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Research Article

Integrating building information modelling with sustainability to design building projects at the conceptual stage

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Abstract

Lately the construction industry has become more interested in designing and constructing environmentally friendly buildings (e.g. sustainable buildings) that can provide both high performance and monetary savings. In general, sustainability integrates the following three related components: (1) environmental, (2) economic, (3) social well-being. Incorporating these components at the conceptual stage is achieved by using sustainable design, through which designers must identify associated materials and systems based on any selected certification (rating) system. The use of building information modelling (BIM) concepts helps engineers design digital models that allow owners to visualize the building before the physical implementation takes place. To apply BIM concepts, designers use tools to create 3D models of buildings where the design materials and systems are selected from the built-in database of these tools. Designers will not be able to quantify the environmental impacts of these materials to support the decisions needed to design sustainable buildings due to the following reasons: (1) a lack of information about the sustainable materials that are stored in the database, (2) a lack of interoperability between the design and analysis tools that enable full life cycle assessments (LCAs) of buildings. This paper presents a methodology that integrates BIM and LCA tools with a database for designing sustainable building projects. The methodology describes the development and implementation of a model that incorporates a database in which information about sustainable materials is stored and linked to a BIM (3D) module along with an LCA module and a certification and cost module. The goal of this model is to simplify the process of creating sustainable designs and to evaluate the environmental impacts (EI) of newly designed buildings at the conceptual stage of their life. An actual building project is presented in order to illustrate the usefulness and capabilities of the developed model.

Keywords

green buildings,
sustainability,
BIM,
LCA,
EI,
LEED certification system and construction cost estimating

Article History

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Architecture and Human Behavior

1 Introduction

Achieving a cost-effective building project requires the evaluation and comparison of all the costs and benefits that will occur over its anticipated economic life. In economic terms, a building design is deemed to be cost-effective if it has a lower life cycle cost, which covers its construction and operating costs. The components of a building's life cycle cost include the initial design and construction cost, ongoing operations and maintenance costs, parts replacement, disposal costs or salvage value (WBDG 2012). In order to meet the requirements of a cost-effective building design, the financial criterion of the selected materials should be taken into consideration.

Studies indicate that lately, the demand for sustainable buildings with minimal environmental impacts is increasing (Biswas et al. 2008). Notably, the construction industry today needs to adopt new technologies for building design to reduce pressures on the environment. An example of these technologies is the green building approach. Incorporating sustainable principles at the conceptual stage is attained by using sustainable design in which designers need to identify associated materials and components based on the selected green building certification system. Building information

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modelling (BIM) for instance, is a revolutionary technology that helps engineers design virtual models of a digitally constructed building. This allows owners to visualize the building before it is built. Various design options for sustainability can be studied and tracked in a building information model (Autodesk 2005). 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 with a direct relationship to BIM. These areas are material selection and use, site selection and management, and systems analysis. Kriegel and Nies (2008) indicated that BIM can aid in the aspects of sustainable design which are building orientation (which can reduce the cost of the project), building massing (to analyze building form and optimize the building envelope), day lighting analysis, water harvesting (reducing water needs in a building), energy modelling (reducing energy needs and analyzing how renewable energy options can contribute to low energy costs), sustainable materials (reducing material needs and using recycled materials) and site and logistics management (to reduce waste and carbon footprints). Generally, using the BIM tools to design sustainable buildings necessitates the selection of materials and systems so that their environmental impacts (EIs) can be easily evaluated.

Hoff (2008) describes EIs as being the result of the inputs and outputs over a product's life cycle. Although the total number of different potential EIs may be very large, the U.S. Environmental Protection Agency has categorized the "top ten" impacts as: (1) global warming potential, (2) ozone depletion potential, (3) photochemical oxidant potential, (4) acidification potential, (5) eutrophication, (6) health toxicity (cancer), (7) health toxicity (non-cancer), (8) health toxicity (air pollutants), (9) eco-toxicity potential, (10) fossil fuel use. Thus, to quantify the impacts of the selected materials on the environment, an assessment method has to be applied. The common method employed is life cycle assessment (LCA), which is a tool used for evaluating environmental concerns (Khasreen et al. 2009). It is because of this that designers must keep the entire life cycle of the building and its associated materials in mind. This will promote sustainable development practices through suited rating systems by recognizing the projects that implement strategies for better environmental and health performance (USGBC 2011). This paper focuses on integrating BIM with LCA for designing sustainable buildings at the conceptual stage with the emphasis on their associated materials.

2 Literature review

The early design and preconstruction phases of a building are the most critical times to make decisions on its sustainability features (Azhar and Brown 2009). The focus of designers when working on a sustainable design is on their ability to evaluate the EI of the selected products by using available methods and tools. The idea of LCA has emerged as the collection and evaluation of the inputs and outputs as well as the potential EI of a product throughout its life cycle (Guinée et al. 2011). While LCA can be used to assess the sustainability of the built environment, its technique provides comprehensive coverage of the product's EI, therefore it is very useful to apply it at the conceptual design phase of building projects. At that stage the designer must be able to acquire, store, and organize LCA data for the components in such a way that it can be used to generate feedback during the design process (Ries and Mahdavi 2001). Traditional computer-aided design (CAD) usually lacks the ability to perform sustainability analyses at the early stages of design development. Meanwhile, BIM represents both the graphical and non-graphical aspects of a building (Eastman et al. 2008), and it offers a database which represents "the truth" in a reliable manner at any given moment in time, which encourages collaboration (McGraw-Hill Construction 2009; Thomson and Miner 2006). It takes a multi-dimensional approach, allowing the building team to see how the pieces of their project fit together in real time (McFarlane 2008). Objects in BIM models not only serve as physical placeholder, but also represent a set of information attached to all the necessary data such as supplier information and maintenance procedures (Thomson and Miner 2006). With the use of BIM, a building can first be constructed virtually on a computer before it is actually built in the field (GSA 2007). It helps owners visualize the spatial organization of the building as well as understand the sequence of construction activities and project duration (Eastman et al. 2008).

The combination of sustainable design strategies and BIM technology has the potential to change traditional design practices and to efficiently produce a high-performance design. BIM technology can be used to support the design and analysis of a building system in the early design process. It includes experimental analysis of structure, environmental controls, construction method, use of new materials, or systems and detailed analysis of user processes. In the field of building system analysis, it involves many functional aspects of the building system, such as structural integrity, ventilation, temperature control, circulation, lighting, energy distribution, and consumption (Azhar et al. 2010).

BIM is an organizing concept that contributes in the life cycle of a facility to create and manage a building's data in a convenient way. BIM technology today has limited impact on the green building process, but it can be enhanced by changing the future design of green building by including valuable tools. New information technology tools that help narrow the existing gaps related to building design and its impact on the environment is needed.

A methodology that integrates BIM models and LCA systems is needed because it would have the potential to streamline LCA processes and facilitate rigorous management of the environmental footprint of constructed facilities. Researchers have looked at the benefits of integrating BIM with LCA and were able to identify the shortages that prevent said integration from taking place. Loh et al. (2007) found that LCA systems are inaccessible and complicated. Fischer et al. (2004) claimed that it is inefficient to input data in LCA applications due to the lack of interoperability between different tools and the uncommon type of data format. Häkkinen and Kiviniemi (2008) identified the following solutions to integrate BIM tools with LCA systems: (1) linking separate software tools via file exchange, (2) adding functionality to existing BIM software, (3) using parametric formats such as Geometric Description Language (GDL). In a recent study, Steel et al. (2010) concluded that BIM tools are useful, not only for design, but also for information exchange between building stakeholders. However, to allow these propositions become a reality, the question of interoperability must be resolved. This paper adopts the method of communication between BIM and LCA tools to be through a text file exchange way.

