Bim for sustainable design essay

Automation in Construction 20 (2011) 217–224 Contents lists available at ScienceDirect Automation in Construction j o u r n a l h o m e p a g e : w w w. e l s ev i e r. c o m / l o c a t e / a u t c o n Building information modeling for sustainable design and LEED® rating analysis Salman Azhar a,? , Wade A. Carlton a, Darren Olsen a, Irtishad Ahmad b a b McWhorter School of Building Science, Auburn University, Auburn, AL, USA Department of Construction Management, Florida International University, Miami, FL, USA a r t i c l e i n f o b s t r a c t Today, there is a high level of demand for sustainable buildings. The most important decisions regarding a building's sustainable features are made during the design and preconstruction stages. Leadership in Energy and Environmental Design (LEED®) is the most widely adopted sustainable building rating system in the United States. For projects pursuing LEED® certi? cation, designers have to conduct in-depth sustainability analyses based on a building's form, materials, context, and mechanical–electrical–plumbing (MEP) systems.

Since Building Information Modeling (BIM) allows for multi-disciplinary information to be superimposed within one model, it creates an opportunity to conduct these analyses accurately and ef? ciently as compared to the traditional methods. In this exploratory research, a case study was conducted on Salisbury University's Perdue School of Business building to demonstrate the use of BIM for sustainable design and the LEED® certi? cation process. First, a conceptual framework was developed to establish the relationship between BIMbased sustainability analyses and the LEED® certi? cation process.

Next, the framework was validated via this case study. The results of this study indicate that documentation supporting LEED® credits may be directly or indirectly prepared using the results of BIM-based sustainability analyses software. This process could streamline the LEED® certi? cation process and save substantial time and resources which would otherwise be required using traditional methods. Article history: Accepted 16 July 2010 Available online 16 November 2010 Keywords: BIM Sustainable design LEED® rating Green building rating systems Building performance analyses . Introduction Recent studies indicate that the demand for sustainable building facilities with minimal environmental impact is increasing [1, 4, 7]. Rising energy costs and growing environmental concerns are the catalysts for such high demand. The environmental and human health bene? ts of sustainable (also called green) buildings have been widely recognized. A slight increase in upfront costs of about 2% to support sustainable design, on average, results in life cycle savings of approximately 20% of total construction costs; which is more than ten times the initial investment [12].

Hence sustainable buildings are economically viable too. Worldwide, individuals and organizations have responded to the increased demand for green buildings. Many countries and international organizations have initiated rating systems for sustainable construction. Currently, a number of different rating systems are used to rate the environmental performance of buildings. These include but are not limited to: Australia's Green Star; Canada's LEED Canada; Germany's DGNB Certi? ation System; India's IGBC Rating System and LEED India; Japan's Comprehensive Assessment System for Building Environmental Ef? ciency; New Zealand's Green Star NZ; South ? Corresponding author. E-mail address: edu (S. Azhar). doi: 10. 1016/j. autcon. 2010. 09. 019 Africa's Green Star SA, United Kingdom's BREEAM, and the United State's LEED. Most of these rating systems' primary criteria are similar in that they evaluate a building's energy consumption, water ef? iency, material use and indoor environmental quality [17]. In the United States, the Leadership in Energy and Environmental Design (LEED®) system is currently the most widely utilized method for rating a building's environmental performance. LEED® was developed by the U. S. Green Building Council (USGBC) in 1998 to provide building owners and operators a concise framework for identifying and implementing practical and measurable green building design, construction, operation and maintenance solutions [15]. The LEED® credits are divided into six categories (LEED® ver. . 2) as follows: sustainable sites, water ef? ciency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation in design [16]. Under the LEED® system, a structure may earn up to 34 total credits. Sixty-nine points are available within the con? nes of the credits. Under certain credit categories, multiple points may be earned for higher environmental performance levels. In addition to credits, each section of the LEED® system includes prerequisites which must be earned even though they do not count towards a building's point total.

