INTEGRATED PROCESS MAPPING FOR BIM IMPLEMENATION IN GREEN BUILDING PROJECT DELIVERY

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ABSTRACT: *Professionals in the architecture, engineering and construction (AEC) industry are becoming more versed with building information modeling (BIM), and start to recognize its synergy with green building. As more owners are demanding better building performance to meet regulatory requirements, business goals or to establish a positive public image, implementing BIM in green building project delivery offers project teams the ideal leverage to meet owners' expectations. Current Green BIM practices are immature, ad-hoc and unsystematic. The lack of an integrated process is the biggest barrier to exploring the benefits of Green BIM to their full extent. The fact that most project teams are transient in nature also makes it challenging to replicate success from one project to another. Other major obstacles reside in understanding the subtleties in differentiating the roles and responsibilities of team members, determining appropriate BIM execution strategies and standardizing information exchange (IE). Hence, the purpose of this research is to conduct a comprehensive review of existing Green BIM strategies and best practices, and to develop an Integrated Green BIM Process Map (IGBPM) to provide guidance on BIM implementation in green building project delivery. The deliverables of this research include a customized worksheet for project sustainability goals and BIM use identification, Level 1 of the IGBPM and several examples of the Level 2 process maps using LEED as a use case. The IGBPM is valuable to industry practitioners since it represents a holistic and systematic approach to efficiently utilize limited BIM resources to overcome the challenges and complexities to successfully delivering the project and achieving the targeted green certification. The structural transparency of the IGBPM also encourages risk/benefit sharing that can help enhance collaboration among team members and eventually facilitate a more integrated delivery of green building projects.*

KEYWORDS: *Building information modeling, green building, process mapping, project delivery.*

1. INTRODUCTION

As BIM and green building both continue to gain momentum, more industry firms are embarking on Green BIM practices, which is an emerging trend in the architecture, engineering and construction (AEC) industry that leverages BIM in green building project delivery and attempts to capitalize on synergies between the two. For the time being, however, only a fraction of firms are knowledgeable about Green BIM, and an even smaller proportion of those firms are able to reap the full potential of what BIM offers for green projects (McGraw-Hill Construction 2010). Most firms are inexperienced and remain vigilant for empirical evidence and hard project data before taking any further steps. The market transformations for green building and BIM are subject to obstacles and uncertainties as commonly seen amid new technology absorption, and will need further stakeholder buy-in. Firms that refuse to use BIM in green building projects contend that BIM is still an evolving technology and has limited functionality. They feel BIM tools and models are too complicated to use, so they are better off relying on existing non-BIM tools that they are comfortable with (McGraw-Hill Construction 2010). Owners are hesitant to procure BIM services to avoid cost inflation and stay away from risks associated with an unfamiliar BIM workflow. Industry players often solely focus on the technical aspects of BIM implementation while overlooking the process aspects. They treat BIM as a technology add-on while eluding the efforts in adapting their business operation to accommodate the necessary organizational change and cultural transition when adopting BIM. Such tactics have seriously undermined the synergies between BIM and green building. As a result, existing Green BIM practices are usually immature, ad-hoc and unsystematic. The success of individual Green BIM project usually relies on the improvisations of a highly competent project team instead of deliberations based upon a well-thought-out, transferable BIM-integration process. Due to the transient nature of project team composition on construction projects, such success is difficult for the peer project teams to replicate. Opportunities are also lost in reinforcing and advancing the information and knowledge of Green BIM practices gained from previous projects. To reduce

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the hindrances of adopting new technology like BIM in green building, Häkkinen and Belloni (2011) suggested the necessity of learning what kind of decision-making phases, new tasks, actors, roles and ways of networking are needed. This encompasses understanding the subtleties in differentiating the roles and responsibilities of team members, determining appropriate BIM execution strategies and standardizing information exchange (IE) along with the green building project delivery process.

This research is a response to the need for a better, integrated process of implementing BIM in green building project delivery that project teams can count upon to capitalize on synergies between BIM and green building. An integrated process map of Green BIM practices, the *Integrated Green BIM Process Map* (IGBPM), was created using Business Process Model and Notation (BPMN), based upon the convergence of existing process models for green building project delivery and BIM execution. The scope of this research is limited to *Level 1: Overall Green BIM Process Map* and some example of *Level 2: Detailed Green BIM Process Maps with LEED as a Use Case*. The whole set of process maps, once completed, will offer a comprehensive and transferrable guide to project teams for planning and executing Green BIM practices. The positive impacts of process mapping on transparency encourage risk/benefit sharing, promote enhanced collaboration among team members and eventually facilitate the integrated delivery of green building projects.

2. BACKGROUND

This research is conducted on the basis of existing process modeling efforts in green building project delivery and BIM execution, initiatives and best practices of Green BIM implementation in industry, and cutting-edge research discoveries in academia on synergies of BIM and green building.