Green building certification systems can be used as guidance for design, to document performance progress, to compare buildings, and to document the outcomes and/or strategies used in the building (Wang et al. 2012). Several methodologies such as: Building Research Establishment Environmental Assessment Method (BREEAM) (Baldwin et al. 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 et al. 1993), and the Leadership in Energy and Environmental Design (LEED) from the United States (USGBC 2011) were developed and are widely applied to establish the level of accomplishment of the environmental goals and to guide the planning and design processes. Apart from that, comprehensive tools for environmental assessment such as the whole Building Design Guide (WBDG 2012) and the World Green Building Council (WGBC 2008) can be found (Ding 2008).

Although the existing tools have an extended use, LEED Rating System (LEED-RS) has established strong credibility among experts (Pulselli et al. 2007). The validation of the LEED-RS to evaluate its importance as a measurement tool for the environmental performance of a building was implemented by 7500 companies and organization members.

In this paper, the process of integrating BIM and sustainable design is pursued by developing an external database that is linked to BIM tools. This database includes information about certified components that are recognized by BIM tools. This information includes links for the manufacturers' webpage, contact information, costs, as well as potential LEED points for every selected building component. Linking the customized BIM tools with LCA applications is discussed in further details in the succeeding paragraphs.

3 Scope and significance of the study

This paper describes a methodology that can be used to implement sustainable design for proposed buildings at their conceptual stage, taking into consideration their EIs. The methodology is implemented through the design and development of a model that simplifies the process of designing sustainable buildings, evaluating their environmental impacts, and listing their potential accumulated certification points. The methodology emphasizes the integration of BIM, management information system, and LCA, thereby providing a reliable tool to owners, architects, engineers, and all participants involved in the design and construction of sustainable buildings. The methodology incorporates an integrated model capable of guiding users when performing sustainable design for building projects. It incorporates three modules: (1) 3D (BIM) module, (2) LCA module, (3) green building certification and cost module. Each of these modules is linked to one or more databases containing necessary data and information. Numerous types of software used in the construction industry such as Autodesk Revit Architecture©, Microsoft Excel©, and Athena® Impact Estimator© were used in the development of this integrated model.

The successful implementation of such a methodology represents a significant advancement in the ability to attain the sustainable design of a building during the early stages, to evaluate its EI, and to list its earned certification points and associated costs.

4 Methodology

The aim is to develop an automated way through which sustainable design in 3D mode will be accomplished and all related earned certification points and their costs identified. In order to attain this objective, the following steps need to be carried out.

4.1 Data collection

The data used in the model is collected from the literature, suppliers' web pages, USGBC and CaGBC websites, and published data. These data are arranged based on the 16 Masterformat divisions, applied to the library of components stored in BIM's tool and used for implementing sustainable design in 3D mode. The aim of developing a separate database is to have it loaded every time the BIM's tool opens. This is done by defining its path, which is linked to the predefined library of the BIM's tool. Furthermore, the developed database contains information regarding around 3000 green components, which are arranged based on the 16 divisions of the Masterformat work breakdown structure. Therefore, users are capable of researching and selecting a variety of sustainable components from the database with their associated specifications, potential LEED points, and manufacturer contact information. Also, users can enhance the database later on by adding new certified components.

4.2 Development of the model

Since the model integrates different applications, the development is carried out through the following four phases:

- Phase 1 consists of creating the relational database the model needs to design sustainable buildings.
- Phase 2 includes the design of the 3D (BIM) module and to customize BIM's tool (Autodesk Revit©) by creating new families and keynotes that have 3D elements for the building's components.
- Phase 3 consists of designing an LCA module that interconnects the 3D design with the LCA tool to evaluate its impacts on the environment.
- Phase 4 incorporates the design of a green certification module that provides a list of the potential earned points and associated costs for the 3D design of phase 2.

Each of these phases is discussed separately in the following paragraphs.

4.3 Model components and architecture

The model consists of components designed in a modular format, incorporating the foregoing modules. Figure 1 shows the model's components. 3D (BIM) module includes components and families, keynotes, as well as 2D and 3D models linked and stored in an external database based on the Masterformat work breakdown structure (WBS). For instance, the information about different parts of each green family such as Windows is saved in the external database. Based on the selected materials and systems used in the 3D model, the LCA module will be able to evaluate their EIs and generate required reports. Then, the green certification

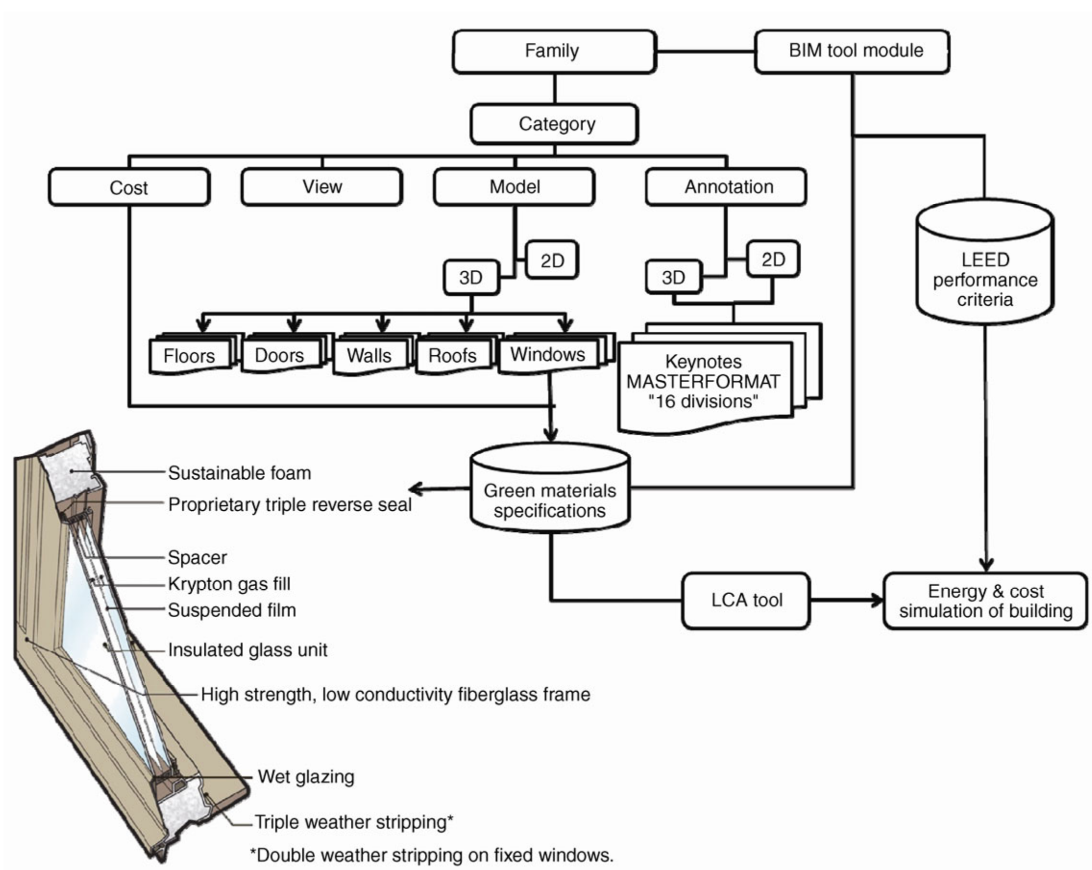

Fig. 1 Developed model's components

system module quantifies the potential number of earned points. The potential points that can be earned by each green family are already provided by their suppliers and stored in the external database. The associated cost of the design in the 3D model is calculated based on published data. Figure 2 shows the model's architecture; it determines the processes for data analysis considering all criteria and specifications. This analysis is applied on the selected materials' environmental impacts, divisions, energy efficiency, green building rating system, and sustainability issues using input requirements. These, in turn, include the project information, sustainable information, Masterformat work breakdown structure with the consideration of criteria such as green building rating system, environmental performance, project type, and unit cost of green materials. The main output of the model is a 3D-BIM sustainable design of the building containing lists of the selected sustainable materials and their environmental impacts, the cumulative points, and associated costs. The innovation highlighted in this paper describes the model's modules, which are integrated together so that the user will be able to start the sustainable design of a project at the conceptual stage of its life.