Points are distributed unequally among the categories as shown in Table 1. There are four levels of LEED® certi? cation: LEED® Certi? ed, LEED® Silver, LEED® Gold and LEED® Platinum. The level of LEED® certi? cation a building earns is determined by the number of points awarded as 218 Table 1 LEED® credit categories and available points [16]. Categories Sustainable sites Water ef? ciency Energy and atmosphere Materials and resources Indoor environmental quality Innovation in design Total S. Azhar et al. / Automation in Construction 20 (2011) 217–224 Available points (LEED® ver. . 2) 14 5 17 13 15 5 69 follows (LEED® v. 2. 2): 26–32 points for LEED® Certi? ed, 33–38 points for LEED® Silver, 39–51 points for LEED® Gold, and 52–69 points for LEED® Platinum [16]. During construction, supporting documentation and evidence are compiled and submitted to the U. S. Green Building Council (USGBC). Based on that information, the USGBC determines whether or not to award the point. No points are awarded and the certi? cation is not received until construction is complete. Any changes made during construction require a resubmission of the supporting documentation.

The early design and preconstruction phases of a building are the most critical times to make decisions on its sustainability features [6]. Traditional computer-aided design (CAD) planning environments usually lack the capability to perform sustainability analyses in the early stages of design development. Building performance analyses are typically performed after the architectural design and construction documents have been produced. This failure to analyze sustainability continually during the design process results in an inef? ient process of retroactive modi? cation to the design to achieve a set of performance criteria [14]. To assess building performance in the early design and preconstruction phases accurately, access to a comprehensive set of data regarding a building’s form, materials, context, and mechanical–electrical–plumbing (MEP) systems is required. Since

Building Information Modeling (BIM) allows for multi-disciplinary information to be superimposed within one model, it creates an opportunity for sustainability measures to be incorporated throughout the design process [3].

Kriegel and Nies [13] indicated that BIM can aid in the following aspects of sustainable design: • Building orientation (selecting a good orientation can reduce energy costs) • Building massing (to analyze building form and optimize the building envelope) • Daylighting analysis • Water harvesting (reducing water needs in a building) • Energy modeling (reducing energy needs and analyzing renewable energy options can contribute to low energy costs) • Sustainable materials (reducing material needs and using recycled materials) • Site and logistics management (to reduce waste and carbon footprints).

A recent survey of 145 design and construction ? rms in the United States indicates that the practitioners implementing BIM-based sustainability analyses are realizing ‘ some-to-signi? cant’ time and cost savings as compared to the traditional methods [4]. The combination of sustainable design strategies and BIM technology has the potential to change the traditional design practices and to ef? ciently produce a high-performance facility design. One such effort on the Columbia campus of the University of South Carolina resulted in approximately $900, 000 in savings over the next ten years at current energy costs [10].

A building information model carries a wealth of information which may be utilized to produce necessary documentation for earning LEED® credits. For instance, schedules of building components can be obtained directly from the model to determine percentages of a material's reuse, recycled content, or salvage. Various design options for sustainability can be studied and tracked in a building information model [2]. Another feature of BIM for sustainability relates to how architects can choose the site of their project.

Architects can input spatial data into the building information model that geographically locates the building site and imports information that helps the design team understand issues related to climate, place, surrounding systems, and resources. Designers can then edit and reorient the building on a site using real coordinates to reduce the building's impact on the surrounding environment and determine the most ef? cient solar orientation [11]. Many LEED® credits require that drawings be submitted to support the quali? cation for credit.

Although most of these drawings can be prepared using conventional CAD software, BIM software produces these drawings more ef? ciently as part of the building information model and have the added advantage of parametric change technology, which coordinates changes and maintains consistency at all times. Thus, the user does not have to intervene to update drawings or links [3]. 2. Purpose of the study, scope and methodology The purpose of this study is to demonstrate the ways designers and planners may use BIM for various sustainability analyses in pursuit of LEED® certi? cation.