2.1 Green building project delivery process modeling

In this study, green building is defined as a construction project that is either certified under a recognized global green rating system (e.g. LEED, BREEAM and Green Globes) or built to qualify for certification (McGraw-Hill Construction 2013). This working definition fits best in the context of the business case for green building. In industry and academia, high performance building or sustainable building are often used interchangeably with green building, regardless of the differences between them.

Horman et al. (2004) have demonstrated that process plays a key role in successfully delivering a high performance green facility within budget and on time. The theory underpinning high performance project delivery is that reduced process waste is able to enhance both sustainable outcomes and the business case for sustainability (Horman et al. 2006). The optimal delivery processes for green buildings are not the same as those for traditional buildings. The integrated project delivery (IPD) method has caught a lot of attention in the industry and is considered superior to traditional processes. Process modeling is the critical first step to better understand the green building delivery processes (Klotz et al. 2007). Building process models emphasize important information, relationships and/or elements concerning the provision of the facility. The essences of the building process models are the steps of "how" the facility is constructed and "who" provides the necessary competencies to do so. A process model provides the basis for developing important understanding about the characteristics of high performance building delivery (Horman et al. 2006).

The Integrated Building Process Model (IBPM) developed by Sanvido (1990) using the IDEF0 modeling language was by far the most comprehensive of the models available to map a facility delivery process from inception to turnover. It has been the foundation for extensive research into how projects are completed. The IBPM was later on adapted and further developed with the additional elements needed for understanding high performance building project processes, such as the IBPM for High Performance Buildings ($IBPM^{HP}$) and the Integrated Design Process Model for High Performance Buildings ($IDPM^{HP}$) (Korkmaz et al. 2010). "Lean" (e.g. Klotz et al. 2007) and "system engineering" (e.g. Bersson 2012) principles have also been incorporated in popular innovations in process modeling. A significant proportion of literature on green building project delivery process modeling has chosen LEED certified buildings as case studies and frequently involved the use of BIM in LEED oriented design optimization and performance simulation. However, these process models have seldom addressed the impacts and implications of BIM implementation on LEED project delivery.

2.2 BIM project execution process modeling

Implementation of BIM on construction projects necessitates greater collaboration and integrated project delivery, and requires dramatic changes in current construction business practices. This is a significant challenge to the AEC industry considering the inherent fragmentation in the overall supply chain (NIBS 2007). Discrepancies in the BIM sophistication of project team members (Wix 2007) and the IE related interoperability issues (Gallaher et al. 2004) due to the heterogeneity of BIM software applications add extra dimensions of complexity to BIM project

execution. The question of what is the best method of adopting BIM has not yet been answered (Coates et al. 2010), and consequently very few projects have been able to utilize the benefits of BIM to their full extent.

The key will be the integration of the BIM process. Conventional process models such as the IPBM (Sanvido 1990) typically represent the information that is not adequate for supporting the strategic decisions to be made by a construction team since an information handover is required encompassing many specific BIM tasks, company information and other external information. The desired process representation will need to address information including: the logical sequence and interdependency of the activities in the project delivery; the inputs, i.e., the Reference Information and BIM deliverables that support the activities within the process; the BIM outputs and the IE between processes; and the team participants or the agents responsible for a particular BIM task (Saluja 2009).

The BIM Project Execution Planning Guide (PEPG) (CIC 2010) provided the first well-formatted process model for BIM implementation at the project level. It defined the appropriate uses for BIM on a project (e.g., design authoring, cost estimating, and design coordination), along with a detailed design and documentation of the process for executing BIM throughout a project's lifecycle. Major contributions of this guide to facilitate better integrated BIM process in project execution include: a method to identify BIM Uses; a procedure for designing the BIM Process for the project; a method for defining the IE Requirements; a method to define the infrastructure necessary to support the BIM Process; a structured method for team implementation of the procedure through a series of meetings and intermediate tasks; and a structured method for individual organizational development of typical methods for BIM implementation.

As one of the underpinnings to an integrated BIM process, IE poses the biggest challenge to BIM practitioners. The Industry Foundation Classes (IFC) has become the interoperable standard for the exchange of building product information, with key enhancements from the Information Delivery Manuals (IDM) and Model View Definitions (MVD) (Eastman 1999). Significant progress has been made in the industry on advocating the IFC/IDM/MVD framework as the open IE standard for BIM execution, despite some of the recognized deficiencies. Eastman et al. (2009) and Panushev et al. (2010) have provided case studies of IE standardization in process modeling for precast/prestressed concrete using this framework. The Architecture, Engineering, Construction, Owner Operator Phase 1 (AECOO-1) Joint Testbed was another epic effort in developing and implementing IDM/MVD based methods to streamline communications between parties in the conceptual design phase to get an early understanding of the tradeoffs between construction cost and energy efficiency (OGC 2010).