5 Model development process

Since the model incorporates four different phases, its development is implemented sequentially, as described in the following sections.

5.1 Model database (phase 1)

The basis of a methodology, which simplifies the process of establishing sustainable design for proposed building projects in an efficient way, includes the importance of instant access to the data needed.

5.1.1 *Design and development*

The design and development of the databases are accomplished in two steps: these being conceptual modelling, and implementation of the model. First, problem investigation and user needs are acknowledged based on the literature review. Then, the database requirements are identified and the conceptual design is carried out. Second, the data model implementation concentrates on the transformation process from conceptual to logical design. Thereafter the physical design starts by creating a list of related tables to store the collected data. These tables are based on the applied WBS. The process of choosing green materials from the collected data and storing them in the database is shown in Fig. 3. The data related to the green materials is saved as family files, which can be identified by the BIM tool. Thus, in the external sustainable database, up to 3000 families are collected

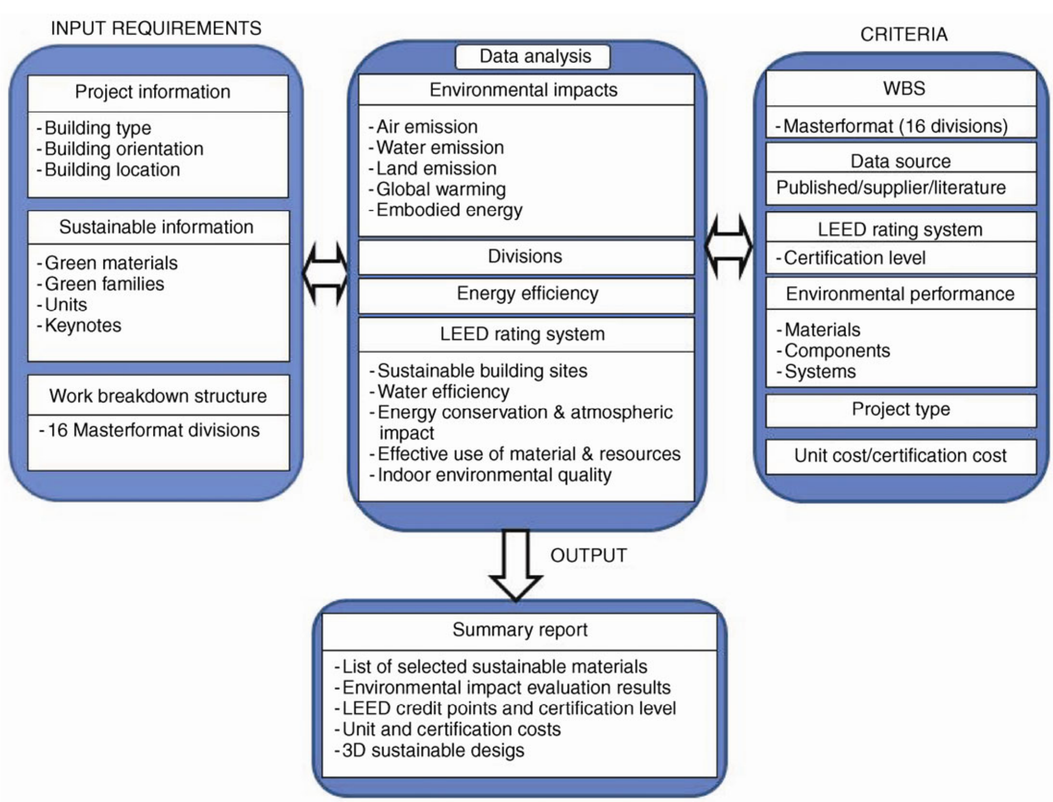

Fig. 2 Model architecture

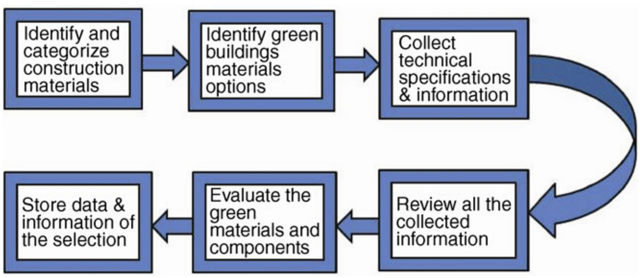

Fig. 3 Processes of selecting and storing green materials

and are arranged based on the 16 Masterformat divisions where various types of information such as details about the material used, suppliers' contact data, assigned keynote, potential certification points, and assembly codes are stored.

5.2 3D (BIM) module (phase 2)

This phase focuses on customizing BIM's tool to fit the modularity requirements of the model. The first step is to design and implement a 3D module capable of storing newly created and added families and keynotes for components employed in residential buildings by using certified green materials. The module is linked to the database developed in the aforementioned phase 1. To simplify the development process of this module, a flow chart is created as shown in Fig. 4.

An efficient coding system is the main aspect that represents the relationship between the stored data. Therefore, it is important to select a unique code for each item that is presented in a separate line in the database. The coding system allows users to accelerate the process of retrieving necessary information. A five-digit number representing the division, subdivision, elements, and material names is used to store the collected data. Creating the families is based on modifying the inherited resources by adding new parameters. Customizing and duplicating an existing family adds an important feature to the model. For instance, the families built in BIM's tool consist of different types such as walls, floors, stairs, windows, and doors.

5.3 LCA module (phase 3)

This phase concentrates on designing and implementing an LCA module that is linked to an external database, which in turn is associated with BIM's module to store the extracted quantities from the 3D design and to evaluate their EIs. The extracted bill of quantity is linked to ATHENA® Impact Estimator© via a text file exchange way. Authors elected to use ATHENA Impact Estimator for Buildings because it is a common tool used by the north American construction industry. It is designed to evaluate whole buildings and assemblies based on internationally recognized life cycle assessment methodology. This is an important step because LCA analysis outlines how the EIs of all products should be documented and communicated to the owner. Hoff (2008) considered that ISO 14020 calls for the implementation of a standardized format for communicating product EI, called Environmental Product Declaration (EPD). Therefore, LCA should be applied to integrated systems in a building by combining all the EPDs of every selected component in a single EI assessment. This paper focuses on analyzing the EIs of architectural and structural systems used in the 3D design that are ranked according to their awarded certification points. To ease the development process of this module a framework is created as illustrated in Fig. 5.

