Measuring Contribution of Building Information Modeling (BIM) to the Construction Sustainability Goals

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"BIM" and "Sustainability" are two frequently used words in construction and academia today. BIM is a design-oriented tool, which generates a virtual three-dimensional model of a project. Sustainability refers to prudent use of earth's natural resources, and Construction Sustainability is the application of this principle to building activities. Societies in general, and the construction industry in particular - one of the largest in terms of natural resources consumed and waste produced - place high hopes on BIM and the principles of Sustainability to reduce consumption and waste, and to increase industry productivity. BIM's capabilities and limitations, currently more focused on model creation and energy simulations, are not well understood as they relate to construction sustainability and its goals. No method yet exists to evaluate BIM's contribution comprehensively to construction sustainability goals. This study presents a construction sustainability goals contribution matrix for BIM. The matrix indicates this contribution may be more limited than is commonly thought.

Keywords: Building Information Modeling, Sustainability Principles, Construction Sustainability Goals, and Building Ecology

Introduction

This intersection of BIM and Sustainability is an area of emerging importance. This is because of growing concerns in many societies about the environment, natural resource utilization, and it's affect upon their economic growth and development. The primary requirement for Sustainable construction is efficient utilization of resources. Construction is the world's primary consumer of materials and energy, consuming about 40% of materials extracted, and about 30 to 40% of primary energy required for operation (Kibert, 2005; Roodman & Lenssen, 1995).

Information Technology has revolutionized many aspects of societies over the last three decades, including agriculture, communication, medicine, music and transportation (Autodesk, 2011). The capabilities of design software and its effect on manufacturing and other industries have been significant. However, the construction industry has not yet achieved the efficiency, suitability and reduced costs that the manufacturing industry has enjoyed. It is expected that BIM might benefit the construction industry in a similar manner. Most BIM practitioners believe that BIM can achieve construction sustainable outcomes far more than currently achieved in the industry (McGraw Hill, 2010).

BIM is a data-rich, object-based, intelligent and parametric digital representation of a building, from which views appropriate to various users needs can be extracted and analyzed to generate feedback and improvement of the building's design (Azhar, 2008).

Materials and Methods

Materials

The primary aspects of sustainable construction are economic, environmental, and social (ISO, 2006). The basic resources needed for construction are materials, energy, water, land, and landscape or biota. There is one more resource, namely the ecological system, which is not well understood by construction industry participants. Efforts should be made to integrate this with the building to improve its services such as heating, cooling, storm-water, waste processing, and other environmental amenities (Graham, 2003; Kibert, 2005).

Construction is "sustainable" only when we are able to apply the principles of reduce, reuse, recycle to protect nature, eliminate toxic substances, apply life cycle economics in decision making, and create a quality built environment. This quality built environment would combine aesthetics, durability, and maintainability with the above mentioned base and scarce resources (Graham, 2003; Kibert, 2005).

Methods

BIM, a recently developed tool, which utilizes a design oriented software in order to generate a virtual three-dimensional model of a project (Autodesk, 2011). Its capabilities have kindled high hopes for industry participants that in combination with the principles of sustainability, it may revolutionize the construction industry and benefit the environment.

There are numerous software programs available to model a construction project using BIM - Architectural applications, MEP applications, Structural applications, Navigation programs, and building performance analysis programs. Some of BIM application programs include Revit, V8i, ArchiCAD, Allplan, Vectorworks, and Digital Project V1 R4 (Khalfan, 2003). Autodesk Navisworks is the software program used for the navigation purpose. There is also a wide variety of building performance simulation software programs, which have been available on the market for more than for more than thirty years. These include BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, EnergyPlus, IES-VE, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE, AND TRNSYS (Crawler, Hand & Griffith, 2005).

Apart from model creation and energy simulation, there have been several recent innovations, which help to realize this technology's full potential. These include interoperability-of-the-software packages, integration of a carbon accounting tracker and weather data (Krygiel & Nies, 2008). Also, other software packages exist for selection of optimum building orientation and for evaluation of various skin options, and for performance daylight studies of the building's position on the selected site (Azhar, 2011). Additionally, software is available for the use of BIM capabilities related to life-cycle cost analysis (LCA), which perform carbon accounting based on exporting the material schedule for the building and the use of BIM software plug-ins for calculation of operational energy use and carbon emissions ((Stadel et al., 2011). Utilization of the benefit of Geographic Information System (GIS), and creation of a GIS/BIM IFC-Based information exchange to resolve the problem of interoperability, are other areas utilized (Przybyla, 2010). These are a few of the recent studies done in an attempt to achieve sustainable construction goals.

Research Objectives

The majority of industry participants now use a wide variety of BIM related software available in the market. Many believe sustainability is the main benefit of BIM, while others consider coordination and visualization to be the main benefits (Bynum et al., 2013). The purpose is to find a comprehensive tool or technique to facilitate evaluation of BIM's contribution to the sustainability of building design and construction.

