Sustainable Cities and Society 18 (2015) 95–107

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings

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ARTICLE INFO

Article history:
Received 7 May 2015
Received in revised form 18 June 2015
Accepted 19 June 2015
Available online 24 June 2015

Keywords:
BIM
Green building
Certification system
LEED
Sustainable design
Cost

ABSTRACT

Designing environmentally friendly buildings that provide both high performance and cost savings is of increasing interest in the development of sustainable cities. Today, we are looking at not just buildings' certification but sustainable practices that go beyond ratings to satisfy our social responsibilities. The construction industry in general will benefit from an integrated tool that will help optimize the selection process of materials, equipments, and systems at every stage of a proposed building's life. Building information modeling (BIM) has the potential to aid designers to select the right type of materials during the early design stage and to make vital decisions that have great impacts on the life cycle of sustainable buildings.

This paper describes a methodology that integrates BIM with the Canadian green building certification system (LEED©). Also, it explains how this integration would assist project teams in making sustainability related decisions while accumulating the required number of points based on the applied green building rating system. The methodology depicts the implementation of a model that automatically calculates the compiled number of LEED certification points and related registration costs for green and certified materials used in designing sustainable buildings all within the concepts of BIM. Using BIM in this methodology will help designers to invent and animate sustainable buildings in 3D mode easily and efficiently at the conceptual stage. The design information of the proposed sustainable building will be produced in a timely manner by using new plug-ins, which are developed for that reason, and which will link the BIM model with an external database that stores sustainable materials and assembly groups. A real case project is presented to illustrate the usefulness and capabilities of the proposed model.

1. Introduction

Studies indicate that the demand for sustainable buildings that have minimal environmental impacts on society is slowly increasing (Biswas, Wang, & Krishnamurti, 2008). Therefore, the construction industry needs to adopt new approaches/techniques, such as sustainability approach, for designing buildings in order to reduce pressure on the environment. Incorporating sustainability principles at the conceptual stage is attained by using sustainable design in which designers need to identify associated materials and components that potentially earn credits based on the selected green building certification system.

Lately, the Architecture, Engineering and Construction (AEC) industry has witnessed an increasing interest in using the concept of building information modeling (BIM) in conjunction with sustainability principles during the design and construction of green building projects. BIM tools have the ability to help designers explore different design alternatives at the early stage and to transfer the design information to energy and simulation tools for validation and analysis efficiently and fast. On the other hand, by using BIM tools, owners can better visualize the development of their building projects all over the different stages of their construction. The building team uses BIM models to coordinate activities, takeoff material quantities, and detect possible clashes between equipment and spaces.

Leadership in energy and environmental design (LEED), which is a recognized rating system for green buildings and homes (USGBC, 2011), has become a thriving business paradigm in promoting sustainability in the AEC industry due to governmental endorsement and the efforts of the USA Green Building Council (USGBC) and the Canadian Green Building Council (CaGBC). LEED outlines the

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http://dx.doi.org/10.1016/j.scs.2015.06.007
2210-6707/

following six key areas: (1) sustainable sites; (2) water efficiency; (3) energy and atmosphere; (4) material selection; (5) indoor environmental quality; and (6) innovation and design process. LEED has become an important aspect for green buildings so that some federal agencies and local governments are requiring their new and existing buildings to be at least LEED-certified. There are different types of systems under LEED that can be applied for homes, interiors, core and shell, and neighborhood development, however the focus of this paper is on LEED Canada for New Construction (LEED-NC). LEED-NC addresses the whole building and its site, which cover both the design and construction of new buildings and the major renovations of the existing ones. LEED-NC is also used for building upgrades, under the condition that less than 50 percent of the buildings' occupants remain inside it during the upgrading process.

According to Eastman, Teicholz, Sacks, and Liston (2008), developing a parametric model within BIM tool is capable of capturing project information and generating documentation. With special care taken on the software side, an enhanced BIM application could potentially resolve what used to be obstinate problems in delivering sustainable design (i.e. dealing with the complexity of conducting full building energy simulation, acoustical analysis, and day lighting design). The possibility that the design team can automatically access the green building rating system credits and associated registration and certification costs has not yet been considered into one simple model. The advantage of using BIM is its ability to act as a single source of all the project information that designers need to analyze and accordingly modify the building's design before its physical implementation. The LEED rating system is a consistent measure of how a building impacts the environment. A major aspect of LEED is the documentations and associated cost calculations that must be submitted in order to reach the required type of certification. Currently, the construction industry is using BIM tools for many tasks, such as materials quantity take off, cost estimating and documentations; however these tools lack the availability of material library that helps design professionals determine the associated LEED credits.

This paper describes the methodology used to implement an integrated platform to do sustainable design for proposed buildings at their conceptual stage. The methodology is implemented through the design and development of a model that simplifies the process of designing sustainable buildings and transferring their design information to an external database in order to list the potential certification points that they can earn based on the Canadian LEED Certification system. The methodology incorporates an integrated model capable of guiding users when performing sustainable design for new building projects. The integrated model uses the LEED-NC information of the buildings' components, which are stored in the external database that is, by its turn, connected to BIM tool to instantly calculate the sum of LEED points for the proposed building. The major task in developing the model is to collect lists of green products and certified materials and have them linked to the database of BIM tool. Creating and linking such a database to BIM tool helps users design and animate sustainable buildings easily and efficiently at the conceptual stage. Part of this integrated methodology is to develop new plug-ins, which are lists of instructions used to automate the transformation of information, to be inherited into BIM tool in order to aid users connect their design models with other application, which is able to evaluate the sustainability of the building's components in an efficient and consistent manner. Automating the process of identifying the potential number of LEED points that the new sustainable building must accumulate in order to comply with the desired level of certification and estimating the associated costs will minimize users' input and will increase the calculations efficiency.

2. Literature review

The main objective of sustainable design is to create buildings in sustainable cities that are livable, comfortable and safe. The sustainable design of these buildings leads to reducing the depletion of critical resources (i.e. energy, water, and raw materials) as well as preventing environmental degradation caused by infrastructure and facilities throughout their life cycle. The current challenge that the AEC industry is facing is to meet the demand for new and renovated facilities that are accessible, secure and healthy while minimizing their impact on the society, the economy and the environment. The whole building design guide (WBDG, 2012) represents the following five fundamental principles for sustainable design: (1) optimize the site design, which includes the locations of access roads, parking, vehicle barriers, and perimeter lighting; and improve the energy performance by reducing the dependence on fossil fuel-derived energy; (2) use the water efficiently and reuse or recycle the water for on-site use; (3) use the type of materials that have minimal life-cycle environmental impacts on global warming, resource depletion, and human toxicity; (4) Enhance the indoor environmental quality (IEQ) of buildings, which means maximize the day lighting and have appropriate ventilation and moisture control; (5) optimize the acoustic performance; and (6) avoid the use of materials with high volatile organic compound (VOC) emissions. Furthermore, taking into consideration the operating and maintenance issues while doing the conceptual design of a building project will contribute to enhancing the inhabitants' productivity, reducing energy costs, and improving the working environment.

Wang, Fowler, and Sullivan (2012) think that green building certification system can be used as a design and operation guide to document progress toward a design or operational performance target, to compare buildings by using the certification systems structure, and to record the design and operation outcomes and/or strategies used in the building.

As the context varies, rating systems in different countries tend to give priority to certain sustainability indicators but the general scope is quite consistent. These indicators, which are embedded in current major green building rating systems address related issues such as land degradation, biodiversity, water shortage, energy efficiency, renewable energy, carbon emission, air pollution, materials and resources, and indoor environmental quality.

Several methodologies have been developed to establish the degree of accomplishment of environmental goals, and to guide the planning and design processes of green buildings. For instance, Building Research Establishment Environmental Assessment Method (BREEAM) (Baldwin, Yates, Howard, & Rao, 1998), Green Star from Australia (GBCA, 2008), the comprehensive assessment system for building environmental efficiency (CASBEE) from Japan (CASBEE, 2008), the building and environmental performance assessment criteria (BEPAC) from Canada (Cole, 1993), and the leadership in energy and environmental design (LEED) from the United States (USGBC, 2011) are developed and are currently widely applied. Very comprehensive inventories of the available tools for environmental assessment methods can be found (Ding, 2008) such as the whole building design guide (WBDG, 2012) and the World Green Building Council (WGBC, 2008).

Although the existing methods and tools have an extended use, LEED has established strong credibility among the experts (Pulselli, Simoncini, Pulselli, & Bastianoni, 2007). The LEED system comprised 7500 company and organization members, validating its importance as the standard environmental performance measure of buildings and becoming a reference system for the design, construction, and operation of green buildings beyond the U.S. (Bowyer, 2007).

