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GREEN BIM APPROACHES TO ARCHITECTURAL DESIGN FOR INCREASED SUSTAINABILITY

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ABSTRACT: The effectiveness of Building Information Modeling (BIM) tools and processes has been recognized by the industry and owners are beginning to adopt Triple Bottom Line accounting practices, to enhance economic performance and environmental and social performance. However, the widespread and practical application of Green BIM remains largely unrealized. The authors identify that lack of understanding of the applicability of sustainability metrics to BIM design process is a significant barrier to this adoption. Through literature review this paper outlines the various sustainability metrics available to construction and elaborates on the potential of BIM for sustainable design. The paper maps and correlates applicable concepts of sustainability evaluation systems to BIM and describes the constraints in current BIM tools.

Keywords: Green, BIM, Sustainability, Metrics, Integration

1. INTRODUCTION

Various approaches to Building Information Modeling (BIM) have been adopted by professionals and researchers to implement sustainable design [1, 2]. While recent industry partnerships such as the American Institute of Architects Committee on the Environment (AIA/COTE) and the U.S. Green Building Council (USGBC) demonstrate the increased interest in green or sustainable design, the widespread and practical application of BIM to sustainable design is still in its infancy. Denoted in this paper as Green BIM, the application of BIM tools and technology to achieve project sustainability or green design goals is an emerging area of study.

In order to provide a framework for understanding the various approaches to Green BIM and the opportunities and barriers, a literature review of measures of sustainable design and performance metrics, and relevant BIM technologies was conducted. At the core of Green BIM processes lie parametric modeling and building simulation tools that support either manual or automated data sharing, and furthermore, multidisciplinary design, optimization, and agent-based modeling technologies [3, 4]. Current technologies still face various technical challenges to effectively support and efficiently process large amounts of data to facilitate sustainability-related decision-making. Nevertheless, this paper demonstrates that BIM provides better tools and processes to enhance overall sustainability when analyzed from a holistic life cycle perspective.

Not that long ago, many building professionals would have classified sustainable design merely as an interesting idea. But awareness of climate change, changes in policy and incentives, and other environmental factors have catapulted it to center stage [5].

Quality sustainable design requires an understanding of how a building will perform after it is built, which in turn requires computer-based simulation software for rigorous building analysis. The advent of Building Information Modeling offers even greater opportunities for building analysis by pairing the analysis software and BIM for the seamless assessment of building performance [6].

A well-populated building information model also carries a wealth of information necessary for many aspects of sustainable design and green certification. For instance, schedules of building material quantities can be obtained directly from the model to determine percentages of material reuse, recycling or salvage. Various design options for sustainability can be pursued in parallel and automatically tracked in the model. Advanced visualization techniques can be used for solar studies and to produce 3D renderings and construction animations of a green project [7].

In order to achieve more comprehensive sustainable solutions, an expansion of traditional thinking is required while making decisions during the design process, including [1]:

- Understanding climate, culture and place.
- Understanding the function of the building.
- Understanding the needs of the community.
- Minimizing the consumption of resources.
- Using locally available resources and natural systems.
- Using efficient manmade systems.
- Applying renewable energy generation systems.

A fundamental tenet of sustainable design is the integration of all the building systems among themselves as well as with the external economic, social and environmental context of the project [1].

Therefore, the combination of high-performance sustainable design strategies and BIM technology has the potential to change the profession dramatically and bring a higher-quality design to mainstream architectural practice. Computer technology by itself is not a universal solution, but combined with a comprehensive sustainable design methodology, it can provide powerful support for efficient, expanded, and improved services. [8]

2. REQUIREMENTS OF SUSTAINABILITY MEASUREMENT

According to the report of the Brundtland Commission submitted to the United Nations in 1987, "sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs" [9]. Although this definition is well known, operationalizing it as a basis for decision-making is challenging. Specific challenges associated with measuring built environment sustainability abound. At the foundation of the problem is the lack of a widely accepted operational definition of the construct of sustainability, although substantial work has been done to date to address this problem [10, 11]. While acknowledging the importance of these efforts, this paper focuses instead on the more practical issues associated with measurement system implementation that can be facilitated by a BIM system. Specifically, the paper presents an overview of three distinct approaches to evaluating the sustainability of any building system – prescriptive, performance-based, and systems-based. An overview of the three systems is given in order to understand which one is better suited to be used in conjunction with BIM technology [12].