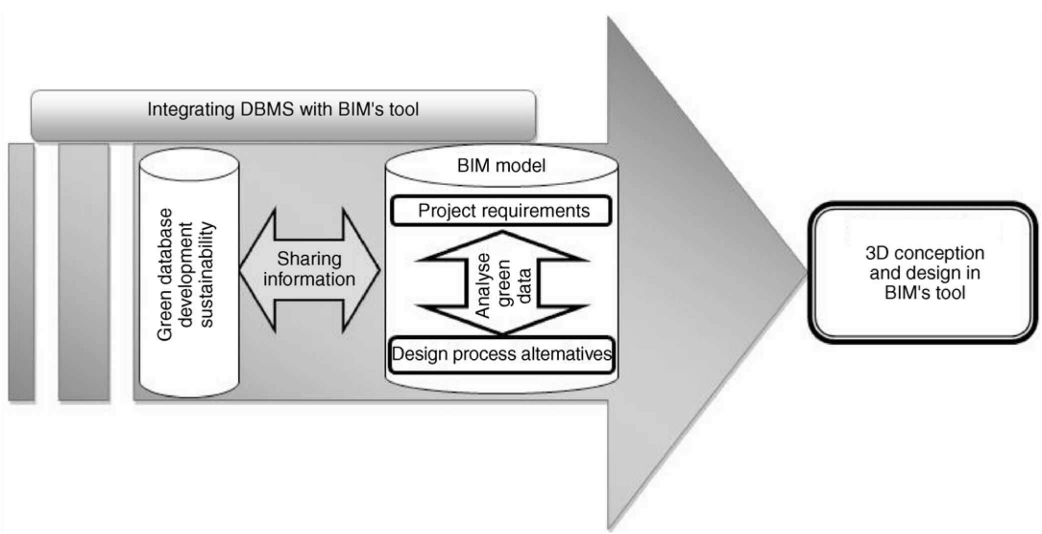

Fig. 4 Process of integrating database management system with BIM for sustainability

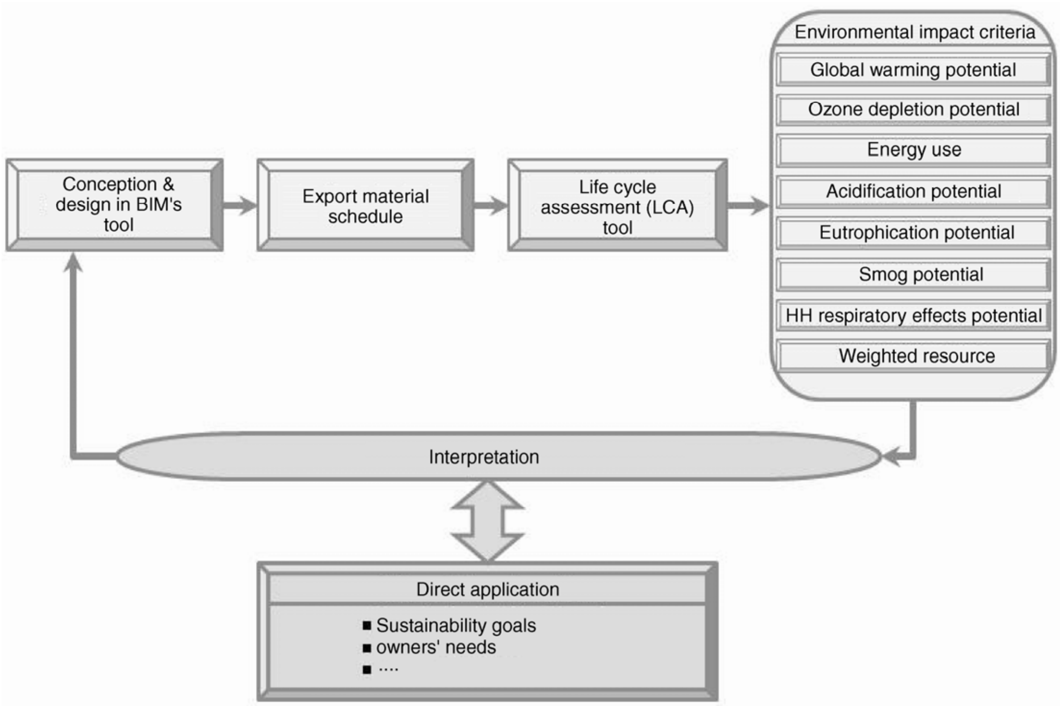

Fig. 5 Framework for integrating BIM and LCA tools

5.4 Green certification module (phase 4)

This phase consists of designing a certification and cost module linked with the other two modules, as explained in Fig. 6. By organizing the data collected from the suppliers and publishers—which are provided in the BIM and LCA modules—it will be possible to link them to this module in order to collect potential certification points and identify the certification level of the designed building. Authors collected information about sustainable materials and components from the manufacturers' and vendors' websites. Included in this information are the potential LEED points that can be gained if these materials or components are used in the design. This information is stored in a database linked to the families of the BIM's tool. Therefore, when designers design 3D models for proposed building projects and select any of these sustainable materials or components, the LEED points potentially gained by these selected items are identified and stored in the schedule associated with the model. Afterwards, users can add up these LEED points to identify the potential number that the proposed building can earn. Furthermore, the associated cost will be generated by linking the BIM module with the cost database for green and certified materials.

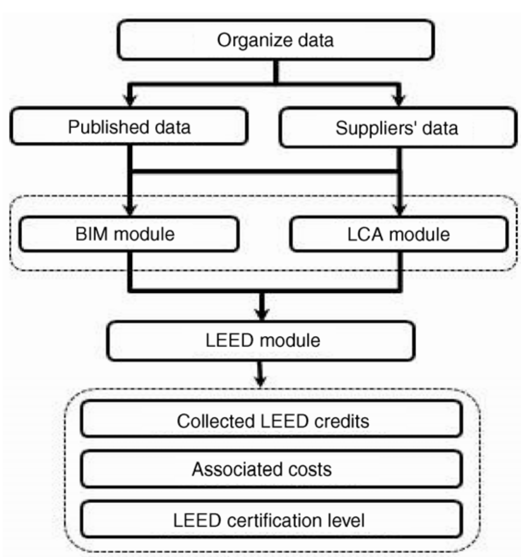

Fig. 6 LEED module data flow diagram

USGBC allows LCA to immediately impact LEED credits for projects using building materials which have been assessed and rated by specific third-party organizations to be eligible for immediate "Innovation in Design" credits under the current certification standard (Hoff 2008). Some of the data collected from the suppliers' webpages includes certification points, which can be potentially earned.

The development of the model described in this paper aims to present a database management system containing information about green and certified materials used to create families and keynotes and to link them to the BIM's tool to enable users to design 3D sustainable building models at the conceptual stage of a project's life. It takes into consideration the process of connecting the output of BIM with different modules such as LCA, green certification system and associated cost. The developed model shows how a variety of information about sustainable buildings can be integrated at their conceptual design stage to be used by owners and designers.

6 Testing and validation

The preceding paragraphs explored in detail the methodology followed in developing the integrated model. This section validates the capabilities of the model. Its performance is examined through designing a 3D model for an actual six floor apartment building project, which is currently at the design stage in the city of Ottawa. The proposed construction land has an area of 7500 ft^2 and the building consists of six units, one on each floor with an area of 1610 ft^2 per floor for a total gross area of 9660 ft^2 and a perimeter of 180 ft. The case example is used to test the workability of the integrated model. 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 example had their specifications as close as possible to the ones used in the real design. Every component, such as floor, wall, roof, and window has its associated LEED information linked to the families of the BIM tool, which includes the manufacturers' web pages and contact information.

Using the developed model to design the new building project in the city of Ottawa shows that owners and designers are provided with a vital tool that helps them when they decide to select green components based on what is introduced in the model as they can automatically see potentially earned LEED points, LCA and cost results during the conceptual design process. Figure 7 shows a rendered snapshot of the proposed green building, which is designed based on the development processes described previously. The process is implemented in three steps.

Fig. 7 Snapshot of the designed building with its green families

6.1 3D conceptual sustainable design (step 1)

A 3D design of the building is executed using Autodesk Revit Architecture©. With the established keynotes and created green families, the sustainable design for the building is fulfilled. First, the user has to link the green keynote file to the current building model by uploading and attaching it to the design as shown in Fig. 8.