The scope of the research is limited to nonresidential new building projects only. This study did not investigate the ? nancial bene? ts and/or de? cits of using BIM for sustainability analyses. A two-step methodology is adopted for this study as follows: 1. Development of a conceptual framework to establish the relationship between BIM and LEED® rating processes. This framework was developed via review of existing literature and in-depth semistructured interviews with professionals heavily involved in BIM and LEED® certi? cation. 2. Validation of the developed framework via a case study.

Brief results of both steps are presented in the following sections. 3. Results 3. 1. Conceptual framework for establishing a relationship between BIM and LEED® rating processes Based on the review of existing literature and feedback collected from building design professionals and LEED® consultants, the following conceptual framework (Table 2) was prepared to illustrate the relationship between various LEED® credits and associated BIMbased sustainability analyses. The table also indicates the project stage at which documentation for these credits can be prepared. More details about this work can be found in Brown [8] and Carlton [9].

This framework is validated using data from a case study which is discussed in the following section. More case studies are planned for further veri? cation and re? nement. The results of these case studies shall be published separately. The presented case study also identi? es the number of LEED® credits for which required documentation can be prepared using results of BIM-based sustainability analyses. 3. 2. Validation of the framework 3. 2. 1. Description of selected project for case study The project selected for case study is the Perdue School of Business building located on Salisbury University’s campus in Salisbury, MD.

S. Azhar et al. / Automation in Construction 20 (2011) 217–224 Table 2 Relationship between BIM-based sustainability analyses types and LEED® credits. Sustainable analysis types with relationships to LEED®-NC credits (ver. 2. 2) Sustainable design related analysis types Energy analysis LEED® Points Max. 14 Required 1 1 1 1 1 1 1 1 1 1 1 1 1 1 Max. 5 2 1 2 Max. 17 Required Required Required 10 3 1 1 1 1 Max. 13 Required 2 1 2 2 2 2 1 1 Max. 15 Required Required 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 Max. 5 4 1 Daylighting/solar analysis Acoustic analysis Material documentation Value/cost analysis Site analysis 19 Water use LEED® Credits Sustainable sites Construction activity pollution prevention Site selection Development density and community connectivity Brown? eld redevelopment Public transportation access Bicycle storage and changing rooms Low-emitting and fuel-ef? cient vehicles Parking capacity Protect or restore habitat Maximize open space Stormwater quantity control Stormwater quality control Reduce heat island effect — nonroof Reduce heat island effect — roof Light pollution reduction Water ef? ciency Water ef? ient landscaping Innovative wastewater technologies Water use reduction Energy and atmosphere Fundamental building systems commissioning Minimum energy performance Fundamental refrigerant management Optimize energy performance Renewable energy Enhanced commissioning Enhanced refrigerant management Measurement and veri? cation Green power Materials and resources Storage and collection of recyclables Building reuse — existing walls, ? oors and roof Building reuse — existing interior nonstructural elements Construction waste management Materials reuse Recycled content Regional materials Rapidly renewable materials Certi? d wood Indoor environmental quality Minimum indoor air quality (IAQ) performance Environmental tobacco smoke (ETS) control

Outdoor air delivering monitoring Increase ventilation Construction IAQ MGT plan — during construction Construction IAQ MGT plan — before occupancy Low-emitting materials — adhesives and sealants Low-emitting materials — paints and coatings Low-emitting materials — carpet systems Low-emitting materials — composite wood and agri? ber Indoor chemical and pollutant source control Controllability of systems — lighting Controllability of systems — thermal comfort Thermal comfort — design Thermal comfort — veri? ation Daylight and views — daylight Daylight and views — views Innovation and design process Innovation in design LEED accredited professional Pre-design stage, ? Design stage, ¦ Construction stage. ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?, ¦ ? ¦ ¦ ¦ ¦ ¦ ? ? ¦ ¦ ¦ ¦ ? ? ? ? ? ? ? ? ? The building is currently under construction and scheduled to be completed in June of 2011. The Perdue building is attempting to earn LEED® Gold certi? cation and will be Salisbury University's third LEED® certi? ed building. Key details of the project are shown in Table 3 while Figs. and 2 illustrate the Southwest and Northwest 3D renderings of the building. Since the building is still under construction and no paperwork has been ? led for LEED® certi? cation, some key information for running a few sustainability analyses was not available within the timeline of this study. Hence this paper only reports validation results of energy and atmosphere, water ef? ciency, and indoor environmental quality credits. Validation results of other credits will be published in a future paper. 220 Table 3 Perdue building project description. Item Project Client Description