LEED encompasses a collection of sustainability indicators to holistically evaluate the building performance and to identify how green the building is. The selection of these indicators does not need specialized knowledge since the issues confronting the industry are straightforward and well understood by the professional community, and to a certain extent, by the general public.

The current version of LEED addresses 21 different market sector adaptations, including new and existing data centers, new and existing warehouse and distribution centers, hospitality, existing schools, existing retail, and multifamily midrise residents (LEED, 2013).

Generally, LEED provides a single score that measures the building's rating or assessment, according to the cumulative points in different impact categories, which are then summed to attain the total score. To attain LEED certification, a project must first comply with LEED prerequisite items. Then there is a range of credits that the project should attain to qualify for different LEED certification levels: certified, silver, gold, and platinum, by meeting increasing minimum point levels (Kibert, 2005).

As an example, in LEED Canada for newly constructed buildings, the cumulative points for each level varies from 26 to 32 points for certified; from 33 to 38 points for silver; from 39 to 51 points for gold; and from 52 to 70 points for platinum. The main categories of LEED criteria include sustainable site (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor air quality (IQ), and the innovation and design process (ID). Each category contains number of criteria and sub-criteria, some of which are assigned a certain number of credits and others are considered as prerequisites (CaGBC, 2011).

A study conducted by Wedding (2007) summarizes the benefits and growth of LEED certified buildings and highlights evidence of the inconsistency between the expected and actual benefits of LEED certification as well as suggestions for revisions to LEED's energy and atmosphere (EA) section to reduce the variation and magnitude in the energy-related environmental impacts of LEED certified buildings. The results of that study show that the variability in the environmental impacts of the LEED certified buildings could be reduced by 62 percent and the median magnitude could be reduced by 30 percent. Mereb (2008) developed a tool called GREENOMETER-7, which is a Life Cycle Assessment (LCA) forecasting tool that assesses the building at the micro- and macro-levels. The micro-assessment level provides in-depth analysis of the building products, components, and operations; while the macro-assessment level measures the sustainability performance of the building as a whole and covers areas that are not applicable at the product or component level. GREENOMETER-7 can be applied to justify LEED scores, to assess the LEED certification level of a building at the conceptual design stage, and to ensure the incorporation of LCA into the LEED system. The energy and atmosphere (EA) and the materials and resources (MR) criteria represent about half of the total credits in the LEED certification system. Energy and atmosphere, also known as energy conservation and renewal energy, is used to maximize the application of renewable energy and other low-impact energy sources such as wind turbines, which will minimize the adverse impacts on the environment. Effective energy conservation and using highly efficient materials and systems, will reduce the cost for renewable energy (GGGC, 2006). Materials and Resources (MR) criteria aim to minimize the use of non-renewable resources such as energy and water, and to maximize the use of recycled materials, modern resource-efficient engineered materials, and resource-efficient composite type of structural systems wherever possible (Ziegler et al., 2003).

The impact of BIM on the design practice is significant due to the fact that it raises new ways and processes of delivering design, construction, and facilities management services. Owners are not only requiring their building projects to be designed and delivered on time, within budget, and with high quality but they also look at their services beyond design and construction (Clayton, Johnson, & Song, 1999). Based on Kubba (2012) and Becerik-Gerber and Rice (2010), the development of a schematic model prior to generating a detailed building model helps designers to make a more accurate assessment of the proposed scheme and to identify whether the design meets the functional and sustainable requirements stated by the owner; this leads to increase the project overall performance and quality. The advent of BIM, along with the emergence of global challenging issues such as sustainability, requires designers to incorporate basic performance analysis at the early stage of design (i.e., special quality analysis, energy performance, social impact and environmental performance) by further developing the concept of virtual space and virtual building (Kam & Fischer, 2004). An integrated BIM system can facilitate the process of collaboration and communication between project participants in an early design phase to effectively provide a well-performing building during operations (Hungu, 2013). BIM helps owners visualize the spatial organization of the building as well as understand the sequence of its construction activities and overall duration (Eastman et al., 2008). Combining sustainability principles with BIM technology has the potential to change the traditional design practice by producing high-performance design for proposed buildings. BIM can be used to support the design and analysis of a building system at the initial stage, which includes experimental structural analysis, environmental controls, construction method, selecting new materials and systems, and detailed analysis of the whole design processes.

Since BIM allows for multi-disciplinary information to be superimposed through one model, it creates an opportunity for sustainability measures to be incorporated throughout the design process (Autodesk, 2008). Hardin (2009) established three main areas of sustainable design that have direct relationship to BIM. These areas are: (1) material selection and use; (2) site selection and management; and (3) systems analysis. Krygiel and Nies (2008) indicated that BIM can aid in the aspects of sustainable design, which are building orientation (to potentially reduce the cost of the project), building massing (to analyze building form and optimize the building envelope), day lighting analysis and water harvesting (to reduce the water needs in a building), energy modeling (to reduce the energy needs and to analyze how renewable energy options can contribute to low energy costs), sustainable materials (to reduce the material needs by using recycled materials) and site and logistics management (to reduce waste and carbon footprints). Wu (2010) proposed a new methodology based on the integration of BIM and green building rating systems. A BIM–LEED framework was established that incorporates two modules: "design assistance" and "certification management". The "design assistance" module took advantage of BIM tool's Application Programming Interface (API) to provide designers with an efficient LEED knowledge that is built into the BIM tool to ensure the design is LEED-oriented. The "certification management" module is a web-based application built upon an open source Web development platform that uses Apache as the Web server, MySQL as the relational database management system and PHP as the object-oriented scripting language, which focuses on managing the project information, LEED documentation and submittals for certification purposes. As described by Wu (2010), the BIM–LEED integration is feasible with considerable constraints. It should accommodate for the requirements of different team members at the different stages of the project delivery process.

LEED takes into account not only social and environmental factors but also financial outcomes. AECOM, which is a construction consultancy company, studied and evaluated the cost per square foot of 138 buildings in the United States in 2005, out of which 93 buildings are non-LEED certified and 45 are seeking LEED certification. The study compared the construction costs of buildings where LEED certification was a primary goal to similar buildings where LEED was not considered during the design. The types of buildings that have been evaluated include – academic buildings, laboratories and libraries, community centers and ambulatory care facilities. All costs were normalized for time and location differences in order to ensure consistency in the comparison processes. The overall conclusion showed that by comparing the average cost per square foot ($/ft2) for one set of buildings to another one does not provide any meaningful information to be used in assessing the cost impact of incorporating LEED during the design stage.

Matthiessen and Morris (2004) developed a comprehensive cost database and budget methodology for green buildings. In their study; they analyzed the cost for each point applicable to the selected project and the number of points achieved for 61 LEED seeking projects. They plot the relationship between the percentage of the points that may be achieved by the projects on the (y) axis and the required LEED-NC points on the (x) axis. LEED-NC points would be counted in the project only if they were included in both the design and the budget of that project. For instance, in the energy and atmosphere criteria, the minimum percentage of energy cost reductions for the first three credits is 10.5 percent, 14 percent and 17.5 percent, respectively. For new buildings and for renovations, those percentages are 3.5 percent, 7 percent and 10.5 percent respectively, which can be achieved with relatively little cost. In the material and resources (MR) criteria, LEED Certified and LEED Silver projects tend to achieve 4 out of 13 points, which are MR 2.1 and MR 2.2 for waste management, MR 4.1 for recycled content and MR 5.1 for locally manufactured material, because the actual specification for these points is neither difficult nor costly for most of the projects. LEED Gold and LEED Platinum achieve 8 or more points. Most projects are unable to meet the reused and renewable materials points (MR 3.1 and 3.2 and MR 6) because of the required percentage of building materials and cost. Most of the points sought are related to the indoor environmental quality criteria, because they have little or no cost impact although they need strong commitment.

Generally, the cost data vary depending on the building type, region, size, and any other criteria that may be involved in the project. Northbridge Environmental Management Consultants (NEMC, 2003) determined that LEED adds between 4 percent and 11 percent to the total construction cost. More than half of this cost is for green design and construction features; the remaining cost fall outside the range of construction known as "soft costs", which is the main focus of this paper. Soft costs include incremental costs for designing, commissioning, Energy modeling, documenting compliance with the various selected LEED criteria, and LEED application fees for the project.