By using the new keynotes, users have the option of selecting the most appropriate type of certified materials: for example the selection of a composite window instead of a single one. Furthermore, users are provided with the unit cost where applicable. As explained in phase 4, the external green database contains detailed stores of information such as URL addresses for every family. As illustrated in Fig. 9, by clicking the family window used in the model, the user can access the information about the certification and the potential earned points of that family as claimed by its supplier. More than 90% of the components and families used in the case example have LEED certification points, which are provided by their manufacturers and stored in the BIM's database.

Moreover, users can extract the materials' bill of quantities and export them to an external database which is linked to the LCA module to implement necessary assessment of the EIs as shown in Fig. 10.

Table 1 shows selected components based on the functional, technical, and financial specifications of sustainable 3D families collected from manufacturers' web pages. Furthermore, it shows the most applicable criteria for those elements boasting environmentally friendly capabilities. The provided information shows that the selected materials used in creating sustainable 3D families meet the functional, technical, and financial specifications and take into consideration the environmentally friendly aspects.

The data provided in the functional part illustrates the capability of the materials used to provide an overall satisfaction for owners and engineers by achieving the sustainable design objectives. Generally, manufacturers provide several technical specifications for each component and family, but the ones shown in Table 1 are information related to the sustainable design factors. In reference to the financial element, the specifications shown are related to the cost of the selected components.

6.2 Assessing the design's environmental impacts (step 2)

Once the design is finished the building is assessed and analyzed based on the sustainability requirements using the LCA module and its associated tool ATHENA® Impact Estimator©. This user-friendly tool provides quick results in the form of tables and graphs. The Impact Estimator allows

