As the figure shows, Green BIM requires the involvement of the owner, architect, a variety of engineers and consultants, contractors, suppliers and manufacturers as well as an accredited professional (AP) representing the designated green certification body [10, 16, 17].

3. Characteristics and requirements of Green BIM

The information management demands of a multidisciplinary design process cannot be managed by a single stakeholder organisation. It requires a range of design, project and IT professionals to coordinate and unify the design domains of different building systems. A comprehensive understanding of the multi-level interconnections between technologies, people, project phases, processes and systems is needed to address the (sometimes competing) requirements of Green BIM. Effective information management practices must meet the demands of the continual generation, transmission, publishing, interpreting, storing and retrieving of a wide range of building design data. Green BIM requires consideration of the policy-, process- and technology- based elements that underpin the BIM methodology [6], as well as strategies for successful information management that can support knowledge transfer and translation in multi-disciplinary ESD collaborations [18].

3.1 Information management

The underlying requirements of information management in Green BIM projects can be seen to relate to four variables: 1) number of participants exchanging information, 2) information standards, protocols and format, 3) timeliness of information exchange, and 4) roles and responsibilities when exchanging information. In addressing policy-based information management issues, various solutions have been suggested including contractual documents, exchange protocols, modelling standards, and specification of the level of detail (LoD) in modelling (such as those found in BIM management plan templates and frameworks specifying e.g., LoD 100 to LoD 500) [19]. Interoperable file exchange schemas can partially assist with the technical difficulties surrounding compatibility (e.g., .ifc, Gbxml, .dwg, Etc.), which enables the development of an integrated data rich model.

Precise and timely information is required to overcome the adverse effects of industry fragmentation during the design process, providing accurate and coordinated 3D models for Green BIM. Tzortzopoulos-Fazenda and Cooper [20] define design management as an ill-structured process and the day-to-day operating boundaries as being imprecise. Information exchange therefore, requires well-defined standards and protocols prior to commencement of the design process. Tracing the timeliness of design information for Green BIM projects and mapping this with the capabilities and interoperability requirements of ESD technologies is essential for understanding reciprocal task interdependencies within the design team. Figure 2 presents an example of the potential information exchange and communication patterns occurring during a Green BIM project, identifying a network of task interdependencies. Green BIM is dependent on the use of digital design technologies for the purposes of both product systems integration and design process integration - such integration can be better addressed if the elements of ESD and GBC are considered in parallel. This leads to the second topic of this section: multidisciplinary collaboration – including the inter-organisational task dependencies and information modelling requirements.

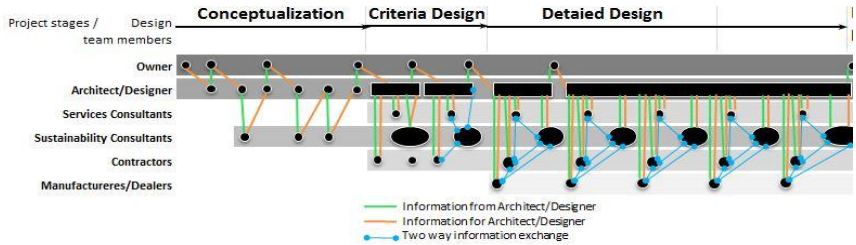

Fig. 2. Tracing task interdependencies of Green BIM

3.2 Multidisciplinary collaboration

Design researchers have studied a range of factors responsible for the complexity surrounding multidisciplinary design collaboration. In digital design collaborations, two concerns are identified as important, namely: 1) the representation, communication and coordination of electronic information [21], and 2) differences in discipline-specific design methodologies. Undefined BIM management practices and standards can result in design team members performing functions independently of each other, and increases in levels of complexity and uncertainty. This may then negatively impact on GBC outcomes despite the time, funds and effort invested. Figure 3 provides a snapshot of the type of interactions that occur between design team members during the development of sustainable building designs. Generally to attain GBC, accreditation is based on specified criteria; to achieve the desired results from the procedure, information must be generated by a range of consultants with expertise covering e.g., water harvesting, recycle-reuse, energy analysis, sustainable material resource, day light analysis and sustainable product development. The information generated must undergo many iterations of revision depending on project requirements and design challenges. Thus, Green BIM projects with high GBC rating objectives require detailed planning during project inception.

