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INTEGRATING BUILDING INFORMATION MODELING (BIM) AND ENERGY ANALYSIS TOOLS WITH GREEN BUILDING CERTIFICATION SYSTEM TO CONCEPTUALLY DESIGN SUSTAINABLE BUILDINGS

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SUMMARY: *It is commonly known that the energy consumption of buildings is quite high; therefore, owners, architects, and engineers should be more concerned about the sustainability and energy performance of proposed building projects. For years, energy analysis tools have been used by designers to design energy-efficient buildings. Generally, the energy analysis for this type of facilities is mostly conducted at the end of the design stage, once their components and elements have already been selected. However, analyzing the energy consumption of those components at the conceptual design stage is very helpful for designers when making decisions related to the selection of the most suitable design alternative that will lead to an energy-efficient building. Building Information Modeling (BIM) has the capability to help users assess different design alternatives and select vital energy strategies and systems at the conceptual design stage of proposed projects. Furthermore, by using BIM tools, designers are able to select the right type of materials early during the design stage and to make energy-related decisions that have great impact on the whole building life cycle.*

The main objective of this paper is to propose an integrated methodology that links BIM and energy analysis tools with green building certification systems. This methodology will be applied at the early design stage of a project's life. It will help designers measure and identify potential loss or gain of energy for different design alternatives and calculate the potential LEED points they may accumulate and gain and accordingly select the best one. An actual building project will be used to illustrate the workability and capability of the proposed methodology.

KEYWORDS: *BIM, Energy Analysis and simulation, Green Building, Certification System, LEED, Sustainable Design.*

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1. INTRODUCTION

Important decisions related to the design of sustainable buildings are made at the conceptual stage of the building life cycle. Energy analysis is typically performed after the architectural/engineering design and related documents have been produced. Schueter and Thessling (2009) think that this practice does not consider the importance of linking the design and energy analysis processes during early stages and yet it leads to an inefficient way of backtracking to modify the design in order to achieve a set of performance criteria. Sartori and Hestnes (2007) claim that buildings demand energy in their life cycles, both directly and indirectly: directly for their construction through operating, rehabilitation and eventually demolition (operating energy); indirectly through the production and installation of the materials they are made of (embodied energy). Thus, one of the emphases of this study is on evaluating and analysing the energy (embodied and operating) of building projects during the conceptual design stage of their life cycles.

Energy efficiency is an important feature in labeling building materials as being environmentally friendly. The goal in using energy-efficient materials is to reduce the amount of artificially generated power that must be brought to a building site (Jong et al., 2010). Generally, building materials consume energy throughout their life cycle starting at the manufacturing stage, passing through that of use, and finishing during the deconstruction stage. These stages include raw material extraction, transport, manufacture, assembly, installation as well as disassembly, deconstruction, and decomposition.

Presently, Building Information Modeling (BIM) tools have the option to provide users with an opportunity to explore different energy saving alternatives early in the design stage, thus avoiding the time-consuming process of re-entering all the building geometry and other supporting information necessary to complete the energy analysis.

The use of BIM tools may help owners and designers make energy-related decisions that have high impact on the life cycle cost of proposed building early of its design stage. Furthermore, integrating BIM with Life Cycle Assessment (LCA) tools at that stage would help designers select components and materials that have lower embodied energy. In most building projects, materials and components are evaluated and selected based on functional, technical, and financial criteria. A clear understanding of the functional criterion of the building materials is essential to ensure the success of a project. It is known that a building project functions successfully only when its design satisfies the emotional, cognitive and cultural needs of the people who use it (WBDG, 2012). Technical specifications provide detailed information about the materials and components used in a building. Usually, such information, which is provided by the manufacturer, contains information about the type, size/dimensions, installation procedures, and other information that show the capabilities and applications of these materials. In order to meet the requirements of a cost-effective design for proposed buildings, the financial criterion of the selected materials should also be taken into consideration. At the present time, environmental impact is gaining priority within the process of selecting construction materials. Technically, construction materials should satisfy strength, serviceability and architectural requirements without having a negative impact on the environment (Somayaji, 2001).