S. Azhar et al. / Automation in Construction 20 (2011) 217–224 Perdue School of Business, Salisbury University University of Maryland System of

Schools/Salisbury University Construction start date 07/27/2009 Construction end date 06/09/2011 Construction budget $39, 000, 000 Delivery method CM-at-risk Construction manager Holder Construction Company, Atlanta Architect Richter Cornbrooks Gribble (RCG) Size 112, 000 ft2, 3-stories with enclosed penthouse Building system Foundations: auger cast concrete piles, grade beams and strip footings Superstructure: structural steel Floors: oncrete slab on grade and slab on deck Interior partitions: gypsum board on metal studs Exterior skin: brick masonry with precast accents, glazing, and some CMU Roof: vertical mansard roof screen wall with built-up roof 3. 2. 2. Software selection for BIM-based sustainability analyses Based on a survey of 91 design and construction ? rms in the United States, Azhar and Brown [5] found that there are three commonly used BIM-based sustainability analyses software: Autodesk Ecotect™, Autodesk Green Building Studio (GBS)™, and Integrated Environmental Solutions (IES)®, Virtual Environment (VE)™.

Based on their evaluation of these three softwares, they found that Virtual Environment (VE)™ is the most versatile and powerful software in terms of sustainability analysis capabilities. Hence, in this study, Virtual Environment (VE)™ was used for running various BIM-based sustainability analyses. The building information model of the building was acquired from the project's construction manager Holder Construction Company, Atlanta. The following framework (Fig. 3) was adopted to export the model into IES-VE™ software to run various analyses and produce necessary documents.

Detailed procedures for formulating and running various sustainability analyses can be found in Carlton [9]. Fig. 1. Southeast rendering of the

Perdue building. Fig. 2. Northwest rendering of the Perdue building. Fig. 3. Framework depicting key steps involved in sustainability analyses and LEED® documentation process. S. Azhar et al. / Automation in Construction 20 (2011) 217–224 221 Fig. 4. IES-VE™ report for energy and atmosphere analysis. Fig. 5. IES-VE™ report for water consumption analysis. Fig. 6. IES-VE™ report for daylighting credit analysis. 222 S. Azhar et al. / Automation in Construction 20 (2011) 217–224

Table 4 LEED® credits that can be documented using results of BIM software. LEED®-NC credits that can be earned using BIM-based performance analysis software Can the LEED® credit be earned using BIM? (yes/no) LEED® points Required 1 1 1 1 1 1 1 1 1 1 1 1 1 1 No Yes No No No No No No No Yes Yes No Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes No Yes No No Yes Yes No Performance analysis software that could be or was used? VE/REVIT Is the credit being attempted by Salisbury Building? Was the credit validated in the case study? (yes/no) LEED credit Sustainable sites SSp1 SSc1 SSc2 SSc3 SSc4. 1 SSc4. SSc4. 3 SSc4. 4 SSc5. 1 SSc5. 2 SSc6. 1 SSc6. 2 SSc7. 1 SSc7. 2 SSc8 Water ef? ciency WEc1. 1 and WEc1. 2 WEc2 WEc3. 1 and WEc3. 2 Credit description Construction activity pollution prevention Site selection Development density and community connectivity Brown? eld redevelopment Public transportation access Bicycle storage and changing rooms Low-emitting and fuel-ef? cient vehicles Parking capacity Protect or restore habitat Maximize open space Stormwater quantity control Stormwater quality control Reduce heat island effect — nonroof Reduce heat island effect — roof Light pollution reduction