Rohracher [22] explains that close interaction and a high level of compatibility between project participants are key necessities for ESD processes. However, a number of barriers to these necessities exist. With the high diversity of project stakeholders it is likely that individual design disciplines are located in different geographical locations and conditions. Like all projects, it may not always be possible to have close interaction with the entire project organization at any one time. In spite of the availability of advanced communication facilities, meeting agendas are difficult to define when projects are characterized by high levels of complexity, uncertainty and ambiguity. It is necessary to manage complexity and eliminate uncertainties resulting from unforeseen knock-on effects of design changes, which can also potentially identify unknown reciprocal task interdependencies [3]. Consequently, extensive resources may be required to support collaboration within Green BIM projects resulting in expensive design and development processes. In the face of complexity and rising cost, team members may revert back to traditional practices.

In Green BIM projects, successful management and coordination requires a multi-dimensional approach. However, the research literature (see Luthra[23]) reports a lack

of appropriate BIM management frameworks, often resulting in the incomplete adoption of the methodology [3]. Amongst the few available solutions addressing this issue, are the AIA's [17, 18] guidelines to Integrated Project Delivery (IPD) and others such as the NATSPEC guidelines, VA BIM Guide and the AEC UK BIM Standard [17, 19, 24-27]. In other work by London *et al.* [28] a BIM process management framework is proposed, which focuses on enabling integrated design. However these frameworks fail to account for the specific technological and design process features of Green BIM. These generic frameworks ignore crucial links and interdependencies between the technical, policy and process components defining the ESD activities underpinning Green BIM.

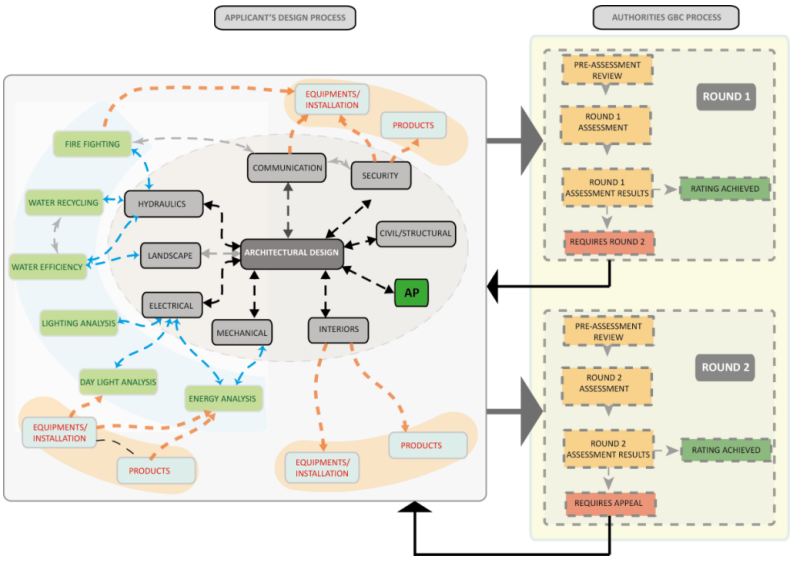

Fig. 3. Multidisciplinary design collaboration for Green Building Certification

Furthermore, in spite of the increasing interest in sustainable design and digital design practices amongst industry professionals and researchers, much attention is directed toward the development of the technical means of integration (i.e IFC-based BIM platforms, web servers for information exchange etc.) and control oriented management systems (e.g., policies, certification programs, regulations, and contract requirements). Azhar *et al.* [11] have mapped BIM capabilities with GBC requirements (in this case LEED), but fail to identify a number of Green BIM requirements including the identification of task and informational interdependencies, and the main actors responsible for generating information to meet GBC criteria.. Consequently there is a need to attend to the process dimensions of Green BIM relative to existing work on sustainable design technologies and policies. In targeting the coordination of task interdependencies along with non-linear information transfer Volker and Prins [29]show how process-based mechanisms can facilitate information management and control outputs. However there is a lack of research that integrates the process, policy and technological components of a Green BIM methodology. It is

therefore necessary to analyse and amend current approaches to Green BIM projects to help achieve desired GBC credits in a more effective and efficient manner.