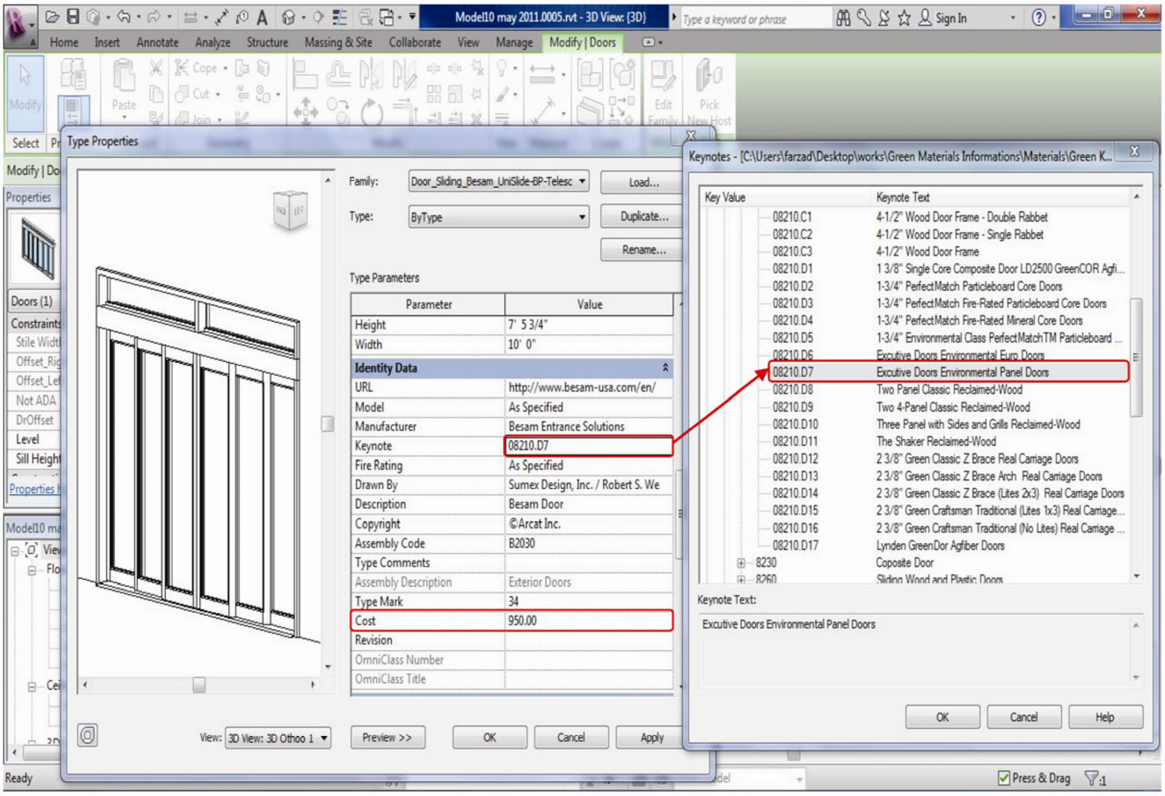

Fig. 8 A snapshot of the keynote in Revit

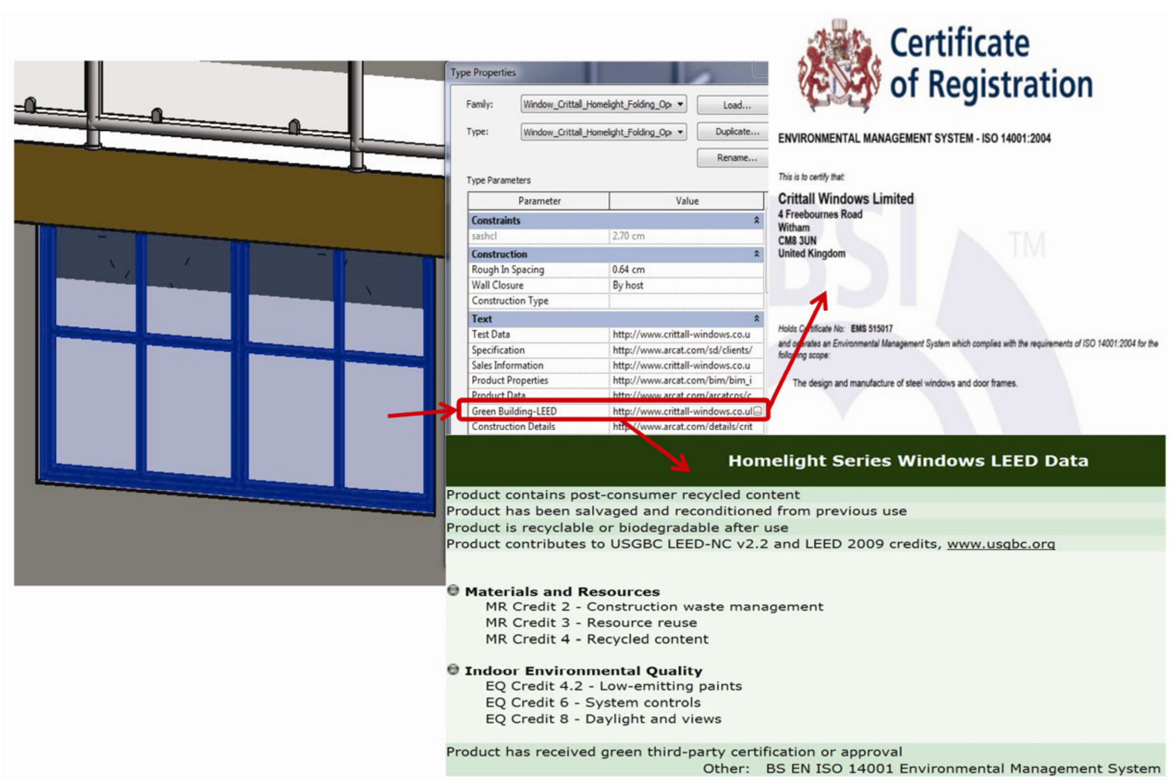

Fig. 9 A snapshot of LEED information which is stored in external BIM database

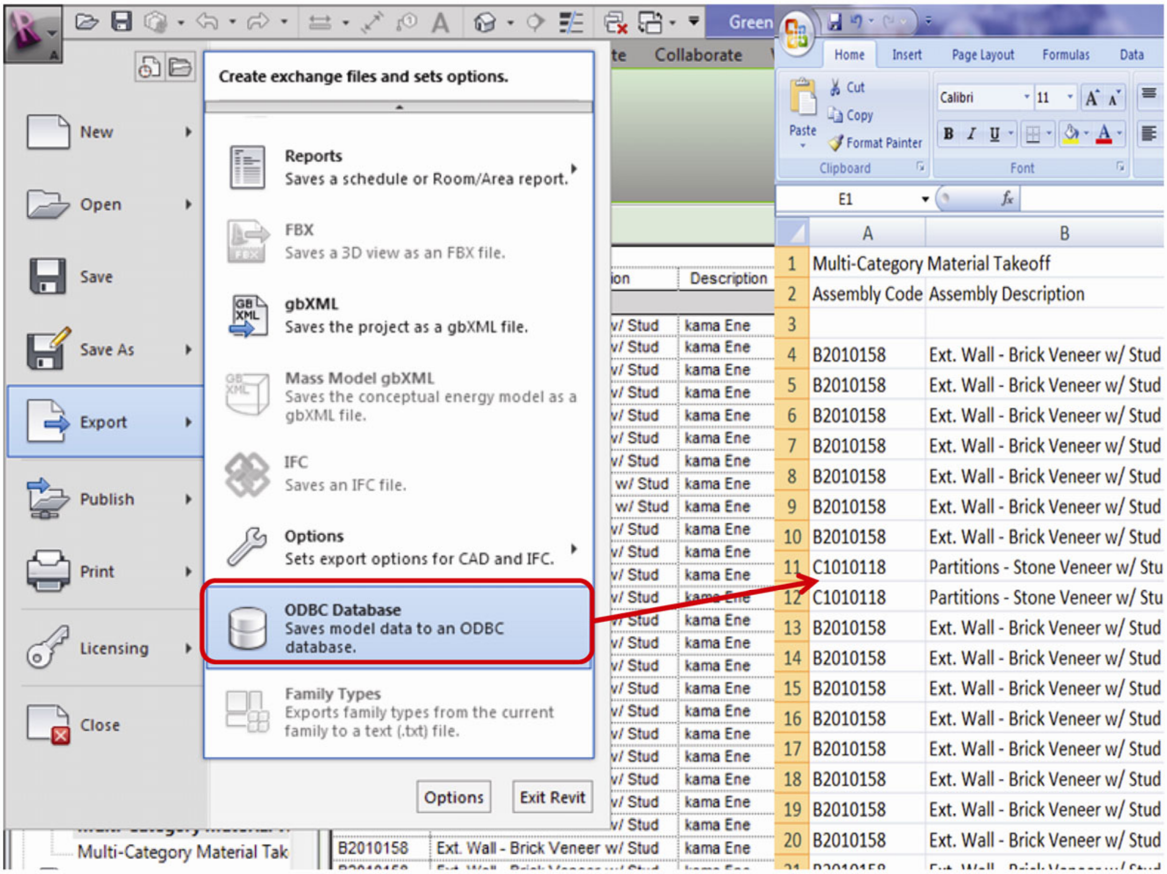

Fig. 10 Exporting materials' bill of quantity to the external database

users to change the design, substitute materials, and make side-by-side comparisons. It also lets users compare similar projects with different floor areas on a unit floor area basis.

First, users input the necessary information such as geographic location, building life and occupancy/type, and, if desired, annual operating energy values into ATHENA. Second, the exported bill of quantities extracted in step 1 is imported as text exchange file into ATHENA® Impact Estimator©. Pre-set dialogue boxes prompt users to describe the different assemblies, such as entering the width, span, and live load of a floor assembly.

It is worth mentioning that this software has some limited options for each assembly. An example of this is that it is necessary to select materials from the Athena library that have specifications close to the ones used in the BIM model. While the Impact Estimator offers a wide array of material and assembly combinations, the user needs to enhance the project design with additional materials. It should be noted that when it is decided to add "Extra Basic Materials", the application doesn't know how or where these materials are to be added and used. Hence, the LCA profile provided for extra basic materials is diminished in the sense that the application delivers the material to the building site, but does not calculate any effects associated with the usage of this material. For instance, using the formerly mentioned case as an example, softwood lumber, which is a green material and is used in different parts of the building, is added beside other assembly groups as extra basic materials.

After entering all the necessary information, Impact Estimator provides series of reports in terms of: (1) Primary Energy Consumption, (2) Acidification Potential, (3) Global Warming Potential, (4) Human Health (HH) Respiratory Effects Potential, (5) Ozone Depletion Potential, (6) Photo-chemical Smog Potential, (7) Eutrophication Potential, (8) Weighted Raw Resource Use, which are the focus of this case example. Figure 11 represents samples of the bar chart reports extracted from ATHENA® Impact Estimator©. As shown in Fig. 11, beams and columns, as well as walls consume fossil fuel more than other assembly groups (600 000 MJ and 700 000 MJ, respectively). Roofs and foundation use about 480 000 (MJ) of fossil fuel consumption.

Table 1 Functional, technical and financial specification of sustainable materials used in the 3D BIM model

Green families used in the BIM's sustainable model	Windows	Roofing systems	Floor	Wall	Door
Functional criteria	-Recyclable packaging materials -Products are certified by Scientific Certification Systems (SCS) to contain pre-consumer recycled content, which includes glass cullet and wood fiber in Fibrex® material -The recycled content certified to retain Forest Stewardship Council (FSC) Chain-of-Custody certification (SCS-COC-001337) for pine wood-based components	-To divert construction and demolition debris from landfills and incineration facilities -Redirect recyclable resources back into the manufacturing process -Redirect reusable materials to appropriate sites -Use materials with recycled content such that post-consumer plus ½ pre-consumer is at least 10% or 20% -Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within 500 miles of the site for a minimum of 10% or 20% -Use rapidly renewable building materials and products for 2.5% of the total value of all building materials -Patented Fibrex® material provides the strength of wood, low cost of vinyl	-Resource reuse -Recycled content -Regional materials -Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 5% of the total value of all building materials and products used in the project	-Framing, off-site fabrication of the structural systems -Utilize proprietary fabrication techniques for limiting waste in a controlled factory environment -Enables resource efficiencies that can often eliminate on-site waste -Reduced assembly time and smaller construction crew -Environmental preferable products -All EPS utilized is Green Guard® certified and therefore have lower emissions of VOCs, which helps reduce a home's contribution to smog compared to earlier EPS foam products -Reduce a home's contribution to smog compared to earlier EPS foam products -Reduction in assembly time and call backs and the predictability and adherence to project scheduling provided by indoor fabrication	-No added urea formaldehyde requirement -Constructed of recycled-content materials and contain insulating core material that does not contribute to ozone depletion -Factory applied finishing is applied based on control of volatile organic compounds (VOC) emissions -Regional manufacturing (500 miles) -Rapidly renewable (bamboo veneer)
Technical specifications	-Exposure category: 2000 (Pa) -Air permeability: not more than $16 m^3/(h \cdot m)$ joint: 300 (Pa) -Water tightness: no leakage: 200 (Pa) -Wind resistance: no damage & only permissible deflection: 2000(Pa) -Design testing, manufacture and installation carried out under Quality Management Systems certified to BS EN ISO 9001	-Asphalt shingles, thermoplastic polyolefin (TPO) and Poly-Vinyl Chloride (PVC) membranes, Ethylene Propylene Diene Monomer (EPDM) membranes, poly Iso insulation, extruded or expanded polystyrene insulation, gypsum board, mineral fiber board, ballast, metal flashings, metal roof panels, and clean wood -Reuse or salvage of ballast, Energy Guard™ roof insulation, and membrane -Material diverted from the waste stream during the manufacturing process -Materials considered being an agricultural product, both fiber and animal, that takes 10 years or less to grow or raise, and to harvest in an ongoing and sustainable fashion -Low-E glass for energy efficient performance -Folding hardware won't interfere with window treatments	-Maintain 100% of shell/structure and 50% in addition to Non-Shell/Non-Structure Green Floors can redeye your old carpet making it look like new. We can also refurbish your carpet floor tiles -Divert 50% from Landfill Green Floors specialists can analyze the carpet in the building -10% (post-consumer + 1/2 post-industrial) -20% manufactured regionally	-The system allows for construction waste per home built being less than 2.5 pounds (or 0.016 cubic yards) or less of net waste per square foot of conditioned floor area -Contain recycled content at a minimum of 25% postconsumer and 50% post-industrial for at least 90% of the building component	-Rigid foam plastics and fiberglass are typically used as insulation core -Interior doors are typically constructed of wood products (veneer, core materials, and styles) and synthetic wood products (plastics)
Financial investments	Minimise disturbance of the existing structure and internal finishes to a minimum, thereby reducing the cost of making good	This roof was selected because of its engineered cooling attributes for a cooler roof and a projected cooling cost saving of 20%	Lowers maintenance costs a minimum of 10% (based on cost) of the total material value	Benefits accrue well beyond the design and construction budget through energy savings, a reduction in the contributory costs of the built environment to global warming	The cost is higher than for conventional doors. Such cost increases are dependent on the sustainable features specified