Revit Revit Revit Revit Water ef? cient landscaping Innovative wastewater technologies Water use reduction 2 1 2 Yes Yes Yes Revit VE VE No No Yes Yes Yes Energy and atmosphere EAp1 Fundamental building systems commissioning EAp2 Minimum energy performance EAp3 Fundamental refrigerant management EAc1 Optimize energy performance EAc2 Renewable energy EAc3 Enhanced commissioning EAc4 Enhanced refrigerant management EAc5 Measurement and veri? cation EAc6 Green power Materials and resources MRp1 Storage and collection of recyclables MRc1. and MRc1. 2 Building reuse — existing walls, ? oors and roof MRc1. 3 Building reuse — existing interior nonstructural elements MRc2. 1 and MRc2. 2 Construction waste management MRc3. 1 and MRC3. 2 Materials reuse MRc4. 1 and MRc4. 2 Recycled content MRc5. 1 and MRc5. 2 Regional materials MRc6 Rapidly renewable materials MRc7 Certi? ed wood Indoor environmental EQp1 EQp2 EQc1 EQc2 EQc3. 1 EQc3. 2 EQc4. 1 EQc4. 2 EQc4. 3 EQc4. 4 EQc5 EQc6. 1 EQc6. 2 EQc7. 1 EQc7. 2 EQc8. 1 EQc8. quality Minimum indoor air quality (IAQ) performance Environmental tobacco smoke (ETS) control Outdoor air delivering monitoring Increase ventilation Construction IAQ MGT plan — during construction Construction IAQ MGT plan — before occupancy Low-emitting materials — adhesives and sealants Low-emitting materials — paints and coatings Low-emitting materials — carpet systems Low-emitting materials — composite wood and agri? ber Indoor chemical and pollutant source control Controllability of systems — lighting Controllability of systems — thermal comfort Thermal comfort — design Thermal comfort — veri? ation Daylight and views — daylight Daylight and views — views Required Required Required 10 3 1 1 1 1 No Yes No Yes No No No No No VE VE Yes Yes Yes Yes No Yes Yes No No Yes Yes Required 2 1 2

2 2 2 1 1 Yes Yes Yes No No Yes Yes No Yes Revit Revit Revit Revit Revit Revit Yes No No Yes No Yes Yes No Yes required required 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 No No No No Yes Yes No No No No No No No Yes No Yes Yes Revit Revit VE VE VE Yes Yes Yes No No No Yes Yes Yes Yes Yes Yes Yes Yes Yes No No Yes Yes Innovation and design process IDc1 Innovation in design IDc2 LEED accredited professional 1 Yes No Revit, VE Yes Yes S. Azhar et al. / Automation in Construction 20 (2011) 217–224 223 3. 2. 3. Brief results of sustainability analyses The following paragraphs illustrate the brief results of energy and atmosphere (EA), water ef? ciency (WE), and indoor environmental quality (IEQ) analyses. The energy analysis indicated that the annual energy consumption of the building would be 7599 MBtu/year as shown in Fig. 4. This analysis can help designers visualize the building's energy consumption very early in the design process.

The VE™ results could not be concluded as very accurate, but they may be taken as a correct assessment of the general energy " range" a building will fall under. The energy analysis eliminates the trivial process of designing a building and waiting for building completion to evaluate its energy use. Using this analysis, a design team can closely predict how many EA points can be earned toward LEED® certi? cation. This energy analysis allows the design team to skip an onerous and demanding set of calculations required in support of the LEED® energy credits when utilizing the traditional tools.