The process of complying with LEED requirements adds time to the design and specification phase of a project because designers must assess the project's design and specifications to make sure they include any additional requirements in order to attain the expected LEED Certification. R.S. Means (2014), which provides cost data for all aspects of building projects, considers that the cost of design for green buildings represents 0.5 percent of the project total construction cost as illustrated in Table 1. The range for this additional cost is 0.4–0.6 percent, whereas the traditional design cost ranges between 8 percent and 12 percent of the construction cost (NEMC, 2003). Commissioning is a prerequisite for LEED certification. It involves an outside team, not part of the project's design and construction team, to ensure that the fundamental elements and systems of the building comply with the LEED guidelines. There is an extra point for additional commissioning. Commissioning cost depend on both the complexity and the size of the project. The cost can be higher for more complex buildings such as laboratories. NEMC (2003) found that the commissioning cost is about 1 percent of the total construction cost as shown in Table 1. However, various construction firms consider the commissioning cost to be in the range of 0.5 percent to 1.5 percent. R.S. Means considers it to be between 0.5 percent and 0.75 percent of the total construction cost while the Weidt Group, the company for energy decision makers[SM] in US, thinks that commissioning cost ranges between 0.75 percent and 1.5 percent of the total construction costs and the Oregon State's Office of Energy considers that a typical range for commissioning cost is from 0.5 percent to 1.5 percent of the total design and construction costs. Energy modeling is another prerequisite of the LEED process, which its soft cost is about 0.1 percent of the total construction costs, as presented in Table 1 (NEMC, 2003). Documentation is the largest obstacle that the project team encounters when working with the LEED process. Proper LEED documentation is necessary for certification. The cost for this documentation depends on the experience of the team involved in documenting the LEED process, regardless of the project's size. After conducting several research projects, NEMC (2003) found that the cost of documentation ranges between $8000 and $70,000 per project, which is an average of 0.7 percent of the total construction cost with a range between 0.5 percent and 0.9 percent for typical projects.

Table 1
Sub-total estimated soft cost.

Type of cost	Estimated cost percent[a]	Purpose
Design cost	0.5 percent	Estimate required additional design cost for green buildings
Commissioning	1 percent	Basic commissioning required
Documentation	0.7 percent	Extensive documentation required to indicate how each LEED point was met
Energy modeling	0.1 percent	Estimated savings beyond national energy code is required
Total	2.3 percent	

[a] Estimated cost as a percentage of the construction costs.

Project registration in CaGBC is the first step toward earning LEED certification, which provides access to LEED's credit interpretations. The cost for registration and certification is cheaper for CaGBC members. Certification cost depends on the size of the building and its type. The details of these fees are provided in Table 2. There is also another optional soft cost, which is the green building consultant cost. This cost is applied when a consultant is hired to work throughout the whole process by securing materials, preparing bid specifications and documents. This cost is not included in the calculation of the total soft cost because it is optional.

Therefore, compiling the costs provided in Tables 1 and 2 would lead to calculating the total soft cost for LEED-NC as shown in Table 3.

Thus, this paper describes the development of a model that integrates BIM with LEED certification system and cost estimating for sustainable building. The model will be used at the conceptual design stage of the project by designers and owners. It automatically provides detailed information about the sustainability of the proposed building. It enables users to calculate the points that can potentially be earned based on the green building certification system (LEED-Canada) during the conceptual design process. Also the model calculates the soft cost that includes the fees required to register and to get the LEED certification for the proposed sustainable building. This calculation is done by using the API of BIM tool after modifying it for that purpose. Using the proposed model at the conceptual design stage of the project helps designers and owners determine the products that best meet their needs, evaluate their potential credits based on the environmental rating systems, and provide the necessary outputs in an easy, quick and convenient way.

Table 2
Registration and certification cost for LEED-NC (CaGBC, 2014).

	Registration		Certification	
	Member	Non-member	Member	Non-member
Standard review				
2500 m^2 or less	$600	$900	$4800	$6500
2501–25,000 m^2 (per additional m^2)	$0.14	$0.20	$0.85	$1.15
25,001–150,000m^2 (per additional m^2)	$0.05	$0.06	$0.25	$0.30
>150,000 m^2 (per additional m^2 for certification)	$10,000	$13,000	$0.15	$0.20
Split review: design review				
2500 m^2 or less	See standard review	See standard review	$3890	$5800
2501–25,000 m^2 (per additional m^2)	See standard review	See standard review	$0.45	$0.6
25,001–150,000 m^2 (per additional m^2)	See standard review	See standard review	$0.13	$0.16
>150,000 m^2 (per additional m^2 for certification)	See standard review	See standard review	$0.08	$0.10
Split review: construction review				
2500 m^2 or less	n/a	n/a	$3890	$5800
2501–25,000 m^2 (per additional m^2)	n/a	n/a	$0.45	$0.6
25,001–150,000 m^2 (per additional m^2)	n/a	n/a	$0.13	$0.16
>150,000 m^2 (per additional m^2 for certification)	n/a	n/a	$0.08	$0.10

3. Scope and significance of the study

Different tools are available to analyze the sustainability features of building projects. These tools affect the proper selection of building materials and components that may achieve certain LEED credits. However, these tools are limited by evaluating partial numbers of all the LEED credits required for New Construction projects. They are not directly linked to a specific credit in order to know whether it has been achieved or not. Furthermore, tools that are used for decisions related to LEED may look at different sets of data and building characteristics in order to test the sustainability of the selected materials and building geometry (Barnes & Castro-Lacouture, 2009). As stated by Krygiel and Nies (2008) many of the tools used to measure the impact of sustainable design strategies are not directly accessible from within the BIM model, therefore, the data needs to be exported to another application or imported from a data source.

The integrated model proposed in this paper, is linked to BIM tool, which is Autodesk Revit Architecture© in the format of a plug-in. Authors decided to use Revit because it is commonly used in the construction industry. All the data available in the model, such as project information and LEED parameters of the building components, are stored in an external database that is connected to BIM tool. The plug-in optimizes the LEED decisions by instantly providing designers with information needed to identify whether the current design meets a certain credit requirement (i.e. materials and resources (MR) and energy and atmosphere (EA)) or not.

Estimating the costs of registration and certification is automatically generated by using the developed plug-in so that designers and owners can include this cost in the overall budget of the project.

4. Methodology

One of the expected contributions of this study is the development of an integrated model that calculates the potential LEED credits the materials and components can accumulate if used in the design, in an attempt to help designers select the best type of sustainable components for proposed buildings based on the principles of sustainability. Traditionally, experts choose materials based on their characteristics or the ones used in previous similar projects, which may cause multiple problems related to expectations, standards, and owner's budgets. Moreover, the model calculates the cost of registering the project to CaGBC as well as the cost to get a specified LEED certification. Since the proposed methodology integrates different applications, as represented in Fig. 1, the development will be implemented through the following four phases:

Phase 1 consists of designing the model's relational database needed when designing a sustainable building. Loucopoulos and Zicari (1992) states that a consistent information system depends on the integration between databases, programming languages, and software engineering and that its life cycle incorporates the interrelated technologies of conceptual modeling and database design. The design and development of this database is accomplished in two steps starting with the conceptual modeling and ending with the physical implementation. First, problem investigation and user needs are recognized based on a comprehensive literature review. Then the database requirements are identified and the conceptual design is carried out. Second, the implementation of the data model requires that the transformation process be made from the conceptual to the logical design (Jrade & Alkass, 2007). Only afterwards the physical implementation is made by creating a list of related tables used to store the collected data

Table 3
The total soft cost calculation formula based on CaGBC.