2.1 Prescriptive Approaches to Measurement

Prescriptive tools consist of sets of recommended or best practices toward achieving the goal state of sustainability, and as measurement tools they are primarily point-based. A facility system could be evaluated using such a tool by allocating one or more points for each best practice that is implemented in the facility at the time of measurement. For example, early versions of the Leadership in Energy & Environmental Design (LEED) Green Building Rating tool [13] assigned a point for using specific technologies such as porous pavement. Porous pavement is an effective technology in many circumstances for addressing the problem of urban storm water runoff, and as such is a recommended best practice for certain paved areas of facility systems.

Later versions of the system [14] still rely for some of their credits on best practices with respect to specific technologies (e.g., Low VOC paints and carpets), although other credits are more performance-based (such as water and energy efficiency credits). Low VOC paints and carpets are actually somewhat of a hybrid between prescriptive and performance-based, since they allow multiple kinds of paints and/or carpets within the envelope of the low VOC criteria (a performance-based approach), but they still limit the points to instances where floors are covered with carpet (not other types of floor coverings) and walls are covered with paint (not other types of wall coverings).

Based on these examples, we can see that prescriptive measurement approaches suffer from several weaknesses. First, they are dependent upon present technologies and best practices, which necessarily change over time due to improvements in state of the art. Second, generalizability to multiple types of facilities in multiple contexts is difficult to achieve with these tools; to be useful in decision making, they must contain recommendations that are specific enough to apply to real facilities in real contexts, which usually means that they are limited in scope to the types of facilities and contexts for which they were developed.

For example, the LEED New Construction (NC) tool is applicable primarily to new commercial or institutional construction in urban or suburban areas. In this type of context and for these facility types, using porous pavement and low VOC paints and carpets makes sense as a best practice. But what about adaptive reuse of existing facilities in urban areas, where pavement already exists that would not usually is replaced? In this situation, removing existing pavement and replacing it with porous pavement to obtain a point would involve significant additional impacts outside the typical scope of work (and perhaps is one of the reasons that porous pavement was removed as a potential point in later versions of the LEED system). What about facilities that contain no paved areas, such as certain residential facilities? From a runoff standpoint, having no paved areas is superior to having porous pavement, which is superior to using impervious pavement. Yet the prescriptive standard would penalize the facility with no paved areas, since it does not meet the criterion as stated. What if the LEED system is being applied to a warehouse, where carpet is not typically used at all? Should project teams include a token amount of low VOC carpet for the sake of the point, even though they would not otherwise do so in a good warehouse design?

Optimizing the facility from this standpoint would likely result in negative impacts from a whole systems standpoint that would overwhelm the benefits realized from undertaking the best practice. What is most sustainable for one type of construction is not necessarily sustainable for other kinds of construction. Yet prescriptive standards for measuring facility sustainability offer an easily understood and easily measured way to encourage industry to adopt sustainability best practices [15] The ethics and talent of the design team are the primary control to ensure that these systems do not encourage sub optimization in the project for the sake of points. Prescriptive methods work well in situations where they are contextually adapted and applied, such as the proliferation of residential green building rating systems that are being developed locally in over 30 cities or regions around the United States [16].

2.2 Performance-Based Approaches to Measurement

Performance-based approaches to sustainability measurement address some of the shortcomings of prescriptive standards. Rather than specify a particular best practice or technology that might not be appropriate for all situations, performance-based tools denote compliance based on whether or not the solution meets or exceeds a threshold on some continuum representing the problem that a best practice is meant to address. For instance, a performance-based measurement system might allocate a point if the pavement used in the parking lot produces less than a certain amount of runoff for a storm event of a certain magnitude, or if the net runoff from the site is less than or equal to pre-development conditions. Newer versions of the LEED rating system have moved toward this type of standard for many credits, although there are still some prescriptive credits (most notably the Alternative Transportation credit and the several credits in Sustainable Sites dealing with site selection). Performance-based measures specify an objective to be met by the pavement, not *which pavement* should be used to meet this objective. The designer or decision maker is free to choose a pavement type that is most appropriate in the context of the specific facility. As long as the pavement results in a condition that meets the objective, the point is obtained.

While performance-based measurement tools represent a significant improvement over prescriptive tools, they still encourage reductionist optimization of specific aspects of a built facility. As such, they fail to recognize that what is optimal from the perspective of a single problem (e.g., storm water runoff) might reduce the optimality of the system from a holistic standpoint (e.g., total resource consumption). How the problem is framed can also have a considerable impact on the overall performance of the whole system. For example, if the measurement tool requires calculation of storm water runoff from the pavement system, the decision maker might never even consider the question of whether pavement is needed at all. Considering tradeoffs among objectives and designing for an optimal balance of points is left to the decision maker, and can be a considerable challenge in all but the simplest of contexts.