2.3 State-of-the-art Green BIM practice and research

The 2010 SmartMarket Report by McGraw-Hill Construction offered a good summary of the cutting-edge strategies and approaches of Green BIM practices (McGraw-Hill Construction 2010). Accompanying the strong market momentum are strong governmental involvements in Green BIM. For instance, in the US, the General Service Administration (GSA) is leading the efforts to leverage BIM for high performance buildings, by establishing the National 3D-4D BIM program and publishing the BIM Guide Series (GSA 2012). In Europe, the 7th Framework Program (FP7) has produced research such as the energy-enhanced BIM (eeBIM) framework, an open and extensible mechanism to support the data flows for energy efficient design and lifecycle management (Katranuschkov et al. 2011).

In academia, there is a good diversity of scholarly research on BIM and green building design and construction, such as BIM for energy and thermal simulation (e.g. Schlueter and Thesseling 2008), lighting simulation (e.g. Huang et al. 2008), and daylighting simulation (e.g. Welle et al. 2012). There is also an interest on BIM-based building evaluation, e.g. Motawa and Carter (2012). With LEED being a globally-recognized green building rating system, BIM implementation in LEED oriented design, simulation, analysis and certification have caught a lot of attention in the research community. Many researchers have addressed the synergies between BIM and LEED. For instance, Biswas et al. (2008) and Wu and Issa (2010a) proposed system level integration of BIM and LEED; Barnes and Castro-Lacouture (2009) and Bank et al. (2010) demonstrated the possibilities of using BIM as a sustainable design decision-making tool, and relying on BIM-based information for LEED points calculation. In addition, O'Keeffe et al. (2009), Azhar et al. (2010), and Wu and Issa (2010b) looked at how BIM could facilitate the LEED certification process with design analysis optimization, information management, documentation generation and certification review. Finally, Wu and Issa (2011, 2012) proposed a cloud-BIM based framework to automate the LEED certification process.

3. METHODOLOGY

3.1 Process mapping methods and procedures

3.1.1 Preparatory tasks

Before conducting the actual process mapping, there are a few preparatory tasks to be completed. This will include the identification of key project stages, project participants, project sustainability goals, and the intended BIM uses to achieve these goals. As concluded from the literature review, IPD is preferred to traditional process in delivering *Green BIM* project. In practice, IPD exhibits fundamental differences from traditional project delivery methods in two primary areas: team assembly and project phasing/execution. It is critical to build an integrated team by: 1) identifying participant's roles at the earliest possible time; 2) pre-qualifying team members; 3) encouraging broad involvement of stakeholders interests groups; 4) defining consensus-based goals and values; 5) aligning organizational and business structure with needs and constraints; and 6) developing agreements on roles and accountability, risks and benefits. IPD redefines project phases into *Conceptualization, Criteria Design, Detailed Design, Implementation Documents, Agency Coordination/Final Buyout* and *Construction,* which enables the integration of early input from constructors, installers, fabricators and suppliers as well as from designers, and the ability to model and simulate the project accurately using BIM tools (AIA 2007). The project sustainability goals, which are directly linked with the primary responsibilities of team participants and expected green building project outcomes, should be determined by the owner's commitment, the allowed time and budget, the project team competency and other contributing factors. Most green building rating systems are prescriptive and offer pre-defined criteria (in both mandatory and optional formats) for desired building features, including site selection, orientation, energy efficiency, water consumption, material reuse and localization, daylighting and open view design, indoor air quality and so on. The overall certification level will be based upon the total points scored in meeting these criteria. Therefore, strategizing the certification approach using these criteria as references is at the heart of the preparatory tasks, and significantly affects the selection of team participants and BIM uses.

3.1.2 Process mapping

Upon the completion of preparatory tasks, the process map of *Green BIM* was created using BPMN in Microsoft Visio. BPMN is a popular process modeling standard and graphical representation specifying business processes. Recently its use was mandated by the National BIM Standard effort commissioned by the National Institute of Building Science (NIBS). BPMN offers simple yet standardized visual communication to users to understand the external and internal business procedures through a business process diagram. BPMN is especially attractive to the BIM/IFC researchers since it offers better integration with the detailed information exchange mapping initiatives used in the IDMs currently being developed for the NBIMS as well as BIM Standards in other countries. The process maps created in this research are limited to: *Level 1: Overall Green BIM Process Map* and several examples of *Level 2: Detailed Green BIM Process Maps with LEED as a Use Case*.