The water analysis demonstrated that the Perdue building would earn 2 water ef? ciency credits (Fig. 5) as well as an innovation in design credit for achieving over 40% water reduction. It took less than 10 min to run the complete analysis and proved to be a quick and easy way for a design team to develop an accurate estimate of a proposed building's water consumption. It may be used during a project's predesign and design phases. The results of the indoor environmental quality analysis demonstrated that the Perdue building would earn LEED® daylighting credit as shown in Fig. . The results of these analyses were also compared with the handprepared LEED® documents supplied by the architect. Though most results produced by the software were in close agreement with these calculations, some notable differences were also recorded due to two factors; (1) the building information model was not regularly updated by the designer and it was lacking some key interior details; (2) Some ? nishes cannot be accurately modeled in BIM software. The readers are advised not to rely blindly on software results and always apply manual checks for veri? cation. 3. 2. . BIM-based sustainability analyses v. LEED credits Based on the results of sustainability analyses and exploration of the BIM software (Autodesk Revit™ and IES Virtual Environment™) features, it was found that documentation for 17 LEED® credits and 2 prerequisites worth a total of 38 points may be directly/indirectly prepared. Some credits will require supporting documentation which cannot be prepared via the software, for example credits that require a narrative be submitted along with necessary computations. Those credits which require supporting documentation are classi? d as indirectly prepared for purposes of this research. This is demonstrated in Table 4. As indicated earlier, due to the limited availability of building data, only 5 credits and one prerequisite worth a total of 16 points have been validated at this stage. The ? nal results of the complete veri? cation process will be published in near future. 3. 2. 5. Final validation results Table 5 depicts the 5 LEED® credits and one prerequisite which were validated via this case study. Each credit was determined to have a direct, semi-direct or indirect relationship between earning LEED® points and BIM.

The direct credits generate a ? nal verdict on whether or not the credit was earned. These credits demonstrated similar results when comparing their analyses to the supporting LEED® documents completed by Salisbury University's partnering companies. The semi-direct credits proved to be able to use BIM to complete the supporting LEED® documents but could not generate a valid ? nal verdict on whether or not the credit was earned. The credits that can be indirectly earned demonstrated some differences between the LEED® documents and the software analyses.

In either case, the Table 5 Summary of the LEED® credits earned using BIM. LEED® credit WEc2 WEc3. 1 and WEc3. 2 EAp2 EAc1 EQc7. 1 EQc8. 1 Total 1. Direct — The credit can be directly earned through the software. 2. Semi-direct — Supporting documents for the credit can be generated using the software. 3. Indirect — Some key LEED® credit information can be provided by the software. Credit description Can the credit be earned directly, semi-directly or indirectly? Semi-direct Semi-direct Indirect Indirect Indirect Direct LEED® points earned 1 3 required 10 1 1 16

Innovative wastewater technologies Water use reduction Minimum energy performance Optimize energy performance Thermal comfort — design Daylight and views — daylight indirect credits can use sustainability analyses to generate valuable preliminary information about a project. 4. Conclusions The following conclusions can be drawn from this research study. 1. No one-to-one relationship exists between LEED® certi? cation process and BIM-based sustainability analyses (except for EQc8. 1: Daylighting credit) due to the lack of LEED® integration features in the currently available software. 2.

The results of sustainability analyses software can be used to directly, semi-directly or indirectly generate LEED® documentation. Up to 17 LEED® credits and 2 prerequisites may be documented using results generated by BIM-based sustainability software; however; only 5 credits and one prerequisite have been veri? ed in this study so far. 3. BIM-based sustainability software generates results very quickly as compared to the traditional methods. In other words, a building information model can be used as a by-product to run these analyses. This could save substantial time and resources. 4.

Some discrepancies were recorded between the software and manual results. This was mainly due to the inaccuracy of the building information model developed for this project. Readers are advised to always perform manual checks to avoid any mistakes in the LEED® documentation. 5. Future research This is an ongoing research project. The next stage of this research will focus on the following issues: 1. Veri? cation of the remaining 12 LEED® credits and one prerequisite which may be earned via BIM-based sustainability analyses. 2. Use of other software (such as Autodesk Ecotect™, Autodesk Green Building Studio™, etc. to run the same analyses and to determine which software is most ef? cient for a particular type of analysis. 6. Disclaimer The opinions and recommendations expressed in this paper are the authors' personal opinions and do not necessarily represent the of? cial position of any organization. This paper does not endorse any software in any capacity. 224 S. Azhar et al. / Automation in Construction 20 (2011) 217–

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