2.3 Systems-Based Approaches to Measurement

Systems-based measurement tools represent the most comprehensive approach to measuring facility sustainability. Systems-based measurement is equivalent to performance-based measurement, but on the scale of whole facilities, not individual building features. As such, systems-based measurement accounts for synergies among subsystems that comprise the facility system as a whole. An example of a system-level standard is to allocate credit if the whole facility system generates less than or equal to a certain quantity of storm water runoff for a storm event. For instance, current LEED v.2.x stormwater credits take this approach. Notice that the idea of threshold-based credits remains the same, but the scale of measurement is based on the response of the facility as a whole – runoff from the pavement system as well as other impermeable surfaces such as roofs could be captured by swales surrounding the parking area, or diverted into a settling basin for later use in groundwater recharge or irrigation, or any of a number of other strategies, as long as the combined effect meets the system-level requirement. What matters is the total impact of the whole facility system, which in the storm-water example can be different than the mere sum of the impacts of the subsystems due to potential interactions among them.

The challenges associated with systems-based approaches to measurement are primarily associated with modeling the synergistic effects of multiple subsystems acting in concert with one another and in obtaining commensurate and reliable data to conduct the analysis. Very few attributes of the built environment have been effectively modeled on this scale in ways that have been widely adopted by designers as a decision aid, but BIM has the potential to overcome these limitations. Energy performance is one example – multiple models of whole building energy performance exist, and a growing number of designers either integrate this capability in-house or rely upon out-sourced expertise to incorporate it into design decisions. Yet the ability to concurrently optimize multiple facilities attributes and easily compare implications and tradeoffs with respect to different design alternatives remains elusive. Approaches to concurrently optimizing multiple systems remain in their infancy and often rely on non-traditional modeling techniques such as genetic algorithms [17-19]. Similar approaches have been applied using tools ranging from case-based reasoning to neural networks and Markov chains [20-22].

An interesting point to note is that while it is difficult to accurately *predict* future performance of a facility using a systems-based approach due to the difficulty of modeling complex systems interaction, it is considerably easier to *monitor* performance at a systems level using such an approach through the use of procurement information. By establishing a boundary around the facility system and tracking the flows of matter and energy across that boundary over time, a mass balance-type model can be constructed to model the *actual* performance of the system, thereby permitting inferences about the synergistic effects of the various sub-systems contained within the larger system. Pearce and Fischer [23] (see also [24] and [25]) have developed and applied a protocol for systems-based sustainability analysis in the context of sustainable rehabilitation of historically significant structures that describes in detail the steps and assumptions involved in such an analysis.

2.4 Utility of Measurement Approaches

Which approach is most useful for a given purpose depends on a number of factors, including the degree of resolution required, the information available during measurement, and the purpose to which the results will be put [12]. Prescriptive measurement approaches tend to be useful where a coarse resolution is sufficient to support decision-making, or where best practices are well established and do not change frequently. Performance-based measurement, on the other hand, is useful when good performance simulation models exist and system behavior is predictable. Systems-based measurement, in contrast, is most useful when facilities are considered within a larger mission context and ongoing changes to the system are possible to optimize performance, such as in early facility design.

3. BIM CAPABILITIES FOR SUSTAINABILITY MEASUREMENT

Building Information Modeling refers to the creation and coordinated use of a collection of digital information about a building project. The information is used for design development and decision making, production of high quality construction documents, predicting performance, cost estimating, and construction planning, and eventually, for managing and operating the facility [26]. BIM has the potential to support life cycle management and decision making for built facilities and represents considerable potential for eliminating process waste as part of the facility delivery process. As such, it is well suited to support efforts to increase project sustainability, although opportunities for additional development of BIM tools abound.

3.1 BIM Information Integration Challenges

A BIM Model has the capability to report areas and quantities from within the model for various parameters that contribute to the sustainability of the project such as water conservation, energy analysis, computational fluid dynamics, and daylighting analysis. However, a significant fact remains that this flow of information at times is so detailed and complex that even specialists avoid using this information, and tend to skip the advantages of BIM because of the considerable effort required in the very beginning of the project to set up the BIM model. Also, the bi-directional flow of information between the architect and the design specialists, in some cases, is restricted during design due to interoperability challenges.

In addition, BIM models still cannot generate documentation for all LEED points automatically, particularly when the design evolves over time and multiple stakeholders are involved. BIM has the potential to support a systems-based approach to measuring sustainability, but projects still have vast amounts of segregated data and no single platform that can integrate it. Once this integration of segregated information is achieved on a single platform, BIM will be able to greatly facilitate systems-based sustainability analysis.