3.2 LEED as a Use Case

The proposed process maps were intended to assist project teams in achieving a certain type of green building certification with integrated, process-driven Green BIM practices. The literature review has justified the selection of LEED as a use case due to its significant market share in the North American green building market and a global recognition as one of the most popular green building rating systems. LEED has been developed into a portfolio of rating systems for various types of buildings with several versions. This research chose LEED for New Construction 2009 (LEED-NC 2009), which had the most registered projects pursuing its certification in the LEED portfolio. When developing the Level 2 process maps, the LEED criteria (i.e. the LEED credit requirements) have been taken into account, either as reference information to a particular task in the process map, or as an input to "what-if" scenario analysis. Some of the IE incidences that took place along the process map were also LEED-dedicated. For instance, at the end of certain tasks/events in the process map, there might be information generated that could be plugged into the required LEED documentation. With LEED as a use case, it became much easier to show how the Green BIM process differs from a generic BIM execution process, and how the project team needs better collaboration to streamline the exchange and synthesis of domain-specific information, yield the desired project performance outcomes and achieve the desired green building certification.

4. RESULTS

4.1 Preparatory tasks outcome

IPD is the preferred project delivery method for green building projects and BIM implementation, and was selected in this research. IPD is also representative of the other major delivery methods, which increases the

usability of the process maps developed in this study. One of the major features of IPD is that it encourages early involvement of stakeholders and encourages concurrent activities and enhanced collaboration among project participants. The identified project phases include: *Conceptualization, Criteria Design, Detailed Design, Implementation Documents, Agency Coordination/Buyout, Construction* and *Post-Construction*. The major project participants include: *Owner, Architect* (expandable to include *Landscape Architect*) *Engineer* (expandable to specify *Civil, Mechanical, Electrical, Structural,* etc.), *Contractor, Commissioning Agent* (*CxA*), *Consultant* (including *LEED Administrator*), *Trade Contractor* (expandable to *M/E/P,* etc.), and *Suppliers*.

To identify the sustainability goals of the project, it is important to refer to the green building rating system under which the project is pursuing certification. To give a meaningful example, LEED-NC 2009 was used here to demonstrate the steps followed and proved to be a great tool to accomplish this task. As shown in Fig. 1 (the view is cropped due to overall large size), the *LEED Goal-BIM Use Identification Worksheet* was developed based on the LEED-NC 2009 Checklist/Scorecard. Usually a LEED project will start with the process called "LEED Charrette", which is a type of workshop where project participants indulge in brainstorming, discussion, and strategy development to create a shared vision. Participants in these workshops usually include the owner, architect, consultants, contractors, landscape architect, and commissioning agents. The outcome of the Charrette includes a first draft of the LEED scorecard, a preliminary rating, and defining the roles of each member of the project team. The *LEED Goal-BIM Use Identification Worksheet* used a LEED scorecard came from a Charrette of the new Biological Science Building at Georgia Southern University that is pursuing LEED-NC Silver and currently under construction. The worksheet clearly indicates the attempted LEED credits, the total points achievable, and the responsible parties for each credit. The LEED scorecard was customized to facilitate the identification of the potential BIM uses. Following the methodology recommended by CIC (2010), BIM uses were focused to meeting the requirements of these targeted LEED points, which were stipulated with more details and recommended strategies in the LEED reference guide (USGBC 2009).