For LEED-NC CaGBC member	2.3 percent of total construction cost + registration fees (either $600, $0.14/m^2, $0.05/m^2, $10,000) + certification fees (either $4800, $0.85/m^2, $0.25/m^2, $0.15/m^2)
For LEED-NC CaGBC non-member	2.3 percent of total construction cost + registration fees (either $900, $0.2/m^2, $0.06/m^2, $13,000) + certification fees (either $6500, $1.15/m^2, $0.3/m^2, $0.2/m^2)
For LEED-NC CaGBC member (design view)	2.3 percent of total construction cost + registration fees (either $600, $0.14/m^2, $0.05/m^2, $10,000) + certification fees (either $3890, $0.45/m^2, $0.13/m^2, $0.08/m^2)
For LEED-NC CaGBC non-member (design view)	2.3 percent of total construction cost + registration fees (either $900, $0.2/m^2, $0.06/m^2, $13,000) + certification fees (either $5800, $0.6/m^2, $0.16/m^2, $0.1/m^2)
For LEED-NC CaGBC member (construction view)	2.3 percent of total construction cost + certification fees (either $3890, $0.45/m^2, $0.13/m^2, $0.08/m^2)
For LEED-NC CaGBC non-member (construction view)	2.3 percent of total construction cost + certification fees (either $5800, $0.6/m^2, $0.16/m^2, $0.1/m^2)

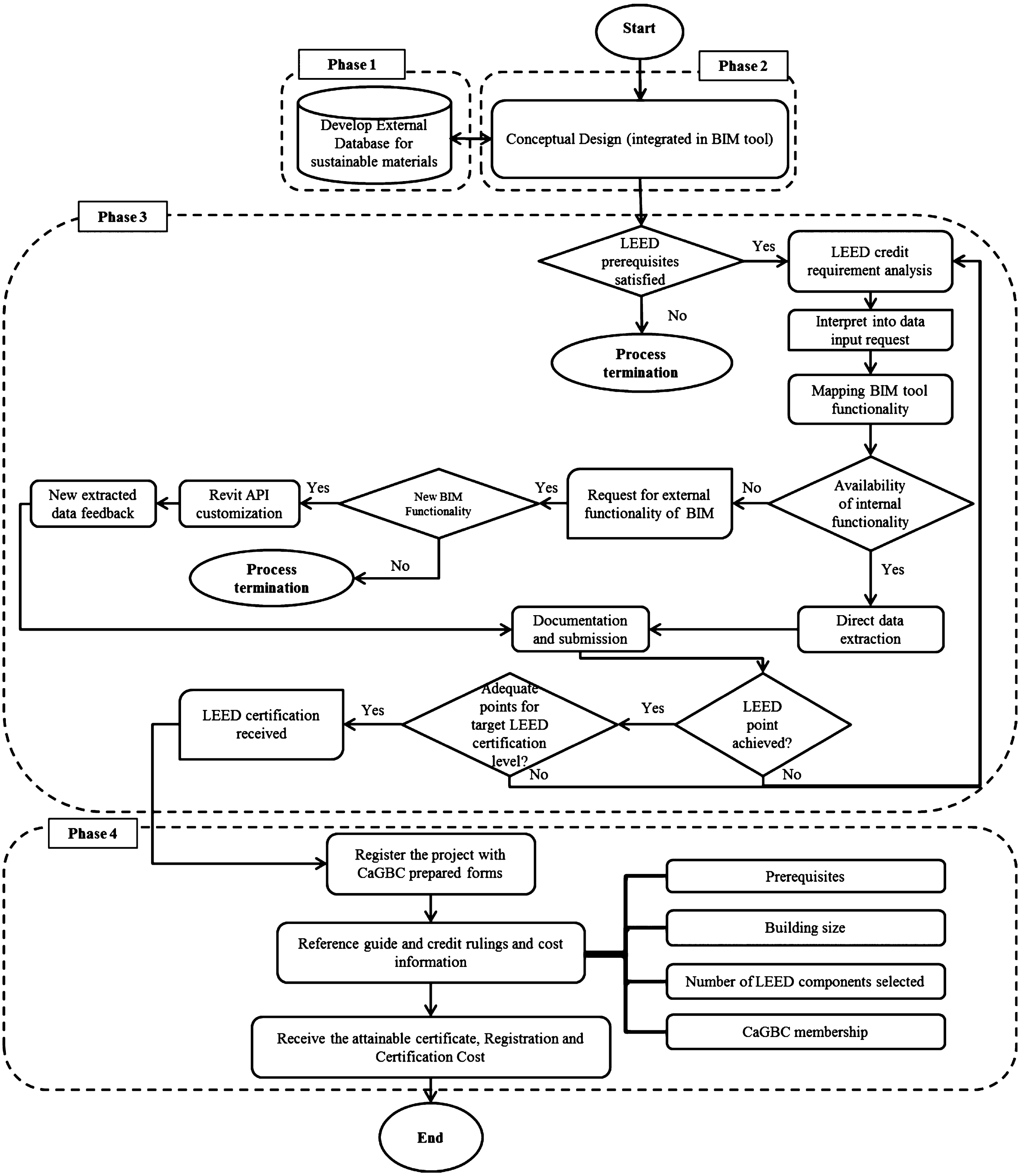

Fig. 1. Flowchart of the integration process.

based on the selected work breakdown structure (WBS). The information related to green materials is stored in an external database in the form of predefined design families files (RFA) or Revit files (RVT) that can be recognized by the BIM tool. Thus, in the external database, up to 3000 design families are collected from the Smart BIM library webpage, suppliers' web pages, as well as published data and are arranged based on the 16 divisions of the Masterformat WBS. Different types of information such as details about the materials used, suppliers' contact data, assigned keynotes, potential LEED points and assembly codes are stored in the external database.

In order to establish the conceptual design, the model outline and its components are created. Subsequently, a conceptual schema is developed. The conceptual schema is a brief description of the data that includes a detailed description of entities, relationships, and attributes (Elmasri & Navathe, 2000). Schema is displayed using a graphical presentation known as an entity-relationship (ER) diagram. The input into the model includes information about the project such as: project name, project address, owner name, total area, total estimated cost, area per square foot, architect name, estimator name, date, etc.; however, the total area and the total cost are the most important inputs for the proposed model, without which the data analysis cannot take place and the results cannot be generated. Furthermore, the user has to select the credits or points that he/she wants to achieve for the project from the selected LEED categories which are: (1) energy and atmosphere (EA) and (2) material and resources (MR).

Phase 2 focuses on customizing BIM tool (i.e. Revit) to fit the modularity requirements of the model. The first step is to design and implement a 3D module capable of storing newly created families commonly used in building projects by using certified green materials and their associated keynotes in the BIM tool. The module is linked to the database developed in Phase 1. Keynotes are textual annotations that relate text strings to specific elements in the model, which are in turn linked to an external text file. A keynote can be used as an external link to the element itself with specific style and specifications so it can be used as a Revit family. The sixteen Masterformat divisions present the main WBS applied in this study. It is very important to select a unique code for each item that is presented in a separate line in the database to ease and simplify their usage.

Phase 3 includes the design and development of a green building certification module, which is linked to the BIM module. This module contains data collected from suppliers' and publishers' webpages. These data are retrieved from the created building model by developing and using the sustainability evaluator plug-in that is loaded into BIM tool. In the sustainability evaluation results, there is detailed information about every component, which includes the potential LEED points that can be gained if these materials or components are used in the design. This information is stored in the external database of the BIM tool. The plug-in developed for EA and MR categories will rely on this data to query the cost information. The information is needed in order to know the required LEED credit that should be achieved by a specific component. In this case, when designers model the design for a proposed building in 3D and select any of these sustainable materials or components, the potential LEED points gained by these selected items are identified and stored in the schedule associated with the building model. Afterwards, users will add up these LEED points to identify the potential number that the proposed building can earn and accordingly its potential level of certification (certified, silver, gold, or platinum).

The module developed in this phase is integrated into BIM tool to automate the process of identifying the required number of points that must be accumulated based on the selected LEED certification level.

Phase 4 focuses on calculating the associated registration cost of the project with CaGBC and the related certification costs. The LEED process consists of three steps: (1) project registration, (2) technical support, and (3) building certification. Only buildings certified by CaGBC under the LEED Green Building Rating System may be considered as LEED certified buildings. LEED certification is a third party confirmation of achieving green principles. The first step in the LEED process is to register the project with CaGBC and receive orientation materials. Registration during the pre-design phase is highly recommended. Helpful resources are available for users, such as LEED letter templates, credit interpretation request (CIR) access, and on-line project registration. The second step comes in the form of a reference guide and credit rulings. In some cases, the design team may encounter questions about the application of a LEED prerequisite or credit to a specific project. The owner should first thoroughly consult the Reference Guide. All this support is available through the credit rulings page on the CaGBC web site. The third step is to give the building its attainable certificate; in order to ensure qualification for a specific certificate the application review must be done. This review can take anywhere from 6 weeks to few months. There are several opportunities for response and request throughout the review stages (administrative, preliminary technical and final technical reviews).

There are 4 specific criteria for new buildings construction: (1) prerequisites for the LEED Category; which consist of 7 new building prerequisites as shown in Table 4. These prerequisites have to be met before one can start selecting the LEED components.

Table 4
New construction prerequisite.