Usually, using BIM tools to design sustainable buildings necessitates the selection of materials and systems whose embodied energy can easily be evaluated. Thus, the common method used to quantify the embodied energy of the selected materials is LCA, which is a concept used to evaluate environmental concerns (Khasreen et al., 2009). For this purpose, designers use LCA tools to model, to modify, and to input energy simulation results and calculate the operating and embodied effects of their design. Hence, it will be necessary to evaluate and to compare the capabilities of different methods of exchanging information between BIM and LCA tools, which are highly important for designers who need to transfer the design information directly from the BIM model to the energy analysis software. Schema such as the Industry Foundation Classes (IFC) data model that is the standard data specification for exchanging information throughout the entire lifecycle of a building (ISO/TC 184/SC 4, 2005) and Extensible Markup Languages (XML), which defines a set of rules for encoding documents in a human-readable and machine-readable format, are currently promoted by various groups in the construction industry. This paper will also focus on analysing the day lighting and measuring the thermal gain / loss of proposed buildings at their conceptual design stage. Using the proposed methodology at the conceptual stage of the project will help designers determine the products that best meet their needs, evaluate the sustainability of the building based on selected rating systems, and visualize the energy and lighting analysis results in an easy, quick, and convenient way.

2. LITERATURE REVIEW

The impact of BIM on design practice is significant due to the fact that it raises new ways and processes of delivering designs, construction, and facilities management services. Owners are not only demanding buildings to be designed and delivered on time, cost efficiently, and with high quality but are also demanding services beyond design and construction (Clayton et al, 1999). Based on Kubba (2012) and Becerik-Gerber and Rice (2010), development of a schematic model prior to the generation of a detailed building model, allows the designer to make a more accurate assessment of the proposed scheme and to evaluate whether it meets the functional and sustainable requirements set out by the owner; this helps increase project performance and overall quality. The advent of BIM along with the emergence of global challenging issues like sustainability, and life cycle cost of buildings, necessitates designers to incorporate the basic performance analysis from an early design phase. Those performance analyses are special quality analysis, energy performance, social impact and environmental performance into its framework by further developing the concept of virtual space and virtual building (Kam et al, 2004). An integrated BIM system can facilitate collaboration and communication processes between project participants in an early design phase to effectively provide a well-performing building during operations (Hungu, 2013). BIM allows multidisciplinary information to be superimposed within one model by incorporating structural, mechanical, electrical, plumbing and lighting information into a single model (Tucker and Newton, 2009). It helps owners visualize the spatial organization of the building as well as understand the sequence of construction activities and the project duration (Eastman et al, 2008). Combining sustainable design strategies with BIM technology has the potential to change traditional design practices and to efficiently produce high-performance designs for proposed buildings. BIM technology can be used to support the design and analysis of a building system at the early design phase. This includes the experimental structural analysis, the environmental controls, the construction method, the selection of new materials and systems and the detailed analysis of the design processes.

For the past 50 years, a variety of building energy simulations and analysis tools have been developed, enhanced and applied by the building industry. Examples of these tools are BLAST, EnergyPlus, eQUEST, TRACE, DOE2, Ecotect and Integrated Environmental Solution (IES-VE) (Crawley et al, 2005). Grobler (2005) claimed that building designs (conceptual and detailed) affect the construction and operation costs of a building. Several researchers describe energy analysis as a holistic evaluation (Abaza, 2008; Dahl et al, 2005; Lam et al, 2004). They claim that decisions made early in a project have a strong effect on the life cycle costs of a building. BIM has received tremendous interest for its impact on the sustainable development and its potential to connect with energy analysis applications. Analysing the energy at the early design stage provides an opportunity to make cost-effective decisions that influence the building life cycle and meet the energy efficiency targets.

The building system analysis involves many functional aspects of a building such as structural integrity, ventilation, temperature control, circulation, lighting, energy distribution and consumption (Azhar et al, 2010). Hence, an ideal opportunity exists for the sustainability measures and performance analysis to be integrated within the BIM model (Azhar and Brown, 2009). BIM includes associated benefits of visualization, built-in intelligent objects of a building model such as spatial data (3D), unstructured data (text), and structured data such as spreadsheets and databases. BIM models not only provide data pertaining to the building geometry but they allow the calculation of volumes and related energy based on the characteristics and orientation of a building.

The Green Building XML schema — known as “gbXML” — was developed to facilitate the transferring process of the information stored in building information models to enable the integration and interoperability between the design models and other engineering analysis tools (Kumar, 2008). Furthermore, gbXML facilitates the exchange of the building information (which includes product characteristics and equipment performance data) between the manufacturer’s database, the BIM models and the energy simulation engines. One of gbXML’s benefits is its ability to carry detailed descriptions of a single building or a set of buildings that can be imported and used by energy analysis and simulation tools. The IFC specification is developed and maintained by buildingSMART International as its “Data standard.” It is registered with ISO as ISO16739 as an open international standard for BIM data that is exchanged and shared among software applications used by the various participants in a building construction or facility management project. It has an open data exchange format that is usually used by model-based applications to exchange data between one another. IFC permits information (i.e., design, analysis, specification, fabrication, construction and occupancy) to be shared and maintained throughout the life cycle of construction projects (Khemlani, 2004). The IFC model consists of tangible components such as walls, doors, beams, and furniture as well as the more abstract concepts of space, geometry, materials, finishes, and activities (Kumar, 2008).