LEED 2009 for New Construction and Major Renovations
Project Checklist

Biological Science Building
1-Nov-10

50	29	31	D/C	Total Project Score	Achieved Points	50	Responsibility		BIM Use	Value to Project (High/Med/Low); Capability Rating (High/Med/Low) R C E; Notes	Proceed with Use (Yes/No/Maybe)
16	3	7		Sustainable Sites	Possible Points:	26	Responsibility				
			D/C				Main	Secondary			
Y			C	Prereq 1	Construction Activity Pollution Prevention		CE		Site Utilization Planning		Yes
								GC	Site Utilization Planning		
		1	D	Credit 1	Site Selection	1	CE		Site Analysis		No
		5	D	Credit 2	Development Density and Community Connectivity	5	LEED-AD		Site Analysis		No
		1	D	Credit 3	Brownfield Redevelopment	1	CE		Site Analysis		No
6			D	Credit 4.1	Alternative Transportation—Public Transportation Access	6	LEED-AD		Site Analysis		Yes
1			D	Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1	ARCH		Site Analysis		Yes
3			D	Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3	ARCH		Site Analysis		Yes
2			D	Credit 4.4	Alternative Transportation—Parking Capacity	2	ARCH		Site Analysis		Yes
1			C	Credit 5.1	Site Development—Protect or Restore Habitat	1	LARCH		Site Utilization Planning		Yes
								GC	Site Utilization Planning		
	1		D	Credit 5.2	Site Development—Maximize Open Space	1	CE		Site Analysis		Maybe
	1		D	Credit 6.1	Stormwater Design—Quantity Control	1	CE		Site Analysis		Maybe
1			D	Credit 6.2	Stormwater Design—Quality Control	1	CE		Site Analysis		Yes
1			C	Credit 7.1	Heat Island Effect—Non-roof	1	ARCH		Site Utilization Planning		Yes
								LARCH	Site Utilization Planning	For Option 1	
	1		D	Credit 7.2	Heat Island Effect—Roof	1	ARCH		Design Review	Check SRI	Maybe
								SE	Egineering Analysis	For Option 2	
1			D	Credit 8	Light Pollution Reduction	1	EE		Lighting Analysis		Yes
7	3	0		Water Efficiency	Possible Points:	10	Responsibility				
							Main	Secondary			
Y			D	Prereq 1	Water Use Reduction—20% Reduction		LEED-AD		Design Review		Yes
								ME	Mechanical Analysis		
4			D	Credit 1	Water Efficient Landscaping	2 to 4	LARCH		Site Analysis		Yes
					Reduce by 50%	2					Yes
					No Potable Water Use or Irrigation	4					Yes
	2		D	Credit 2	Innovative Wastewater Technologies	2	LEED-AD		Sustainability Evaluation		Maybe
								ME	Mechanical Analysis		
3	1		D	Credit 3	Water Use Reduction	2 to 4	LEED-AD		Sustainability Evaluation		Yes
					Reduce by 30%	2		ME	Mechanical Analysis		Yes
					Reduce by 35%	3					Yes
					Reduce by 40%	4					Maybe
5	13	17		Energy and Atmosphere	Possible Points:	35	Responsibility				
							Main	Secondary			
Y			C	Prereq 1	Fundamental Commissioning of Building Energy Systems		CxA		Asset Management		Yes
									Building System Analysis		
									Building Maintenance Scheduling		
								TC	3D Coordination		
								GC	Phase Planning		
Y			D	Prereq 2	Minimum Energy Performance		LEED-AD		Energy Analysis		Yes
								CONS	Energy Analysis	Energy Simulation	
								ME	Mechanical Analysis	Space, Zone, Load	
Y			D	Prereq 3	Fundamental Refrigerant Management		ME		Mechanical Analysis		Yes
5	5	9	D	Credit 1	Optimize Energy Performance	1 to 19	LEED-AD		Energy Analysis		Yes
					Improve by 12% for New Buildings or 8% for Existing Building Renovations	1		CONS	Energy Analysis	Energy Simulation	Yes
					Improve by 14% for New Buildings or 10% for Existing Building Renovations	2		ME	Mechanical Analysis	Space, Zone, Load	Yes
					Improve by 16% for New Buildings or 12% for Existing Building Renovations	3					Yes
					Improve by 18% for New Buildings or 14% for Existing Building Renovations	4					Yes
					Improve by 20% for New Buildings or 16% for Existing Building Renovations	5					Yes
					Improve by 22% for New Buildings or 18% for Existing Building Renovations	6					Maybe
					Improve by 24% for New Buildings or 20% for Existing Building Renovations	7					Maybe

Fig. 1: LEED Goal - BIM Use Identification Worksheet (cropped view).

4.2 Process Mapping – Level 1

Process mapping using BPMN was fairly straightforward, and the Microsoft Visio streamlined the efforts. The basic steps of creating *Level 1: Overall Integrated Green BIM Process Map (IGBPM)* included: defining the each process of specific *Green BIM* practice per project delivery stage; allocating potential BIM uses in this process; designating the responsible party; specifying the process input and output, and necessary Level 2 processes; and

repeating similar steps to map the rest of the process between the process Start and End. The resulting Level 1 process map is partially shown in Fig. 2 (due to its size). The upper swimlane shows all BIM uses over the integrated Green BIM project delivery. The lower swimlane illustrates the incidences of IE and various inputs/outputs generated along with process progression. Some of the IE incidences were highlighted because they represented a specific LEED deliverable that could be used to prepare relevant LEED documentation for certification review purposes. This Level 1 process map was developed based upon the BIM PEPG (CIC 2010) and the LEED-NC 2009 rating system. In comparison with the Level 1 process map in the BIM PEPG, it has a lot more BIM uses up front. As mentioned previously, this is due to the fact that IPD encourages early involvement of stakeholders, and a lot of concurrent activities are taking place at the early stage of the project delivery process.