Number	Code	Description
1	SS prerequisite 1	Construction activity pollution prevention
2	EA prerequisite 1	Fundamental commissioning of building energy systems
3	EA prerequisite 2	Minimum energy performance
4	EA prerequisite 3	Fundamental refrigerant management
5	MR prerequisite 1	Storage and collection of recyclables
6	IEQ prerequisite 1	Minimum indoor air quality performance
7	IEQ prerequisite 2	Environmental tobacco smoke (ETS) control

(2) Building size: calculating the certification cost is based on the building area (size). There are four size categories under the building size, which are: (a) building area less than 2500 m^2, (b) building area between 2501 m^2 and 25,000 m^2, (c) building area between 25,001 m^2 and 150,000 m^2, and (d) building area more than 150,000 m^2. (3) Number of the LEED components selected: this will affect the expected type of certification. Each certification type has a minimum and maximum number of points. The total number of points achieved has to be within the ranges as listed in the literature review. (4) CaGBC membership: the status of the project's owner will affect the cost of registration and certification; for members, cost will be less as shown in Table 2.

5. Model implementation and validation

The Conceptual development of the methodology is depicted as a data flow diagram. This data flow diagram begins with the data entry, which consists of inputting all the information required for the calculations in the data analysis phase. The input consists of: project name, project address, owner name, architect name, estimator name, number of stories, total area, total cost, cost per square foot, and date. The data entry is done in an input screen. Once the user chooses the type of building a new screen will appear showing the different LEED certification types. Then the user has to select the LEED components for each of the building types (which are either new or existing) from the LEED categories starting by the EA, then IEQ all way to the WE.

As the user select a category, a new screen opens where the user can choose from the list of credits that are associated with that category. The user may choose none or many credits depending on the project requirements. The user is then guided to select the membership status. A member of CaGBC pays less soft cost if compared with a non-member for the same number of credits. The calculated soft cost is one of the model's outputs, which also consists of the accumulated selected points and the LEED certificate type.

Since the LEED rating system and all the credits information are completely external to the BIM tools environment (i.e. Revit), it is very difficult to count on their functionalities to achieve the goals of the integrated model. For this reason, API is used to interrelate the external applications into the BIM tool's platform. The API will be loaded as plug-in, into BIM tool, so that it can be run and used by designers to access the database that is linked to BIM tool. That database includes information related to sustainable building components with their associated LEED credits information. The LEED information is integrated into BIM tool to help designers make LEED-informed design decisions. The categories in BIM tool

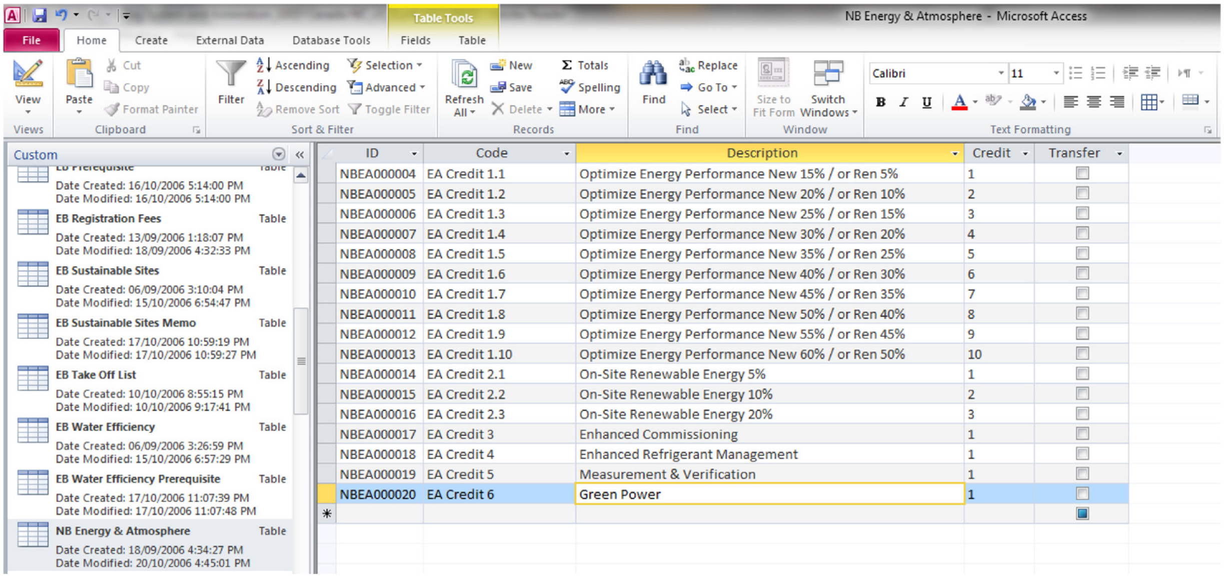

Fig. 2. Design view of one of the tables in the database.

are collections of interrelated families of building components. For instance, the category "Walls" captures all the wall instances in the model, regardless of the wall shape, size, materials and other features. For each category, there are definitive parameters, which are called "fields", to comprehensively describe the characteristics of a component. Designers can customize parameters to be added into the existing schedules of BIM tool. They can even add shared Parameters, which are used for adding specific data that is not already predefined in the families. The material and resources category, for instance, is selected for the application of shared parameters. Terms such as "reused", "post-consumer", "pre-consumer", "regional", and "rapidly renewable" specify the materials' features, which should be defined in the LEED project template in BIM tool. Currently, BIM tool (i.e. Revit) supports direct data export through open database connectivity (ODBC) to Microsoft Access and Microsoft Excel, which are widely used as database management system. Therefore, it is possible to export the project's design information through ODBC into a predefined database. Unfortunately, the current BIM tool does not have the option to allow users export defined data and information to an external database. Instead, it strictly controls the exportation process through predefined tables and data types. MR credits, include list of subcategories that range from MRc1 to MRc7, which all deal with unique material properties that contribute to sustainability. These properties are not predefined in the BIM tool platform, which requires the customization of its external database. Simply put, in order to evaluate the materials that satisfy a certain criterion, which could vary among "reused", "recycled", "regional", and "rapidly renewable", it is desirable to tag the materials in the building information model with such features. During the development of the shared parameters, such as MRc5: Regional Materials, it is noticed that in order to tag certain products as "Regional", the designer needs to know where the material suppliers are located, and how far they are from the project's location. To solve this problem, a distance calculator plug-in has already been created by the authors (Jalaei & Jrade, 2014) and embedded in Revit as part of the design assistance module. The developed plug-in uses the API of Google Maps to calculate the distance between the location (origin) of the materials' suppliers and the location of the project (destination) once the required postal codes are entered by the user. Then the distance between the two postal codes is automatically calculated and the result is displayed in kilometers. Since postal codes are commonly available information for all building products, it becomes handy for the designer to use this calculator to determine whether or not a product is regional.

Whereas for the development of the LEED registration and certification cost calculator, a database that stores the needed data is first designed and implemented. The design of any database consists of the following four major steps: (1) creating the tables; (2) finding the relationship between the tables (relationship); (3) entering data into the tables (forms); and (4) getting data from the tables (queries). The developed database of the proposed model consists of 21 tables that store project information, new construction categories, estimated subtotal soft cost, the actual cost (registration and certification cost), the building certification cost, and the LEED certification categories. Fig. 2 shows a design view of a sample table created in the database.

An alphanumeric coding system is used to create the primary keys, which contains ten digits. The most important feature in a relational database is having all the tables' related one to another. Relationships are used to tie the tables together. Although there are three different types of relationships that can be used to relate tables, in this model only one type is used, which is the one-to-one relationship, where each record in a table will have only one matching record in the other table.

Queries select records from one or more tables in a database in order to be viewed, analyzed, and sorted on a datasheet. The selection of records, which is called a dynaset (short for dynamic subset), is saved as a database object and can consequently, be easily used in the future. Whenever the original tables are updated the query will be updated as well. An SQL query is a query, which is created by using an SQL statement such as SELECT, UPDATE, or DELETE, and includes clauses such as WHERE and FROM. This type of query is used in this model to retrieve data from one or more tables and display the results in a datasheet where the user will be able to update the records. The data source of a form can be from tables or from queries. Fig. 3 shows one of the forms used in the model.