When creating sustainable design, designers are concerned about their ability to evaluate the environmental impact (EI) of the selected materials and components by using available methods and tools. In this perspective, the idea of LCA has emerged as the collection and evaluation of the inputs, outputs and the embodied energy 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 energy consumption. Thus, its application at the conceptual design stage of building projects will be very useful for designers. In order to analyze the embodied energy of buildings' components, a methodology that integrates BIM models with LCA systems is needed due to its potential to streamline LCA processes and facilitate the rigorous management of the environmental footprint of constructed facilities. Jrade and Jalaei (2013) describe a methodology emphasizing the integration of BIM, Management Information Systems, and LCA that can be used to implement sustainable design for proposed buildings at their conceptual stage all the while taking into consideration their Environmental Impacts. Häkkinen and Kiviniemi (2008) identify 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 and 3) using parametric formats such as Geometric Description Language (GDL).

Generally, data such as transport, energy, recycling, and case studies are available from various industries. This type of information is useful but finding relevant ones for a specific usage can be extremely difficult. Commercial databases are often inherited in commercial applications or tools. These databases hold data about some specific products that are better than the ones in the free databases. Lehtinen et al (2011) listed a couple of free LCA databases such as CCaLC database in the UK and the US Life Cycle Inventory Database, which is supplied by Athena Sustainable Materials Institute. Athena Impact Estimator allows users to input the building's estimated annual operating energy by fuel type and they can subsequently compare and contrast the life cycle operating and embodied energy and other environmental effects of the building design. It provides a cradle-to-grave life cycle inventory profile for a whole building (Athena, 2012). In LCA terminology, the effects associated with the making, transporting, using, and disposing of products are referred to as "embodied effects." Until recently, only operating energy was considered, owing to its larger share in the total energy life cycle. However, due to the advent of energy efficient equipment and appliances, as well as more advanced and effective insulation materials, the potential for curbing operating energy has increased and, as a result, the current emphasis has shifted to include embodied energy in the building materials (Crowther, 1999; Nassen et al, 2007). Thus, there is a genuine demand for measures to calibrate the performance of buildings in terms of both embodied and operating energy in order to reduce their energy consumption (Langstone et al, 2008; Treloar et al, 2001).

While green building certification systems can be used as guidance for design, to record performance progress, to compare buildings and to document the outcomes and/or strategies used in the building (Wang et al, 2012), different types of methodology such as Building Research Establishment Environmental Assessment Method (BREEAM) (Baldwin R et al, 1998), Green Star from Australia (GBCA, 2008), and the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) from Japan (CASBEE, 2008) have been developed. More locally, we can also find 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, 2001). All of these methodologies are widely used to establish the environmental goals' level of achievement and to guide the planning and design processes. Furthermore, comprehensive tools for environmental assessment can be found (Ding, 2008) such as the whole Building Design Guide (WBDG, 2012) and the World Green Building Council (WGBC, 2008).

Although these tools have an extended use, the LEED Rating System (LEED-RS) has established a strong credibility among the experts (Pulselli et al, 2007). The LEED-RS was evaluated as to its importance as a measurement tool for the environmental performance of a building by 7,500 companies and organization members around the world. Yet, in order to automate the evaluation of the environmental specifications of the proposed building model in BIM at the conceptual design stage, designers can use a sustainability evaluator tool (i.e. EcoScorecard©), which is a plug-in to the BIM tool. This plug-in has the ability to evaluate and document the environmental data for various rating systems such as those of the US Green Building Council "USGBC," the Canadian Green Building Council "CaGBC," the Collaborative for High Performance Schools (CHPS) and the National Green Building Standard (NGBS) as well as other third-party product certification systems.