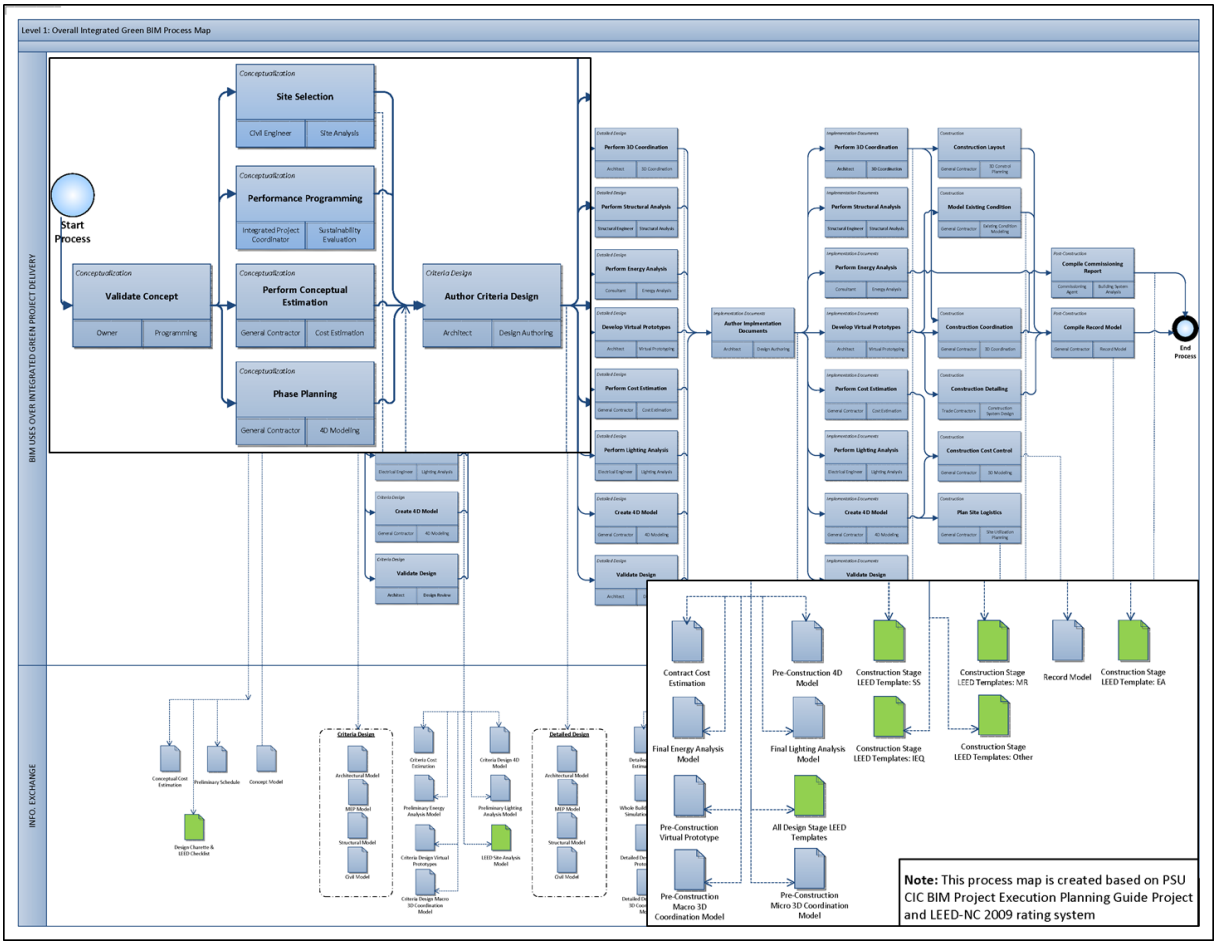

Fig. 2: Level 1 Process Map: Overall Integrated Green BIM Process Map (IGBPM) (partially enlarged).

4.3 Process Mapping – Level 2

The complete set of Level 2 process maps is still an ongoing effort. Some sample process maps, the *Level 2 Process Maps: Site Analysis* and *Energy Analysis with LEED as a Use Case* was exhibited here in Figs. 3-4 as examples. As noted, the Level 2 process map examples were also developed based on the current efforts of OGC AECOO-1 Joint Testbed (OGC 2010), BIM PEPG (CIC 2010) and the LEED-NC 2009 rating system. Using a similar methodology, other Level 2 process maps can be developed to incorporate the green recipes such as LEED criteria along the integrated green building project delivery.

Generally speaking, the differences between the IGBPM Level 2 process maps and the ones developed by CIC (2010) reside in how the prescribed green criteria, or the LEED credits requirements in the use case, influence the BIM uses planning and execution. This influence also occurs in different manners. For instance, a LEED credit requirement might offer extra information for performing a task/event in the process. In this case, it is a piece of "REFERENCE INFO.", located at the uppermost swimlane of the Level 2 process maps. A LEED credit requirement may also show up in the middle "PROCESS" swimlane and directly impact the process by necessitating a "what-if" scenario analysis, as where the "LEED Gateway" (the Yes/No gateway in green color) is shown in Figs. 3-4. It engenders extra sub-processes in the process map, when the team decided to evaluate the feasibility of achieving these LEED points. A third circumstance of the LEED influence is when an incidence of IE