One example of this degree of integration might be a facility whose orientation is altered during design in order to improve energy efficiency, which may affect daylighting schemes, fenestration, shading, and heating and cooling systems for the building. Changes in the products used for these components could also impact tallies of materials with properties such as recycled or rapidly renewable content. In order to calculate the overall effects of a single change in design process in a holistic fashion, an integration of all the relevant information on a single platform is required, a big obstacle that needs to be overcome. This scenario reflects the fact that a BIM model could be better suited for a systems-based approach where the whole facility is analyzed and assessed over its entire lifecycle.

3.2 BIM Interoperability Challenges

Governments around the globe are implementing new policies and building regulations that mandate sustainable design [27-29]. However, the design community still lacks widespread experience and understanding of sustainability concepts [30]. For decades, simulation software tools have been available to assist the design of energy-efficient buildings. Unfortunately these tools have historically been difficult to use and thus limited to specialists, so many designers rely instead on simple hand-calculation methods to assess building performance.

Also, structural and mechanical models are being used to interact with architectural models for the purpose of coordination. However, the capacity of software to perform all the aspects of modeling and analysis critical for achieving sustainable design remains unrealized. Versions of BIM models are exported and then imported into separate software packages that produce information that is then translated back to the design team for further adjustments to the design [1]. Further, information regarding the environmental impact of material and system choices is still collected and integrated in the legacy fashion of catalog and manual referencing.

To date, projects concerned with incorporating sustainable design have used more conventional methods of design and documentation. For instance, a series of models may be created, including visual, analytical, and some purely for documentation purposes. Then, these separate analysis and design functions are analyzed and brought together to produce an energy efficient design. One of the examples of such projects was the Lewis and Clark State Office Building in Missouri built by BNIM Architects, where different parameters such as Physical Design Model, Solar Analysis Model, Digital Design Model, Energy Model, Daylighting Model and Construction Documents Model were created in order to complete the necessary design intent of the project [1]. As all these models affected each other, changes in one led to a need to physically change the other features as well. This project highlighted the need to for a tool to communicate and manage the information so that all the changes are simultaneously kept up to date with one other.

Although Building Information Modeling is a useful source for building geometry, it still lacks certain characteristics of becoming a complete analysis tool. The primary need to achieve better sustainable solutions with BIM is better interoperability among software. Studies have shown that moving the building geometry and other necessary ancillary data from the BIM model to an analysis package involves considerable time as the whole building geometry is re-created in each new application [1, 31-32].

3.3 BIM Data Comprehensiveness Challenges

BIM does not currently contain capabilities to track energy, light, and water opportunities. Being able to input metrics related to these factors directly into the building design is a major requirement of the design tools in the future. Still another integral component to measure sustainability typically missing from BIM models is the complete calculation of Carbon Footprint which includes life cycle analysis of all the materials installed in the building to track its carbon output as the building is being designed.

Perhaps the most interesting connection for sustainable design is the link between BIM and analytic tools that provide insight about the predicted energy or resource use for a proposed design. For example, BIM users can directly link to third-party proprietary suites of building performance management tools, enabling architects and engineers to visualize daylighting, fluid dynamics, and energy performance for specific spaces in a proposed project. By quickly revising the model and analyzing the impacts of these performance parameters on the building, architects can work in a more fluid but integrated and semi-automated process, while creating increasingly sustainable designs.

However, realizing the true potential of BIM tools to incorporate sustainability requires an understanding of the different types of sustainability measurement systems. While BIM tools offer significant potential to support sustainable design and the data needs of all three approaches to sustainability measurement, there are still considerable needs for further tool development to bring this technology to the point where it can be truly useful for systems-based sustainability analysis. Table 1 provides an inventory of current BIM tools in terms of their abilities to measure inputs and outputs to a facility system [33], a core part of systems-based sustainability analysis. While this flow inventory is not comprehensive, it does highlight the state of the art in current tools in terms of their ability to support systems-based sustainability analysis.

BIM technologies can also be characterized and described by the sustainable design strategies that can be investigated using these capabilities, as follows:

1. Parametric modeling: building orientation, massing
2. Simulation and analysis tools: daylighting, water harvesting, energy modeling, renewable energy, materials
3. Integration: combining parametric automation capabilities with simulation tools for design optimization
4. Agent-based modeling: integrated software solutions that track a building's carbon footprint such as embodied energy of materials, emissions from construction, and emissions from fuel it takes to get work crews to the job site [1].