4. Toward a Green BIM management framework

The literature review highlights a lack of research into the specific modelling requirements and related challenges surrounding simulation and analysis for Green BIM and its alignment with the relatively recent introduction of GBC processes. Modelling interdependencies between building systems remain a major challenge to the coordination of design processes (e.g., water efficiency analysis requires detailed modelling of multiple building systems, including MEP services, hydraulic equipment). A Green BIM management plan that is capable of supporting the progression of ESD throughout the design stages requires further consideration of information management practices, such as the specification of information exchange protocols, the LOD in ESD modelling, and software and interoperability requirements. Consequently design coordination must focus on ESD modelling, simulation and analysis with an emphasis on 'co-design' methods.

In a bid to structure and rationalise the management and coordination issues of Green BIM, the authors have synthesised the related literature in a conceptual framework aimed at developing a Green BIM management methodology. Figure 4 describes the framework as a roadmap that structures the requirements of technology, policy and process management for Green BIM. The proposed roadmap organises these requirements from the initial stages of project planning to the final stages of design using the AIA's (2007) definition of IPD project stages (Conceptualisation, Criteria Design, Detailed Design, and Implementation Documents). The inter-linking components described in the roadmap are as follows.

1) *Conceptualisation Stage*: During this stage, a 'Green BIM Requirements Assessment' system is essential to project initiation. Client and project objectives for GBC and ESD must be identified in conjunction with the details of implementing BIM tools and processes, as well as IPD methods and contractual arrangements. Information and modelling standards, protocols, along with specification of the level of detail (LoD) throughout the design process, design team members responsible for generating information, and the ESD simulation and analysis requirements should be defined. To define these it is first necessary to identify the scope and purpose of the project before then: (a) assessing GBC criteria specifications, (b) identifying resources including key actors and assessing BIM capabilities for ESD and GBC by mapping criteria to BIM tools, and (c) assessing overall project organisation capabilities to achieve desired GBC targets. Once these requirements assessment activities have been achieved it is then possible to inform the development of IPD methods and contracts as well as provide the basis for a Green BIM methodology.

2) *Criteria Design Stage*: During this stage, it is crucial to develop the Green BIM implementation strategy; this procedure requires: (a) assessment of the feasibility of GBC/ ESD and BIM tools to achieve targeted credits, (b) identification of an ESD design activity plan that maps design participants with informational dependencies across modelling, simulation and analysis activities (e,g., water efficiency, energy

efficiency, day light analysis and material resources), (c) define modelling standards and communication mediums, (d) refine information exchange protocols and assess interoperability requirements between architectural modelling and ESD team consultants before initiating the design process, and (e) map reciprocal ESD task interdependencies between design team participants relative to GBC criteria. Thus during the Criteria Design stage, detailed process stages, stage gates and a process management matrix (describing reciprocal task interdependencies) should be developed. This will assist in mapping interdependencies between design activity plan and discipline-specific BIM technologies with emphasis on ESD methods and analysis tools. As part of this mapping process, it is also necessary to consider the interoperability requirements of each software application. Once this strategy has been developed IPD contractual arrangements can be evaluated and updated so as to ensure that the targeted GBC credits can be achieved collaboratively.