generates a piece of information that becomes part of the LEED documentation, shown as process deliverables in the lowest "INFO. EXCHANGE" swimlane. To be specific, in Fig. 3, the *Level 2 Process Map: Site Analysis with LEED as a Use Case* enables "what-if" scenario analysis to encourage the developer to select the project site with development density and neighborhood connectivity in mind. The parking capacity requirements of LEED SS credits also attempt to reduce unnecessary hardscapes due to the construction of excessive parking lots. Fig. 4 exemplifies the BIM-based energy analysis process in a LEED project when the project team decides to go for the whole building energy simulation option. This option is the most challenging one but it could earn the most LEED points as needed for the certification. In a generic Level 2 Energy Analysis process map, it does not specify the base condition and the reference standards (e.g., ANSI/ASHRAE/IESNA 90.1-2007) that the energy analysis should follow. In contrast, the Level 2 Process Map: Energy Analysis with LEED as a Use Case did specify all these premises and requirements, which apparently better advises the project team on appropriately conducting the desired whole building energy simulation.

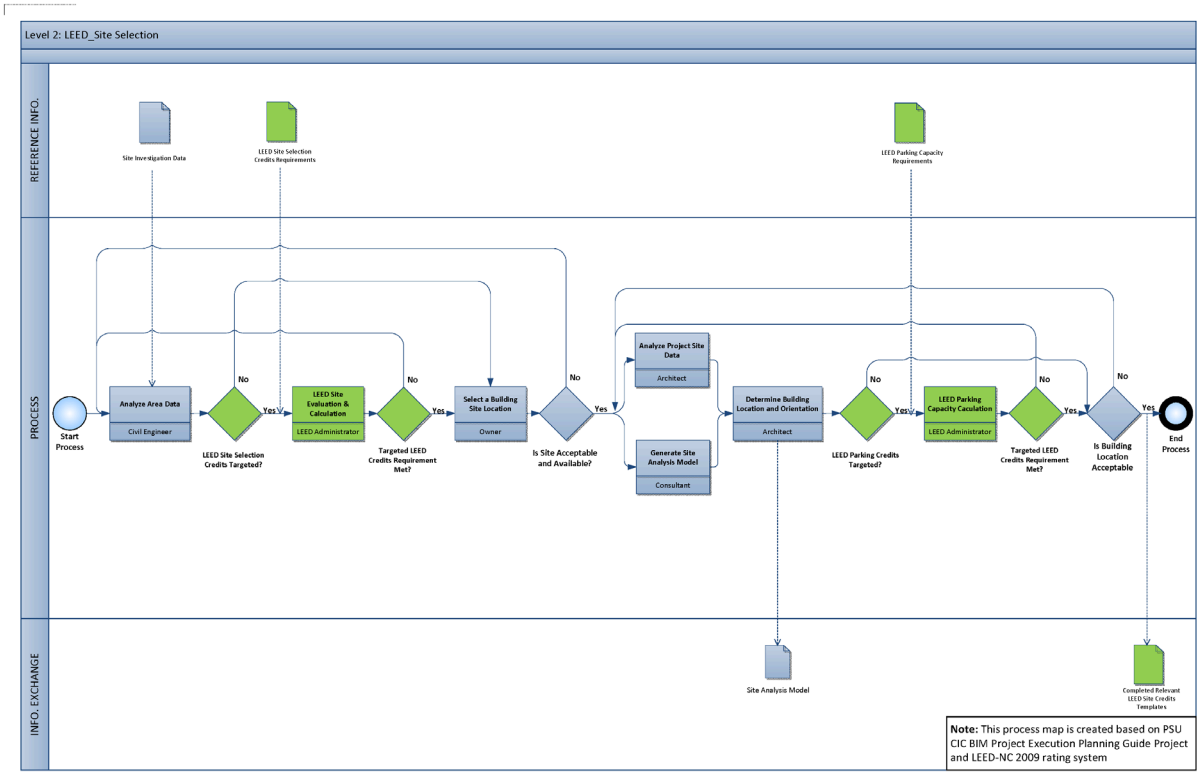

Fig. 3: Level 2 Process Map: Site Analysis with LEED as a Use Case.

5. CONCLUSIONS

In conclusion, this research investigated a critical issue in promoting Green BIM practice in the AEC industry, which is the need for an integrated process. Project teams have been struggling to capitalize on the synergies between BIM and green building to the full extent, due to the immature, ad-hoc and unsystematic practices. This is frustrating and can be avoided with the availability of better guidelines. Existing efforts on process modeling for both green building and BIM execution have laid a solid foundation for this research to take one step further, and create an Integrated Green BIM Process Map (IGBPM). The strengths of the proposed IGBPM include:

- The clear identification of sustainability goals, corresponding BIM uses, and the responsible parties without too much extra efforts compared with the typical green building project delivery.
- The Level 1 process map provides an overall roadmap to plan for Green BIM practices early on in the project delivery stage, which adds value to the project, and reduces uncertainty and risks.
- The Level 2 process maps offer step-by-step operational guidance on detailed execution of specific Green BIM practices. It ensures that the right tools, desired resources and competent personnel will be mobilized to perform the tasks. The anticipated process outcomes and IE/ER are well understood by all project participants, which will significantly improve productivity and reduce the costs associated with interoperability issues.