The objective of this study is to investigate ways in which BIM can better assist in achieving construction sustainability and sustainable project development goals. These objectives include:

1. To understand what sustainable construction goals and objectives are;
2. To determine how well BIM is helping the objectives be achieved, and;
3. To suggest what capabilities BIM should develop next.

Research Approach

The literature review led to the development of a matrix, which became the basis of evaluation of the BIM contribution to the construction sustainability goals. This matrix was then applied to evaluate the contribution of BIM to a case study from "University of California, Davis, USA" which was designed through the use of BIM.

Existing Evaluation Systems and their focus

There have been, since 1992, several initiatives to establish building sustainability related organizations around the world. Some of these include the US Green Building Council, the UK's Association for Environmentally Conscious Builders, the Australian Building Energy Council, and similar organizations in Canada, the Netherlands, Japan and South Africa.

These independent bodies have proposed assessment programs which rate the environmental performance of a building's design or a completed building as a whole. Some rating programs concentrate on a single environmental performance criterion, such as greenhouse gas emissions (e.g., Australia's Sustainable Energy Development Authority Greenhouse Rating Scheme). The Building Research Establishment in Britain was the innovator of multiple criteria rating schemes, and created the British Research Establishment Environmental Assessment Model (BREEAM). The Dutch Institute offers a more technical system called the Environmental Index for Building Biology and Ecology (NIBE). The Sustainable Building Assessment Tool (SBAT) assessment scheme developed by CSIR in South Africa adds an assessment of a building's social performance to its environmental performance.
In the United States, there are three rating systems in use for the evaluation of commercial buildings: LEED (Leadership in Environmental and Energy Design) (USGBC, 2008), Green Globes, and ENERGY STAR for Buildings and Plants. Among these, LEED is the most widely used rating system. However, this rating system has problems such as encouraging the designer's focus on obtaining the lowest-cost possible to achieve a particular LEED certification, rather than realization of any sustainability goals (Navarro, 2009). Other problems include the conflict among different aspects of LEED's sustainable performance goals (Nature, 2009) e.g. the increasing ratio of glazed surface area versus energy efficiency. Another example would be the conflict that could exist in making a decision for use of regional versus recycled versus reused materials.

As a whole, these rating systems also lack important assessment features for social and ecological aspects of a building's sustainability. An example of this is Life Cycle Costing (LCC), without which any claim to sustainability cannot be credibly made. A building should be sustainable in the totality of its life, which includes its operation, maintenance and eventual demolition, and not just its design and construction

This study offers ways to evaluate current contributions of BIM as well as potential for contributions in the area of construction and building sustainability.

Evaluating the contribution of BIM to the construction sustainability goals

This research presents a systematic approach to answer two related questions: Is BIM contributing to the realization of sustainable construction goals? If yes, how much?

As mentioned in introduction the principles of reduce, reuse, recycle, and the protection of nature, the elimination of toxic substances, the determination of life cycle economics, and the creation of a quality building (its aesthetics, durability, and maintainability) are applied to the base and scarce resources of Land, Materials, Water, Energy, Landscape and Building Ecology (Graham, 2003; ISO, 2006; Kibert, 2005; Stewart et al., 2006) to evaluate BIM's present and future capability to realize the construction industry's sustainability goals.

A matrix to evaluate the contribution of the BIM to the sustainability factors is developed which is referred to as "Matrix – A: Evaluation of BIM Capability against the Sustainable Construction Factors" (See Appendix – A). The scoring matrix was developed based on the findings from a study performed by Charles J. Kibert (Kibert, 2005) and Peter Graham (Graham, 2003). This matrix identified six parameters as objectives to be achieved: Land, Materials, Water, Energy, Landscape and Building Ecology. A sustainably designed and constructed building is one in which these six parameters are made more sustainable by using the following three principles of conserved or reduced, reused, recycled or eliminated (Kibert, 2005).

Economic efficiency, which is to occur over the life of the building, is known as Life Cycle Costing (LCC). LCC is the total cost of all resources used in the construction of building - construction, operation and maintenance (Mearig et al., 1999). Presently, BIM application programs are used to calculate the life cycle costs of building energy use. This calculation is carried out using the energy simulation programs, which are commercially available. These programs have the capacity to share BIM models, and can perform tedious energy use calculations. Construction activities have an especially great impact on ecology and ecological systems. Few studies exist which address the parameters of Building Ecology. The authors could not find the research done particularly in the intersection of BIM and building ecology.

After relationships and possible BIM contributions to each parameter were identified, a scoring method was established. Equal weights were given to these six parameters because the relative importance of these six parameters is yet to be determined. Therefore, each factor within the six parameters of Land, Materials, Water, Energy, Landscape and Building Ecology each received 2 points. A total of 84 possible points were available for a project.