Although the potential of using BIM models for energy simulation is well known, a systematic approach that can be used to share the necessary information is still lacking (Young, et al 2009). The data related to the buildings' HVAC systems and to the internal loads such as occupancy and lighting should be included in the data exchanging process between BIM tools and energy simulation software in order to avoid any repetitive data inputs (Pimplikar and Esmaeili, 2012). The first step to pursue the integration procedure is to test the data inputs and outputs using different interoperable formats and to select the more efficient one. Since the automation process will take place at the conceptual stage of a project's life while doing sustainable design, another aspect of this study is to use an application to evaluate the created model in order to get details about its environmental and sustainability specifications in a systematic way. In this case, users can add up the potential points that can be earned during the design based on the selected green building certification system. This would provide the design team with the opportunity to compare different energy results for the whole model and to analyse the embodied energy of every component in that model. Autodesk Revit®, which is used as BIM tool in this research, provides the opportunity to develop API's that can be used to create custom tools that plug directly into Autodesk Revit®. This would extend the functionality of the BIM tool and would allow users make well-informed decisions in selecting optimum sustainable building components.

3. SCOPE AND SIGNIFICANCE OF THE STUDY

This paper proposes a methodology that can be used to implement an integrated platform to do sustainable design for new buildings at their conceptual stage and afterwards analyze and simulate their energy and day lighting respectively and assess their sustainability. The methodology is implemented by designing and developing a model that simplifies the process of designing sustainable buildings and transmitting the design information to energy analysis tools to implement energy and lighting analysis as well as identifying and listing the potential certification points that can be earned based on the selected system for sustainability. The methodology incorporates an integrated model capable of guiding users when performing sustainable design for new building projects. It incorporates the following five modules: 1) A Database Management System (DBMS) module, 2) An Energy and lighting analysis module, 3) A Life Cycle Assessment (LCA) module, 4) A LEED accreditation module and 5) A cost estimating module. Each of these modules is linked to one or more databases containing necessary data and information. The major task of the model is to collect lists of green products and certified materials and have them linked to the building database in the BIM tool. Creating and linking such a database to the BIM tool helps users design and animate sustainable buildings in the BIM environment easily and efficiently at the conceptual stage. Part of this integrated methodology is to develop new plug-ins and customize the existing ones built into the BIM tool in order to assist users to connect their design module with the abovementioned five modules in an efficient and consistent manner. The main objectives of this study are:

• Investigate the feasibility of creating full integration between BIM, Energy and lighting analysis tools,

• Collect, create and store series of design families that incorporate sustainably certified components in a database in an attempt to improve the workability and capability of the BIM tool used to do sustainable design at the conceptual stage.

• Create and develop an efficient framework for this integration that takes into consideration the sustainable design requirements and the functionality of the BIM tool,

• Develop a BIM sustainable design model that incorporates the five previously mentioned modules,

• Analyze the data and information associated with the proposed building's model, which is transmitted during the transformation process from one file format to another to identify how much of this data was retained and how much was lost.

Numerous types of software used in the construction industry, such as Autodesk Revit Architecture©, Autodesk Ecotect, Integrated Environmental Solutions (IES-VE), Microsoft Excel© and Athena® Impact Estimator© were used in the development of the integrated model. The successful implementation of such a model represents a significant advancement in the ability to attain sustainable design of a building during the early stages of its life, to evaluate its EI and to list its potentially earned certification points and the associated costs.

4. METHODOLOGY AND DEVELOPMENT

The major objective is to develop an automated methodology that helps a designer do 3D conceptual design of a sustainable building and to analyse and simulate its energy as a whole and for every one of its components. Since the proposed methodology integrates different applications, it will be implemented through six sequential phases. Fig. 1 illustrates the sequential flow of implementing the integrated methodology.