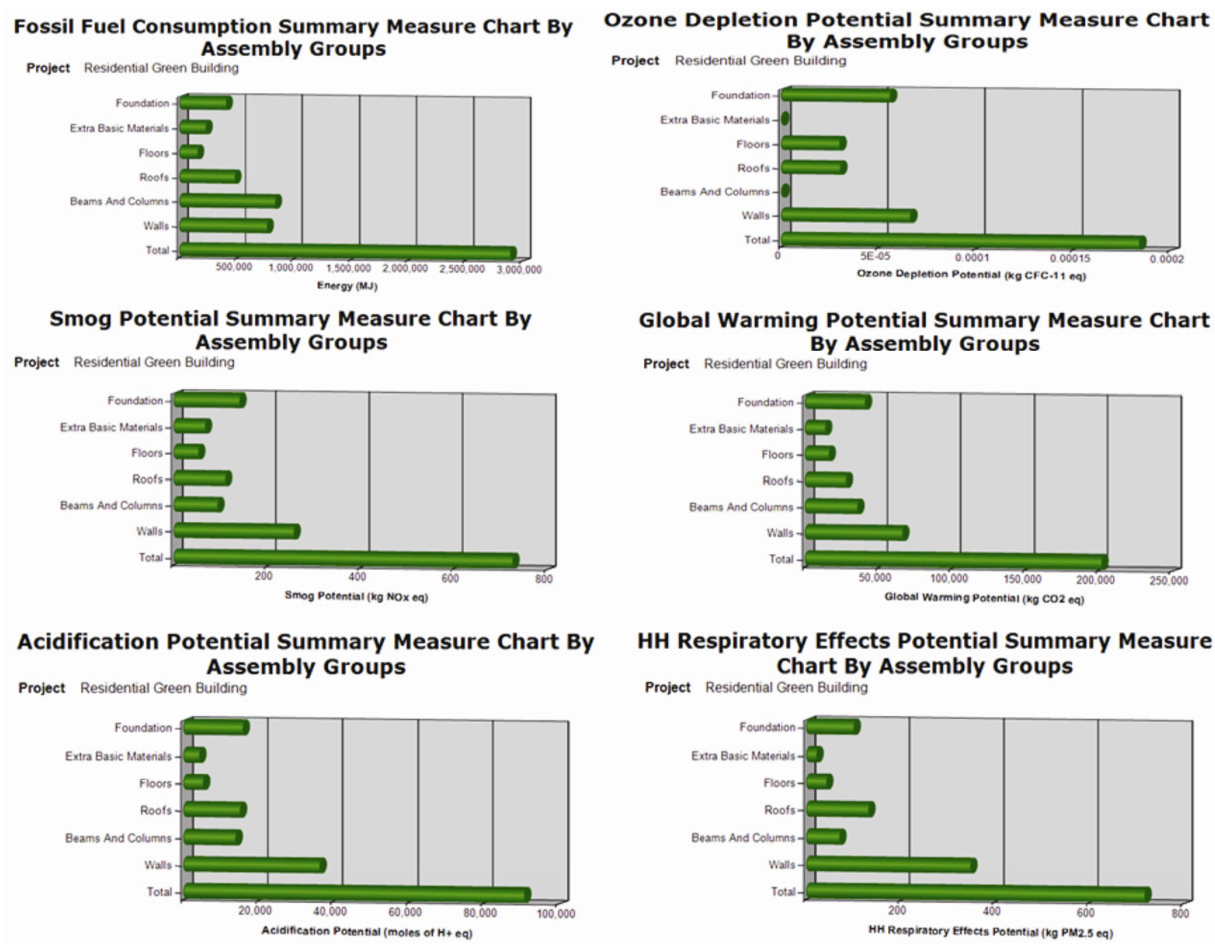

Fig. 11 Environmental Impact sample report of the implemented design

Conversely, when it comes to ozone depletion, walls, with 6E–5 (kg CFC), and foundation, with 5E–5 (kg CFC), are two groups with noticeable amounts. Meanwhile, floors and roofs are similar, both having 3E–5 (kg CFC). Walls, on the other hand, seem to have the most smog potential with around 250 (kg NO_x) out of the total amount, which is 720 (kg NO_x). Walls create the highest amount of Global Warming Potential, averaging around 60 000 (kg CO_2), followed by the foundation, with 40 000 (kg CO_2). Foundation, roofs, beams and columns produce similar amount of acidification potential, usually around 17 000 (moles of H^+), whereas walls produce much more than the others with around 35 000 (moles of H^+). Similarly, the HH Respiratory Effects for walls have the most effects, averaging around 320 out of a total of 700 (kg PM2.5). In the ultimate interpretation among the selected components, walls have the most impact on the environment in comparison with other assembly groups. Two reasons for this can be described here. The former is that walls are in direct contact with the outdoor environment while having several openings (wants and voids) and the various layers of walls are not made from sustainable materials based on the information provided by the supplier. The latter reason is that all the green materials stored in the BIM's model and its associated library are not supported by ATHENA® Impact Estimator©. The results provided by ATHENA® Impact Estimator© represent an appropriate overview about the EI of the design.

Based on the LCA reports, designers are able to identify the environmental impacts of the materials used in the design and decide on the ones that best fit the project's sustainable goals at its conceptual stage. Users, however, may identify the number of points gained by using the LEED and Cost module, which is linked to the other two modules.