Finally, the case study building project "Graduate School of Management and Conference Center, University of California, Davis, USA" was evaluated based on the construction sustainability parameters developed in the matrix. The project scored 0/14 on Land usage, 9/14 on Material usage, 8/14 on Water usage, 14/14 on Energy usage, 0/14 on Landscape usage and 0/14 on Building Ecology. This means the project scored 31 out of the potential total possible score of 84 on sustainability. Because of limitation of the length of the paper, the project score calculation matrix is not provided in this paper. Only "Matrix – A: Evaluation of BIM Capability against the Sustainable Construction Factors" with the score is presented in the Appendix –A.

Results and Discussion

The following findings of the study are shown in the matrix presented in the appendix:

- BIM makes significant contributions to three design parameters: Materials, Water and Energy.
- BIM is not presently contributing to the achievement of conservation of Land or improvement of Building Ecology systems.
- BIM cannot yet directly contribute to the realization of sustainability in areas of achieving elimination of toxins, more accurate life cycle costing, or increased quality of the building resources.

Conclusions and Recommendations

The study allowed the following conclusions to be drawn:

- BIM is contributing to the realization of achieving reductions in three of six design parameters: Reuse and recycling of construction materials, and reduction in water and energy use;
- The three design parameters to which BIM cannot yet contribute - Land, Landscape and Building Ecology - are the next capabilities which BIM should develop;
- BIM utilizes its potential reasonably well in optimizing energy consumption, and;
- BIM is used to a lesser potential in optimizing Material and Water consumption.

The authors offer the following recommendation for further research and development:

- Authors plan to do further work with design and construction firms to test and validate the tool to increase its reliability. The result will be presented in a future paper.
- Further research needs to be done on integration of Land, Landscape and Building Ecology into BIM capabilities.
- Further research can be done to utilize BIM for optimizing Material and Water consumption.

Acknowledgements

The authors would also like to thank Mr. Strachan Forgan for the case study data of the "Graduate School of Management and Conference Center, University of California, Davis, USA" project. Finally, author would like to thank Mr. John J. Burger, JD, for his assistance.

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APPENDIX – A

Matrix - A: Evaluation of BIM Capability against the Construction Sustainability Factors

and (Natural and agricultural land; environmental amenity and biodiversity)

Y	?	N	SUSTAINABILITY PRINCIPLES	SUSTAINABILITY FACTORS	CURRENT BIM CAPABILITY	Possible Points: 14
	?		Conservation	Site selection; alternative transportation; storm water erosion and sedimentation control; urban inf and sprawl; greenfield	BIM application, Google Earth, and GIS may help in future	2
	?		Reuse	Brownfield redevelopment; alternative transportation	BIM application, Google Earth, and GIS may help in future	2
	?		Recycle	Brownfield redevelopment; alternative transportation	BIM application, Google Earth, and GIS may help in future	2
	?		Protect Nature	Protect or restore habitat; maximize open space; greenfield; floodplains; tree preservation; erosion and sedimentation control	BIM application, Google Earth, and GIS may help in future	2
	?		Eliminate Toxics	Heat island effect; light pollution; chemical and pollutant source control; environmental tobacco smoke control	Visualization; daylighting (BIM application, and energy simulation programs)	2
		N	Life Cycle Costing	NONE	Not aware of any existing BIM tool - area of future development	2
	?		Quality - aesthetic, durability, maintainability	Stormwater design; development density and community connectivity; greenfield; floodplains	BIM application, Google Earth, and GIS may help in future	2

Materials (All construction materials e.g. concrete, steel, wood, glass)

Y	?	N	SUSTAINABILITY PRINCIPLES	SUSTAINABILITY FACTORS	CURRENT BIM CAPABILITY	Possible Points: 14
Y			Conservation	Rapidly renewable material; regional materials; minimized use of raw materials	Create schedule and quantities (BIM application)	2
Y			Reuse	Building reuse; material reuse	Create schedule and quantities (BIM application)	2
Y			Recycle	Recycled content; construction waste management	Create schedule and quantities (BIM application)	2
Y			Protect Nature	Recycled content; construction waste management	Create schedule and quantities (BIM application)	2
	?		Eliminate Toxics	Low emitting materials; construction waste management; Environ Tabaco Smoke control	Not aware of any existing BIM tool - area of future development	2
	?		Life Cycle Costing	NONE	Not aware of any existing BIM tool - future development area	2
Y			Quality - aesthetic, durability, maintainability	Construction waste management; regional material	Create schedule and quantities (BIM application)	2

Water (Potable water sources: surface and subsurface; water consumption)