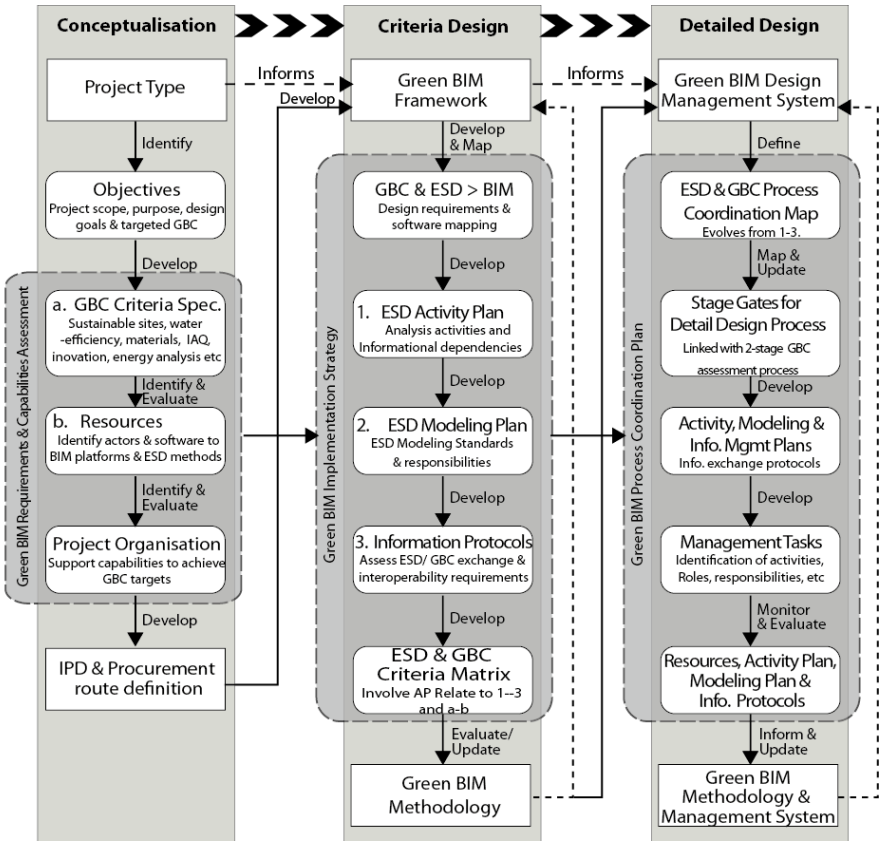

Fig. 4. Conceptual roadmap for Green BIM design management system

3) *Detailed Design Stage:* The detailed design stage must be supported by a comprehensive process coordination plan that will define a Green BIM design management approach. Prior to initiating design there is a need to prepare a design

activity plan, based on process management matrix aligning ESD objectives and design tasks with information requirements and stage gates of the GBC process. To produce and implement such a plan it is necessary to: (a) update stage gates for the detailed design process (b) map stages gates to and update the design activity and modelling plans as well as information protocols, (c) develop an ESD and GBC process coordination map, (d) define management roles and responsibilities, (d) monitor and evaluate resources, plans and protocols. These components of a Green BIM coordination plan can then be used to inform and update the overall methodology and design management system in an iterative way.

5. Conclusion

The literature reveals a number of critical elements of Green BIM encompassing technological, process and policy based attributes. Studies surrounding recent developments in digital modelling and analysis technologies show how they assist in informed decision making and meeting GBC procedures. Further, a range of studies documenting exemplar building projects provide evidence of Green BIM implementations and the challenges faced and achievements made. Numerous industry-driven BIM management protocols are also reported in the literature. Researchers conclude that it is necessary to recognise the significance of design management methodologies and the importance of supporting sustainable building design by addressing the key requirements of information modelling and exchange in multidisciplinary design environments. There is no evidence based research that proposed process stages for development of Green BIM. The process coordination and information management requirements identified here are inseparable elements and many of the vital decisions regarding these elements are defined in the early planning and design stages. Developing information management strategies, process stages based on ESD and GBC objectives are therefore pre-requisites of successful Green BIM.

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