- The IGBPM was designed with transferability in mind, which makes it easily customizable to any project delivery method in pursuit of any green building certification.

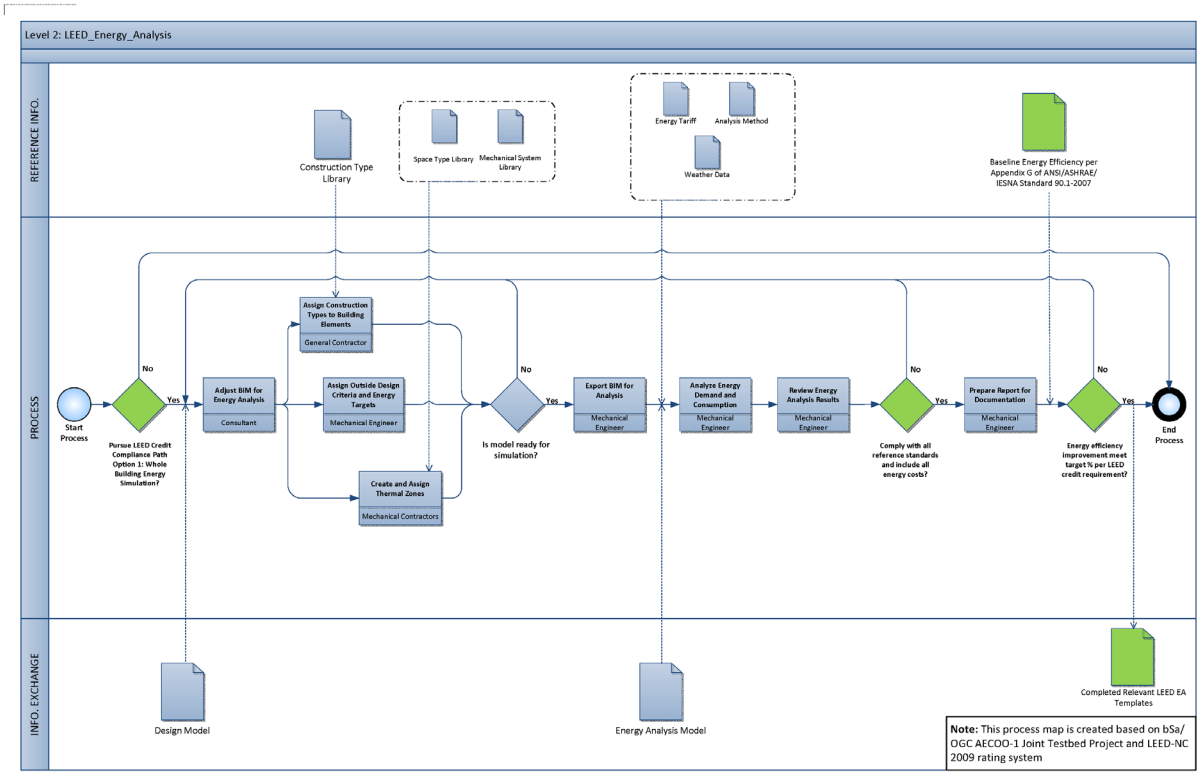

Fig. 4: Level 2 Process Map: Energy Analysis with LEED as a Use Case.

However, there are limitations to this research and the proposed IGBPM. At this moment, the IGBPM is not a finished product. Most Level 2 process maps, IE and ER are still under development. Another major weakness is that the IGBPM has not been validated with actual Green BIM projects. Some preliminary validation has been attempted with the Biological Science Building on Georgia Southern campus. The developed process maps were originally planned to be validated through this case study. Nevertheless, after the preparatory tasks were performed based on the information from this project, a conversation with the GC revealed that the design-stage BIM models were never further developed with construction details and thus were rarely used during the construction process. As a result, the process maps have not gone through any comprehensive validation yet.

Meanwhile, from a research perspective, there are still broad concerns regarding BIM contracting, and the lack of an adequate understanding of the IPD method. In order to achieve the expected outcomes of implementing the IGBPM, relationship building and collaborative project management are indispensable, since they are the supporting infrastructure for integrated Green BIM practices.

Further development of the IGBPM will be looking at the Open BIM initiative and how the IFC/IDM/MVD framework will influence Green BIM practices, and the impact on its development due to the use of open standards for information exchange under this framework. In closing, it is encouraging to observe that the BPMN standard provides good integration with IFC, and more BIM software vendors are embracing IFC as a standard for BIM information exchange.

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