By running the certification cost calculator plug-in, the designer is asked to enter the following project general information: project name, project address, owner name, architect name, estimator name, number of stories, total area, and construction cost. Cost per square foot is calculated automatically by the model as well as the date. The total area and the construction cost are very important, because they will be required later to calculate the total soft cost. After entering this mandatory information the "Continue" tab will

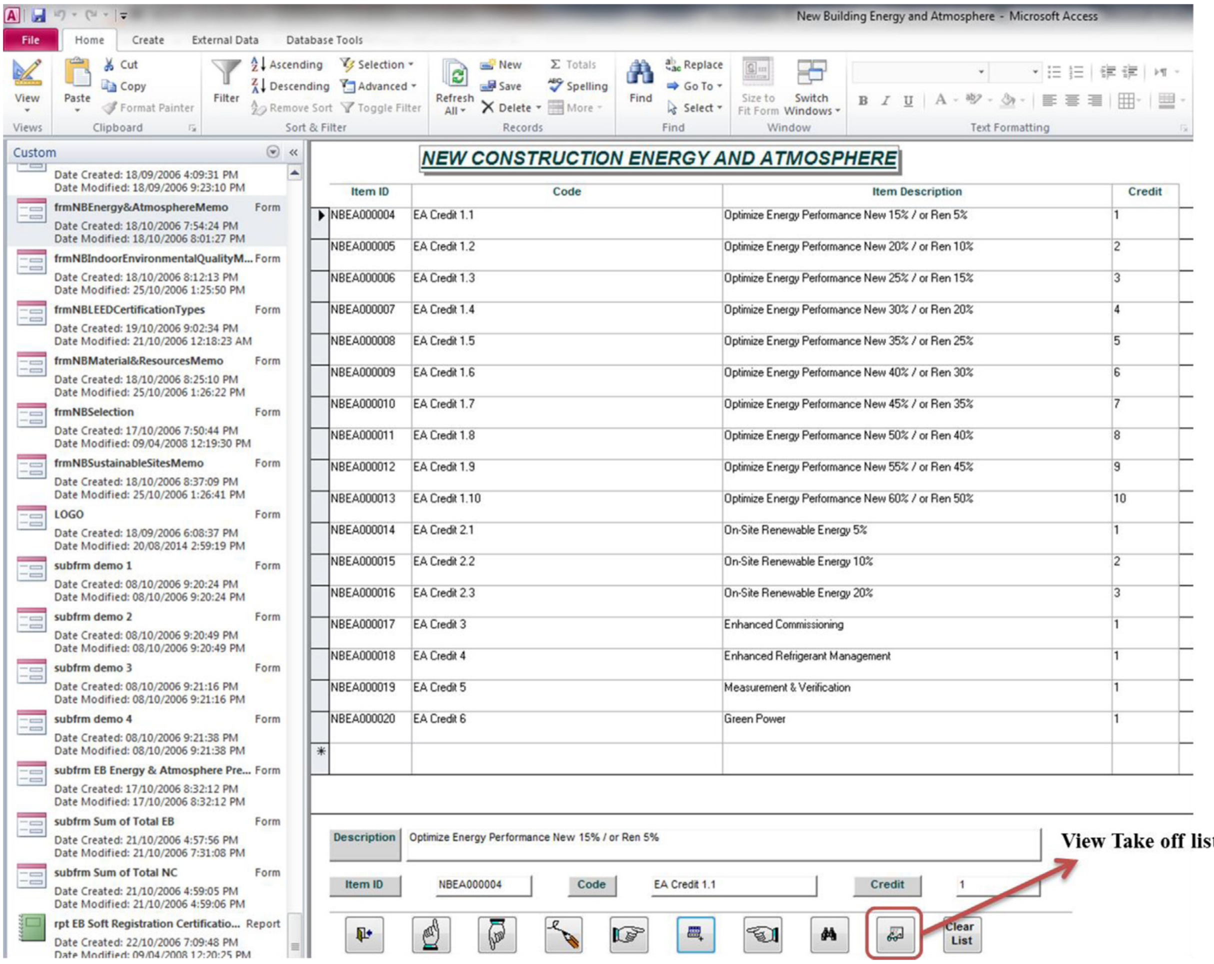

Fig. 3. The energy and atmosphere form used in the model.

be activated. Clicking on the "Continue" button, the other tabs will come into view; clicking on the "New Building" tab gives nine different choices: LEED certification criteria, six LEED-NC categories, and "Continue" and "Back to Project Information" tabs. When clicking on any of the tabs a related form will appear. The New Construction tab lists the four different certification types and their associated range of points that should be attained to qualify for each type of certification.

The next six tabs, after clicking "New Construction", are for LEED-NC credit categories. Selecting each of these tabs opens a prerequisites memo that lists what is required to be achieved before the user is guided to the credit details for each category, in order to choose the points required for a specific certification. Because the implementation procedure for the six categories is the same, apart from the different credit and point fields; the new construction energy and atmosphere category is taken as a sample.

When clicking on the "Energy and Atmosphere" tab, the prerequisites memo will appear as shown in Fig. 4. The user then has to ensure that these prerequisites are met before proceeding to select the credits. If these prerequisites are not fulfilled, the "Close" tab is chosen so as to exit the model instantly. Otherwise, if all the prerequisites are met then the "Continue" tab is clicked to open the energy and atmosphere credit details screen as shown in Fig. 3. This window allows the user to choose the credits that should be achieved for the proposed project.

The first part of the window in the form includes the item ID; the next column is the credit code that is assigned by the CaGBC; the third column describes the credit; and the last column is the number of credits that each item can earn.

It is important to be careful when selecting the credits, as some items have an upgrade option. When an upper level point field is selected it will include all the lower level points under the same credit. For example, in the Energy and Atmosphere credit 1, if Optimizing Energy Performance is selected it has a different scale depending on the building type (new construction or it is a major renovation building as in Fig. 2; so if EA Credit 1.7. Optimize Energy Performance for new construction with 31.5 percent cost saving is selected; a total of 7 points will be automatically accrued because it adds all the cost saving points under 31.5 percent. Thus, choosing an EA Credit with a cost saving of less than 31.5 percent along with the highest (in our case EA Credit 1.7) is not allowed in this model, as the credit scores will be replicated.

If "View the Takeoff List" icon is selected the LEED component (credits) screen comes into view, which includes all the points that are selected from different categories. Next, click on the "Continue" tab; would calculate the total soft cost. A confirmation message will appear about the project area that we entered earlier in the project information screen. This message will prompt the user to select the membership status (if a member of CaGBC or not) because that will affect the registration cost.

Finally the LEED certification status is stated based on the accumulated points. However, if the total of the points achieved is less than the minimum amount required for the LEED certified type, then the LEED certification field would be blank.

Fig. 4. "Energy and atmosphere" prerequisites memo.

To validate this model, its performance is examined through the use of an actual four floor residential complex project with capacity of around 172 people (occupants) that is under design in the city of Toronto, Canada. The proposed construction site has a total area of 30,138 ft^2 (2800 m^2) and the building's gross area is 114,206 ft^2 (10,610 m^2). Floors one to three have each 14 units whereas the fourth floor has 11 units. The main concept of the design is that the majority of residential buildings would have a central courtyard. They combine the two typologies of the residential buildings (i.e. central courtyard and terraced houses). In densely populated areas, a courtyard can provide privacy for a family, a break from the frantic pace of everyday life, and a safe place for a children's playground besides being a main part of any sustainable city. To mediate the private and semi-public dimension, the building project is going to be built around spaces designated for sports and recreational activities, but at the same time these spaces can be modified for a specific use. The authors created a 3D conceptual design of the current project where its associated sustainable components and materials were selected from the developed database. The components used in the design of the case building had their sustainability specifications as being part of the plug-in's database. Every component, such as the floor, walls, the roof, and windows has its associated LEED information linked to the families in BIM tool, which includes the manufacturers' web pages and contact information. Fig. 5 shows a rendered snapshot of the proposed sustainable residential building, which was created using the developed model previously described.

During the design of the case building, the designer needs to make a decision while selecting the materials from different alternatives for the current design, such as choosing the best type of materials for doors, roofs, ceilings, walls, windows, and floors and wants to know the potential LEED points/credits that every component can earn. The designer is also concerned about estimating the soft cost of registering and certifying the project. To start, we will use the developed LEED plug-ins in BIM tool, which is in this case Autodesk Revit. After running the plug-in, there are few drop-down menus that contain the assembly group list, the manufacturing company, and the product line of each company, which has to be selected by the designer based on the products that are applied to the design. The plug-in reads the list of sustainable building components from an external database, which is developed to store the exported materials take offs and shared documents. To run the plug-in the designer must click on the LEED result tool bar. The final results will be presented as a list of building components and the associated credits they can potentially earn. Fig. 6 shows the list of materials and components used in the case building for both MR and EA credits.