6.3 Identifying the potential LEED points earned and associated cost (step 3)

In this step we identify the points earned by the 3D design based on the LEED-RS. Table 2 lists information related to the collected materials and the potential points that can be

Table 2 Potential and actual LEED points that can be / are earned by the model

LEED-NC credits that can be earned by each family and assembly groups using BIM-based performance analysis software			Roof		Floor		Windows		Doors		Wall		Beam& column		Spiral stairs& railing	
LEED credit	Credit description	LEED points	PEP †	EPM ††	PEP	EPM	PEP	EPM	PEP	EPM	PEP	EPM	PEP	EPM	PEP	EPM
Sustainable sites																
SSp1	Construction activity pollution prevention	required														
SSc1	Site selection	1														
SSc2	Development density and community connectivity	5														
SSc3	Brownfield redevelopment	1														
SSc4.1	Public transportation access	6														
SSc4.2	Bicycle storage and changing rooms	1														
SSc4.3	Low-emitting and fuel-efficient vehicles	3														
SSc4.4	Parking capacity	2														
SSc5.1	Protect and restore habitat	1														
SSc5.2	Maximize open space	1	*	1 point							*	1 point				
SSc6.1	Storm water design: quantity control	1	*								*					
SSc6.2	Storm water design: quality control	1	*	1 point												
SSc7.1	Heat island effect: non-roof	1	*													
SSc7.2	Heat island effect: roof	1	*													
SSc8	Light pollution reduction	1	*	1 point												
Water efficiency																
WEp1	Water use reduction	Required														
WEc1	Water efficient landscaping	2–4														
WEc2	Innovative wastewater technologies	2														
WEc3	Water use reduction	2–4														
Energy & atmosphere																
EAp1	Fundamental commissioning of building energy systems	Required														
EAp2	Minimum energy performance	Required														
EAp3	Fundamental refrigerant management	Required														
EAc1	Optimize energy performance	1–19					*	1 point								
EAc2	On-site renewable energy	1–7														
EAc3	Enhanced commissioning	2	*	6 points			*	8 points			*	10 points				
EAc4	Enhanced refrigerant management	2														
EAc5	Measurement and verification	3	*	1 point			*	1 point			*	1 point				
EAc6	Green power	2									*					
Materials & resources																
MRp1	Storage and collection of recyclables	Required														
MRc1	Building reuse: maintain existing walls, floors, roof	1–5														
MRc2	Construction waste management	1–2					*	1 point			*	1 point				
MRc3	Materials reuse	1	*	1 point							*	1 point				
MRc4	Recycled content	1–2	*				*		*		*					
MRc5	Regional materials	1–2	*	1 point	*	1 point	*	1 point	*	1 point			*	1 point	*	1 point
MRc6	Certified wood	1	*	1 point	*	1 point	*	1 point	*				*	1 point	*	
Indoor environmental quality																
EQp1	Minimum indoor air quality (IAQ) performance	Required					*									
EQp2	Environmental tobacco smoke (ETS) control	Required														
EQc1	Outdoor air delivery monitoring	1														
EQc2	Increased ventilation	1					*				*	1 point				
EQc3	Construction IAQ management plan: during construction	1														
EQc4.1	Low-emitting materials: adhesives and sealants	1					*	1 point			*	1 point				
EQc4.2	Low-emitting materials: paints and coatings	1	*	1 point	*	1 point	*									
EQc4.3	Low-emitting materials: flooring systems	1													*	1 point
EQc4.4	Low-emitting materials: composite wood and agrifiber products	1			*		*	1 point								
EQc5	Indoor chemical and pollutant source control	1							*	1 point						
EQc6	Controllability of system: thermal comfort	1					*									
EQc7	Thermal comfort: design	1					*	1 point								
EQc8.1	Daylight and views: daylight	1					*									
EQc8.2	Daylight and views: views	1					*	1 point								
Innovation & design process																
IDc1	Innovation in design		1–5								*					
IDc1	Accredited professional		1								*	1 point				
Regional priority																
RPc1	Durable building		1				*	1 point			*					
RPc2	Regional priority credit		1–3								*	1 point				

Certified	40–49	Total earned points by 3D model
Silver	50–59	57
Gold	60–79	
Platinum	80 points above	

† Potential earned points

†† Earned points in the model

earned from them as well as the actual points earned by the design of step 1. As it is shown, the designed 3D model gets 57 LEED points and stands for a Silver level based on the CaGBC rating system. This number of LEED points is approximate since the focus of this study is at the conceptual design stage, therefore the calculated points do not reflect the final number that can be earned when the building is consummated. The intent is to just provide owners and designers with an idea about the potential LEED points that the proposed building may earn if a decision is made to continue the project. At the conceptual stage, owners and designers do not have detailed information about the project. This integration will give them an approximate idea allowing them to realize the potential LEED points the designed 3D model can earn them.

Table 3 shows a sample of the costs of the selected materials based on R.S. Means data. In this table the total estimated cost of each family is calculated using R.S. Means Green Building Cost database. In this database the unit cost of each family is calculated based on the national average value for the year 2012 and adjusted for the city of Ottawa. To prepare the cost estimate, materials with similar specifications as to the quantity take off extracted from the developed 3D-BIM design, which are selected from R.S. Means database.

7 Conclusions and future research

This paper presents a methodology for modelling the procedures of implementing sustainable design for building projects at their conceptual stage by integrating BIM, LCA and relational databases with a workable model. The model includes a 3D (BIM) module, an LCA module and a LEED and Cost module. The databases of the model are based on collected data from the literature, suppliers, publishers, CaGBC, and USGBC websites. The developed model is intended to assist owners, architects and engineers in accomplishing conceptual sustainable design for building projects and measuring their environmental impacts at early stages. Furthermore, the model allows users to identify the earned points based on the LEED-RS. The model is simple and user-friendly where user inputs and error prediction are minimized. Time reduction, fast calculations, and professional output reports are some of its advantages. The major limitation of the proposed model is that it cannot be applied at the detailed design stage of a building project because its integrated database stores information only for components that are commonly used in building projects. Furthermore, the developed database has been designed based on couple of collected BIM files which contain limited number of certified components, all of which are

Table 3 Associated cost of the selected components based on R.S. Means cost data

Description	Unit	Quantity	Material ($)	Labor ($)	Total unit cost ($)	Total item cost ($)
Windows						
Windows, vinyl double hung, grids, low-E, J fin, 37" × 69", including grill, J finish, low-E, extension jambs	Ea.	5	262.00	44.0	306.00	1530
Windows, wood, casement, vinyl clad, premium, double insulated glass, multiple leaf units, double unit, 3'-4" × 3'-0" high, incl. frame, screens and grilles	Ea.	18	430.00	59.0	489.00	8802
Windows, wood, casement, vinyl clad, premium, double insulated glass, 2'-0" × 6'-0" high, incl. frame, screens and grilles	Ea.	6	375.00	44.0	419.00	2514
Roof						
Wood shingles, white cedar, 3/4" thick × 16" long, 5" exposure on roof	Sq.	27.41	154.00	147.0	301.00	8250
Floor						
Resilient flooring, cork tile, standard finish, 5/16" thick	S.F.	18 820	8.60	1.04	9.64	181 425
Doors						
Doors, wood, residential, exterior, combination storm and screen, pine, cross buck, 7'-1" × 3'-0" wide	Ea.	1	330.00	78.5	408.5	408.5
Doors, wood, residential, entrance, flush, birch, solid core, 1'-3/4" × 7'-0" × 2'-4" wide	Ea.	30	111.00	44.0	155.00	4650
Column						
Column, structural, mild steel scrollwork, flat, stock unit, plain, painted, 9" W, shop fabricated	V.L.F.	870	9.15	9.95	19.86	17 278
Railing & stairs						
Railing, ornamental, bronze or stainless, 3'-6" high, posts @ 6' O.C., hand-forged, plain	L.F.	907.1	101.00	33.0	134.00	121 538

designed and provided by manufacturer companies. This is a limitation for the model because it does not cover all the existing green elements. This means that there are several green families that require being designed and converted to BIM format files and added to the database. Moreover, the proposed model is not fully automated; users still have to do some manual steps such as linking the database directly without importing or loading the green materials, linking the model's information with LCA tools to execute LCA, and cost estimate calculations. The research in this domain is ongoing, and its authors are currently engaged on enhancing the databases linked to the developed model in addition to achieving a full automated integration between different tools needed to take part in sustainable conceptual design for building projects.

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