Y	?	N	SUSTAINABILITY PRINCIPLES	SUSTAINABILITY FACTORS	CURRENT BIM CAPABILITY	Possible Points: 14

Y			Conservation	Water efficient landscaping; stormwater design; water consumption	Water usage estimator or water review (GBS, IES-VE)	2
Y			Reuse	Innovative wastewater technology; water use reduction	Water usage estimator or water review (GBS, IES-VE)	2
Y			Recycle	Innovative wastewater technology; water use reduction; water treatment	Water usage estimator or water review (GBS, IES-VE)	2
Y			Protect Nature	Innovative wastewater technology; water use reduction	Water usage estimator or water review (GBS, IES-VE)	2
		N	Eliminate Toxics	Water treatment	Not aware of any existing BIM tool - area of future development	2
		N	Life Cycle Costing	NONE	Not aware of any existing BIM tool - area of future development	2
		N	Quality - aesthetic, durability, maintainability	NONE	Not aware of any existing BIM tool - area of future development	2

Energy (Envelope resistance heat transfer-conduction, convection and radiation; renewable energy design and passive design)

Y	?	N	SUSTAINABILITY PRINCIPLES	SUSTAINABILITY FACTORS	CURRENT BIM CAPABILITY	Possible Points: 14
Y			Conservation	Renewable energy; green power; onsite renewable energy; power demand reduction	Photovoltaic potential; wind energy potential; low carbon technology (BIM application and energy simulation programs)	2
Y			Reuse	Renewable energy; minimizing re-heat and re-cool	Photovoltaic potential; wind energy potential; low carbon technology (BIM application, and energy simulation programs)	2
Y			Recycle	Renewable energy; green power; onsite renewable energy; power demand reduction; minimizing re-heat and re-cool	Photovoltaic potential; wind energy potential; low carbon technology (BIM application, and energy simulation programs)	2
Y			Protect Nature	Renewable energy; green power; onsite renewable energy	Photovoltaic potential; wind energy potential; low carbon technology (BIM application, and energy simulation programs)	2
Y			Eliminate Toxics	Light pollution; refrigerant management; heat island effect; light reduction control; exterior luminaires and controls; acoustic analysis	Low carbon technology; visualization; acoustic analysis (BIM application, energy simulation programs)	2
Y			Life Cycle Costing	Value/cost analysis	LCC and LCA of energy components (energy simulation programs)	2
Y			Quality - aesthetic, durability, maintainability	NONE	Whole Building. Energy, Thermal, Daylight, Solar Radiation, Shows & Reflection Analysis (energy simulation programs)	2

Landscape (Control external building loads; processing waste; absorbing storm water)

Y	?	N	SUSTAINABILITY PRINCIPLES	SUSTAINABILITY FACTORS	CURRENT BIM CAPABILITY	Possible Points: 14

		N	Conservation	Site selection; alternative transportation; storm water erosion and sedimentation control; urban infill and sprawl; greenfield	Not aware of any existing BIM tool - area of future development	2
		N	Reuse	Construction waste management; stormwater technology	Not aware of any existing BIM tool - area of future development	2
		N	Recycle	Construction waste management; stormwater technology	Not aware of any existing BIM tool - area of future development	2
		N	Protect Nature	Site selection; alternative transportation; storm water erosion and sedimentation control; urban infill and sprawl; greenfield	Not aware of any existing BIM tool - area of future development	2
		N	Eliminate Toxics	Exterior light pollution; prescriptive light requirement; alternative transport- alter. Fuel	Not aware of any existing BIM tool - area of future development	2
		N	Life Cycle Costing	NONE	Not aware of any existing BIM tool - area of future development	2
		N	Quality - aesthetic, durability, maintainability	Prescriptive light requirement; development density and community connectivity; greenfield; floodplains	Not aware of any existing BIM tool - area of future development	2

Building Ecological System (Interactions of organisms, populations and biological species-including humans with living and non living environment)

Y	**?**	**N**	**SUSTAINABILITY PRINCIPLES**	**SUSTAINABILITY FACTORS**	**CURRENT BIM CAPABILITY**	**Possible Points: 14**
		N	Conservation	Protection and restoration of habitat	Not aware of any existing BIM tool - area of future development	2
		N	Reuse	NONE	Not aware of any existing BIM tool - area of future development	2
		N	Recycle	NONE	Not aware of any existing BIM tool - area of future development	2
		N	Protect Nature	NONE	Not aware of any existing BIM tool - area of future development	2
		N	Eliminate Toxics	Ozone-depletion; global warming; direct heating	Not aware of any existing BIM tool - area of future development	2
		N	Life Cycle Costing	NONE	Not aware of any existing BIM tool - area of future development	2
		N	Quality - aesthetic, durability, maintainability	NONE	Not aware of any existing BIM tool - area of future development	2
					Subtotal	**14**
				Total Possible Points		**84**