The distance calculator embedded in the transportation energy plug-in, as stated in the development part, shows the location of the manufacturing company. As shown in Fig. 7, all the assembly

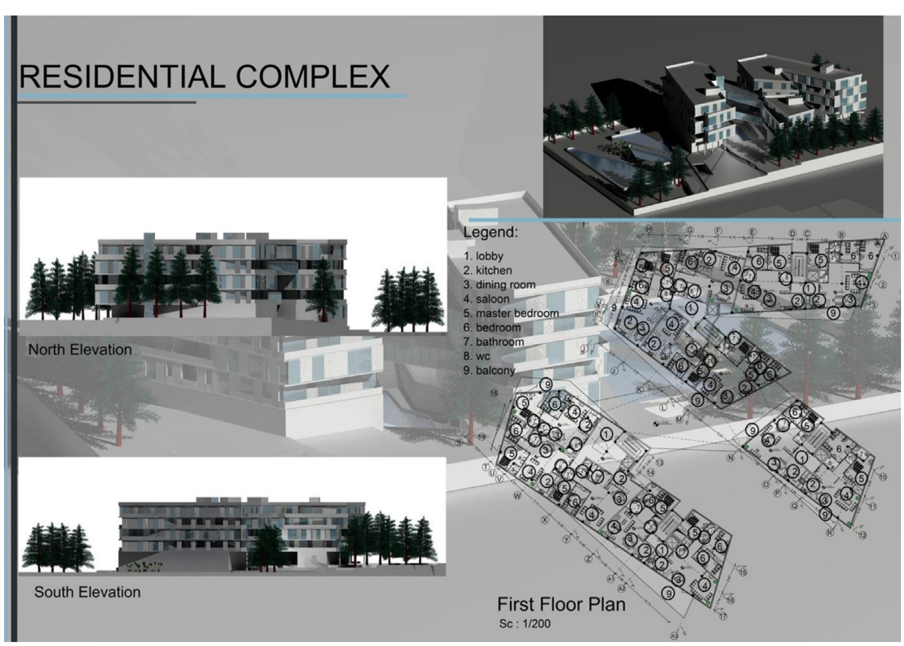

Fig. 5. Snapshot of the sustainable case building model (residential complex).

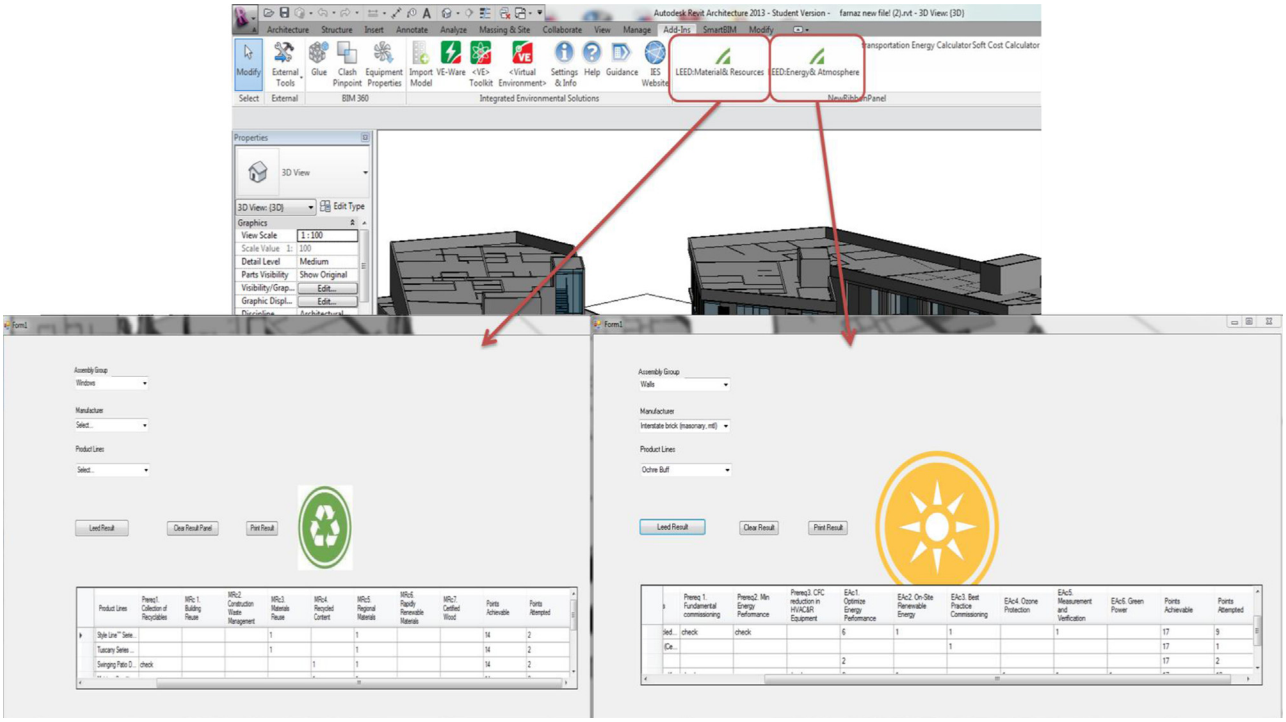

Fig. 6. List of the MR and EA credits that the case building can potentially earn provided by the developed plug-in.

groups for this case building can be purchased within a distance of 800 km (500 mi) from the project site. In this case they are eligible to earn the potential points for regional materials. After reviewing the potential LEED credits that the used components can earn, and by using the soft cost calculator plug-in, a user will be able to calculate the total LEED points of the project as well as estimating the registration and certification costs. By running the plug-in, a form is opened, where the user is needed to input the general information for the project, as shown in Fig. 8, and by assuming the project team are members of CaGBC, the "Yes, I am a member" tab is chosen, to proceed to the "Total Soft Cost for New Construction". Fig. 9 shows the Project Area and Project Construction Cost that was entered by the user. The registration fee is also shown in this screen and this fee is calculated based on the membership status with the CaGBC. The certification fees are calculated based on the project area provided by the user. The estimated soft cost is calculated according to the total construction cost, and then the total soft cost is given by adding the registration fee, the certification fees and the estimated

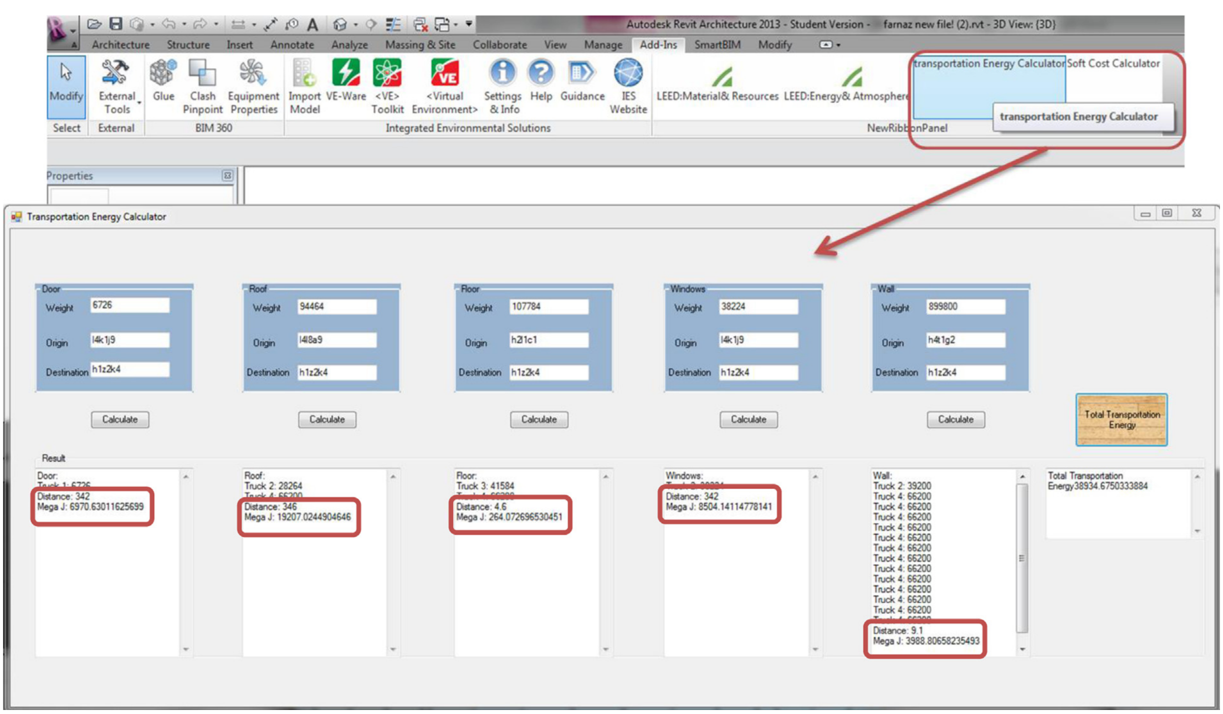

Fig. 7. Distance calculator plug-in to illustrate regional materials (Jalaei & Jrade, 2014).