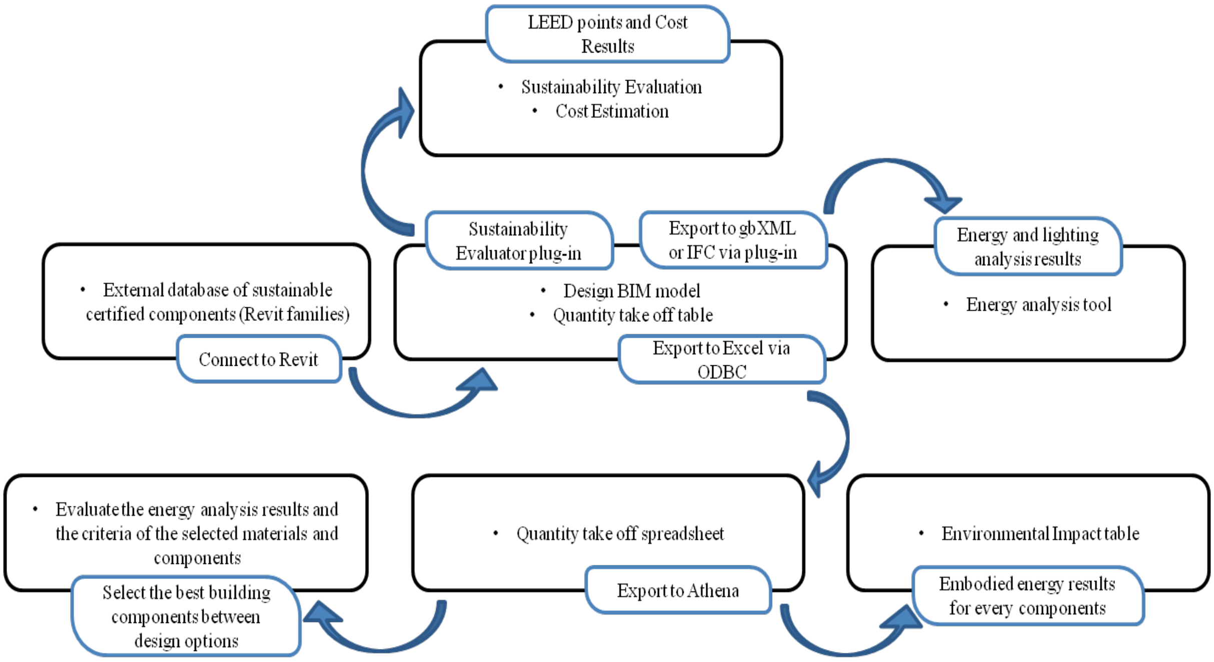

FIG. 1: Sequential flow of implementing the integrated methodology

Phase 1 consists of designing the model's relational database needed to design sustainable building. Loucopoulos (1992) states that a consistent information system depends on the integration between databases, programming languages, and software engineering and that its lifecycle 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 modelling and ending with the physical implementation. First, the 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. Secondly, the implementation of the data model requires that the transformation process be made from the conceptual to the logical design (Jrade and Alkass, 2007). Only afterwards is the physical implementation made by creating a list of related tables used to store the collected data based on the selected Work Breakdown Structure (WBS). The information related to the green materials is stored in an external database in the form of predefined design families that can be recognized by the BIM tool. The reason for developing a separate database is to have it loaded every time the BIM tool (Revit) opens and this is done by defining its path, which is linked to the predefined library of Revit. The data related to the green materials is saved as family files (RFA) or Revit files (RVT), which can be identified by the BIM tool. Thus, in the external sustainable database, up to 3,000 design families are collected from the literature, suppliers' web pages, USGBC and CaGBC websites 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.

Phase 2 focuses on customizing the BIM 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 families, in the BIM tool, and their associated keynotes for components commonly used in residential buildings by using certified green materials. 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. It can be used as an external link to the element itself with a specific style and specifications so it can be used as a Revit family. This means that a user can insert different text family types in Revit. Keynotes can be assigned to elements which are typically used if the user wants to note an entire assembly, such as a wall assembly. A material type keynote is used to note a specific material in Revit (i.e. concrete, gypsum board or acoustical tile). The sixteen Masterformat divisions present the main WBS applied in this research. 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. The coding system allows users to accelerate the process of retrieving any necessary information from keynotes. There are five-digit numbers that represent the divisions, subdivisions, elements and material names. 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 into the BIM tool consist of different types such as walls, floors, stairs, windows, and doors.

Phase 3 concentrates on developing a plug-in, which is a type of algorithm that adds functionality to the BIM tool by integrating it with the energy analysis and simulation tools. The C# programming language is used in developing the plug-ins that will be applied to the BIM tool. In this algorithm, the exporting process of the materials quantity take-offs into gbXML and IFC is done automatically and saved in a pre-defined location by the plug-in. Then the plug-in recalls ECOTECT.exe to pop-up and opens the saved files from that pre-defined location. To load and run the plug-in, an add-in which includes information used by the BIM tool must be added. It is a file located in a specific location that BIM tool looks at while it is loading. Therefore, the whole process of transferring data from BIM to the energy analysis tool is done automatically by using the plug-in.