4. CONCLUSIONS AND FUTURE WORK

The important question arising from this research is how much of BIM technology can actually enhance facility sustainability. Is it just limited to the rating of the building and the 'Feel-Good Factor' on the part of the owners and designers, or can it be really used to look at the design of the building from a holistic perspective over its whole life cycle? BIM may help to mitigate a common problem among designers new to projects seeking green building ratings: the temptation to incorporate sustainability features to obtain points, even though they may not be the best way to achieve sustainability for a particular building [15]. As BIM evolves to support systems-based sustainability analysis that considers performance of the facility system as a whole, the pitfalls of suboptimization will become more apparent to the project delivery team.

It is also important to note that USGBC and Autodesk are working together to create a platform that will allow users to predict the behavior of the building before it is constructed [34], The aim is to create BIM software capable of calculating real-time performance parameters within the building and determining USGBC LEED points based upon evolving design decisions.

The intent of this conference paper is to provide an insight as to how the integration of the BIM and sustainable design solutions will facilitate easier adoption of sustainable project delivery processes. Architects, specialists, consultants, and engineers will ultimately be able to examine the implications of alternative design strategies, helping them achieve higher life cycle efficiency and building performance.

Table 1: BIM Tool Capabilities for Tracking Sustainability-related Facility Flows

FLOWS IN	FLOWS OUT	TOOL
CASH FLOWS		
Design Cost		E, I, R
Construction Cost		I
O&M Cost		I
Annual Maintenance Costs		I
	Building-related Revenue	
WATER		
Total Water Demand		G
Potable/Nonpotable Water Demand		G
Indoor/Outdoor Water Demand		G
Rainfall		G
Recycled Water		
On-site Source		
	Municipal Wastewater	
	Groundwater Infiltration	
	Stormwater Runoff	
ENERGY		
Percent Renewable		G
Photovoltaic Power		E, G
Fossil Fuel		G, I
Nuclear Energy		G
Hydroelectric/Wind Energy		G
Total Electricity Demand		G, I
Electricity for Lighting		E, G, I
Electricity for HVAC		E, G, I
Other Electricity Use		G, I
Solar Heat Gain		E, I
Light Penetration		E, G, I
	Radiant Heat Loss	E, I
	Energy Produced by the Building	G, I
MATERIALS & WASTE		
Total Material Quality		I, R
Individual Material Quantity		I, R
Recycled Content		I, R
Other Material Attributes		I, R
	Carbon Emissions	G, I
	Total Material Waste	
	Waste Recycled	
	Waste to Other Sinks	
LEGEND		
E = Ecotect	I = IES Virtual Environment	
G = Green Building Studio	R = Revit Architecture	

With continued evolution of BIM to support project sustainability, the fragmented nature of the construction industry and its reluctance to use sustainable options because of cost and schedule issues may be overcome as Green BIM evolves to revolutionize the way the industry functions. More specifically, through a more holistic and comprehensive way to virtually represent and understand buildings, the project delivery team will have better knowledge of the parameters related to sustainability and will be able to examine the implications of tradeoffs among project alternatives.

In the future, BIM will hopefully continue to evolve to support sustainability assessment not only at the scale of individual facilities, but also at other scales of analysis. Combining BIM models for individual projects to support portfolio-scale analysis is one such opportunity. Table 2 highlights other examples of existing types of sustainability assessment tools that may be supportable by BIM tools [12]. At each scale, there are both threshold systems that provide a single result or value, and profile systems, which provide values for an array of variables relevant for consideration.

Ultimately, Green BIM has the potential to lead to more sustainable projects at multiple levels. With better understanding of how facilities perform and how their delivery can be streamlined, Green BIM has the potential to reduce the impact of the construction industry and create a better, more sustainable built environment for humans.

Table 2: Examples of Sustainability Assessment at Various Scales [12]

Scale	Threshold Systems	Profile Systems
Raw Material	Forest Stewardship Council Certification (http://www.fsc.org)	BEES (http://www.bfrl.nist.gov/oae/software/bees/)
Product or Assembly	GreenSeal (http://www.greenseal.org), GreenLabel Plus (http://www.carpet-rug.org)	Athena (http://www.athenasmi.ca)
Building	LEED (http://www.usgbc.org), GreenGlobes (http://www.greenglobes.com)	GBTool (http://www.iisbe.org/gbc2k/gbtool/gbtool-main.htm)
Development, City, or Region	LEED-ND (http://www.usgbc.org), Ecological Footprint (http://www.gdrc.org/uem/footprints/index.html), Carbon Footprint (various)	ICLEI Profile (http://www.iclei.org)
Enterprise	Ranking in Dow Jones Sustainability Index (http://www.sustainability-indexes.com), Carbon Footprint (various)	Global Reporting Initiative's Triple Bottom Line (http://www.globalreporting.org), SAM Corporate Sustainability Assessment (http://www.sam-group.com)

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