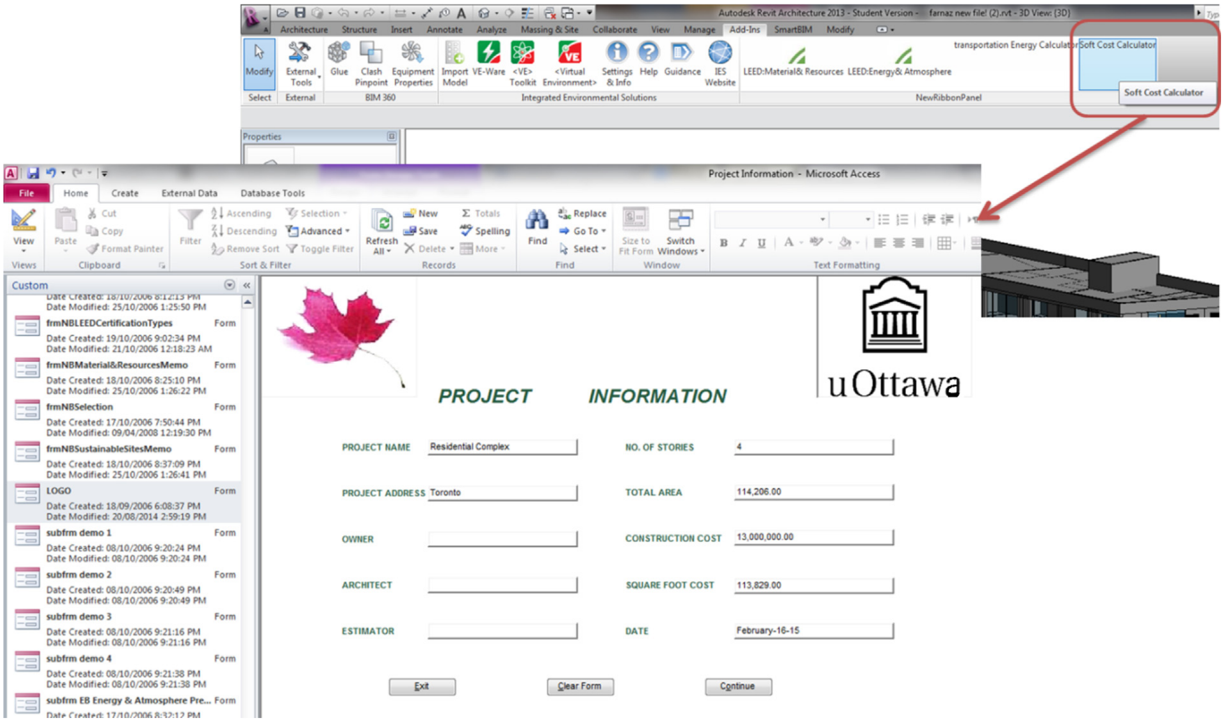

Fig. 8. The snap shot of soft cost calculator plug-in and the input form.

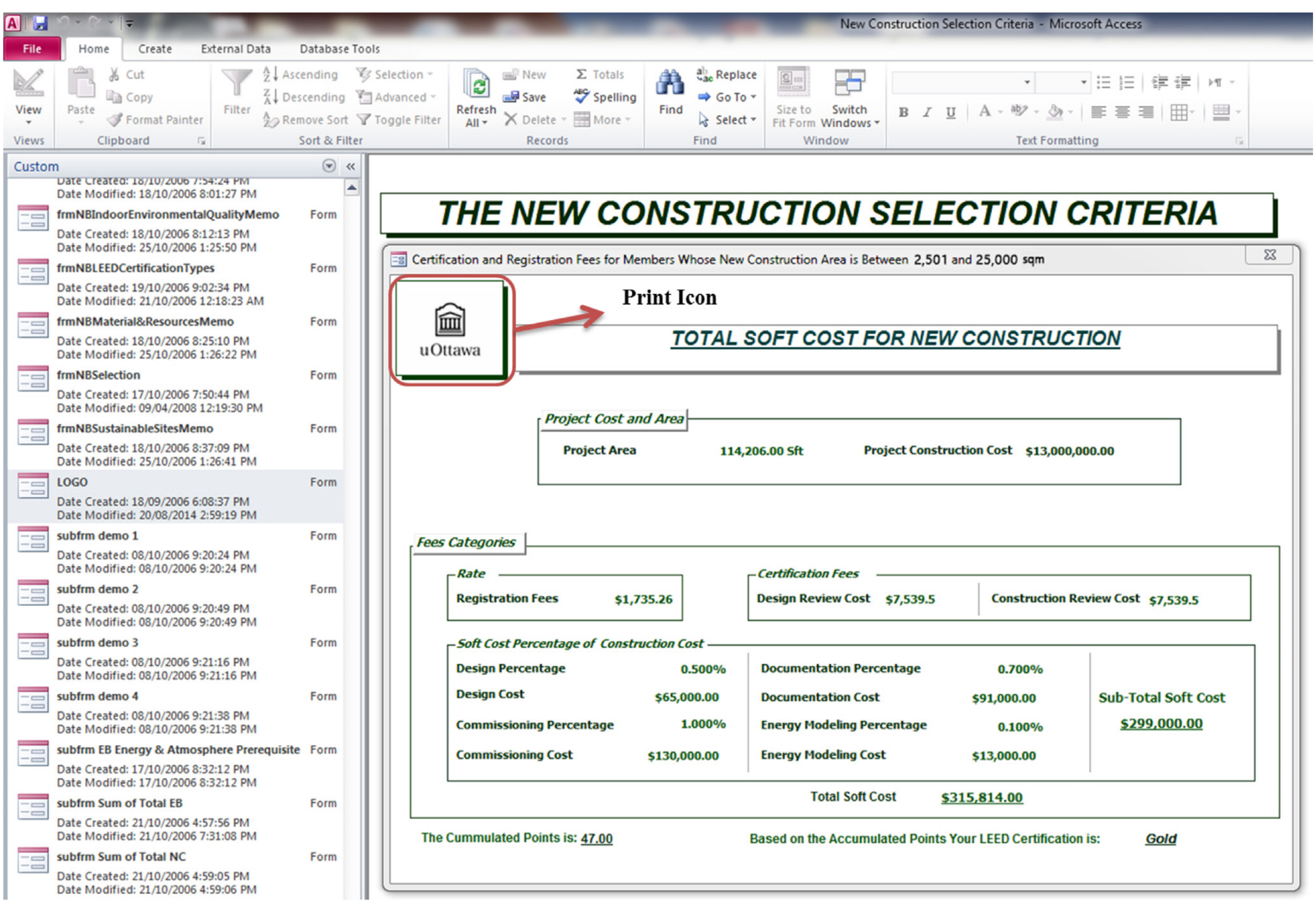

Fig. 9. Snap shot of soft cost results

subtotal soft cost. Fig. 9 also gives a summary of the soft cost. A report can be printed by clicking the icon at the upper left corner. As illustrated in Fig. 9, based on the information provided by the designer and by inputting the project definition, it was found that the total points the case building can earn for floors, roof, walls, doors and windows is 47 points, which shows that this building has a potential to be gold certified if it is registered for a LEED certificate. Fig. 9 shows the cost for registration, certification and total soft cost of the project as $315,814.

6. Conclusion

This paper described a developed model that automates the process of identifying the required number of points based on the selected LEED certification categories, accumulates the total selected credits/points as well as suggests the qualified certification type within BIM platform. Furthermore, the developed model estimates the total soft cost associated with the registration and certification of proposed buildings.

The model helps in reducing one of the biggest barriers for going green by eliminating the documentation process. It is the first model that deals with LEED categories, associated certification levels and soft cost estimation, by saving users' time and effort. The model concentrates on the soft cost. Also, it does not analyze the cost associated with the different materials or systems that can be used to attain each credit or point.

Overall, this research demonstrated that BIM and LEED integration was feasible with considerable constraints. This model does not include all the LEED products; it includes only LEED-NC and in the LEED credit accumulating plug-in, this model only focused on EA and MR credits. The model does not incorporate the cost analysis for each point depending on the materials and systems used besides the project size and cost.

This study looked only at the integration of BIM and sustainability from the LEED perspective, and only one LEED rating system (LEED-NC) was analyzed. The results thus were limited to the LEED instead of the general framework of sustainability. However, this is an ongoing research, where authors are working on improving and enhancing the model to include all the above listed shortcomings.

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