Phase 4 consists of designing energy analysis and simulation modules that help to export the design created in the BIM tool in the IFC and gbXML file formats. One of the energy analysis tools used in this research is Ecotect, due to its efficiency in evaluating the thermal and solar gains for the architectural designs of proposed buildings. It easily creates or cleans up models in a format that includes both the geometry and the zones of a building, besides having interoperability potentials with other tools. This interoperability makes it an ideal tool to import and export the design between BIM tools, which generate the geometry of the proposed building, and different energy analysis tools. IES-VE, which can be linked to the BIM tool as a plug-in, provides information for thermal analysis, value engineering, cost planning, life-cycle analysis, airflow analysis, lighting, and occupant safety all in one unified system (Khemlani, 2006). IES-VE contains an Integrated Data Model that captures all the information related to the proposed building including the geometric data, which is needed to do all the necessary analyses. Yet, it must be said that the 3D geometric information can also be imported straight from the BIM tool using the gbXML file format. Construction materials can also be selected from the IES-VE built-in database, which is known as the Apache construction database.

Phase 5 consists of designing an LCA module that interconnects the design created in the BIM tool with the LCA tool through an ODBC connection to directly transfer the materials' bill of quantity into the latter tool in order to evaluate the environmental impacts of these materials. That LCA module is connected to an external database that stores the extracted quantities of materials, which is then imported into the ATHENA Impact Estimator© via a text file exchange format. The authors elected to use ATHENA Impact Estimator© for Buildings because it is commonly used by the North American construction industry and because it is designed to evaluate the whole building and its assemblies based on the internationally recognized life cycle assessment (LCA) methodology. When using this tool, the focus is on analyzing the embodied energy of the architectural and structural systems that are used in the 3D conceptual design.

One of contributions of this research is the ability to measure the transport energy, which is one significant component of the embodied energy used to transfer materials and building components from suppliers' locations to the building site. The IE tool does not recognize this type of energy and accordingly it does not have the capability to calculate it. Transport energy is a function of the weight of materials, the transport method and the travelled distance. From these three factors a reasonably accurate calculation of the transport embodied energy can be done. Many materials are delivered to the site by rigid trucks, thus the developed model considers this as one of the inputs stored in the database developed in phase 1.

Phase 6 includes the design and development of a green building certification and cost estimating module, which is linked to the BIM and Energy analysis modules. This module contains data collected from the suppliers' and publishers' webpages, which are retrieved from the created model by using the sustainability evaluator plug-in that is loaded into the BIM tool. The authors collected information about sustainable materials and components from the manufacturers' and vendors' websites and from using the smart BIM green components, which can be detected by the sustainability evaluator. 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. Therefore, when designers model the design for a proposed building project 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 BIM 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). Furthermore, the associated cost will be generated by linking the model created in the BIM tool with the cost module, which is linked to the database that stores information about green and certified materials. The associated cost of the developed design is then calculated based on R.S. Means published data.

The development of the model described in this paper focuses on automating the process of connecting the output of the BIM module with other different modules, (energy analysis and day lighting simulation, embodied energy of the building's components and Green Certification System and associated costs). The model is an integrated tool that helps owners and designers share a variety of information at the conceptual design stage of sustainable buildings. It assists designers in comparing and evaluating each design family and its associated components that are selected during the conceptual design taking into consideration the materials' selection criteria.

Fig. 2 shows a flowchart of the integration process that is used in this study. It determines the processes applied to the design created in the BIM tool while considering all related criteria and specifications based on the described phases. Fig. 3 illustrates the model's architecture when the input section includes the certified components stored in the database, based on the Masterformat WBS, containing keynotes and families as well as suppliers' information. Project orientation and the specified green building rating system for sustainability analysis are identified as inputs. The criteria section includes the green building rating system as well as the environmental performance and principles to select green materials. The main output will be a sustainable design in 3D mode of the proposed building that includes lists of the selected sustainable materials and their environmental impacts as well as the results of the energy simulation and daylight data analysis. The innovation highlighted in this paper describes the model's different modules, which are integrated with each other through an automated process that uses newly created plug-ins as well as the existing ones after improving their functionality in an attempt to assist users start the design of a proposed sustainable building at the conceptual stage of its life.

This platform provides a suitable environment to establish a Decision Support System (DSS) to help the design team decide on the selection of the best type of sustainable building components and families for proposed projects based on defined criteria (i.e. Energy consumption, Environmental impacts and Economic properties) in an attempt to identify the influence of the design variations on the sustainable performance of the whole building. The final design will be influenced by the results of the energy and lighting analysis, the LCA and Environmental Impact and embodied energy results, and the sustainability evaluation of every building component based on the LEED rating system, as well as the initial costs of these components. These results represent a reasonable perspective to evaluate how far the design deviates from the standards and from the owners' expectations.

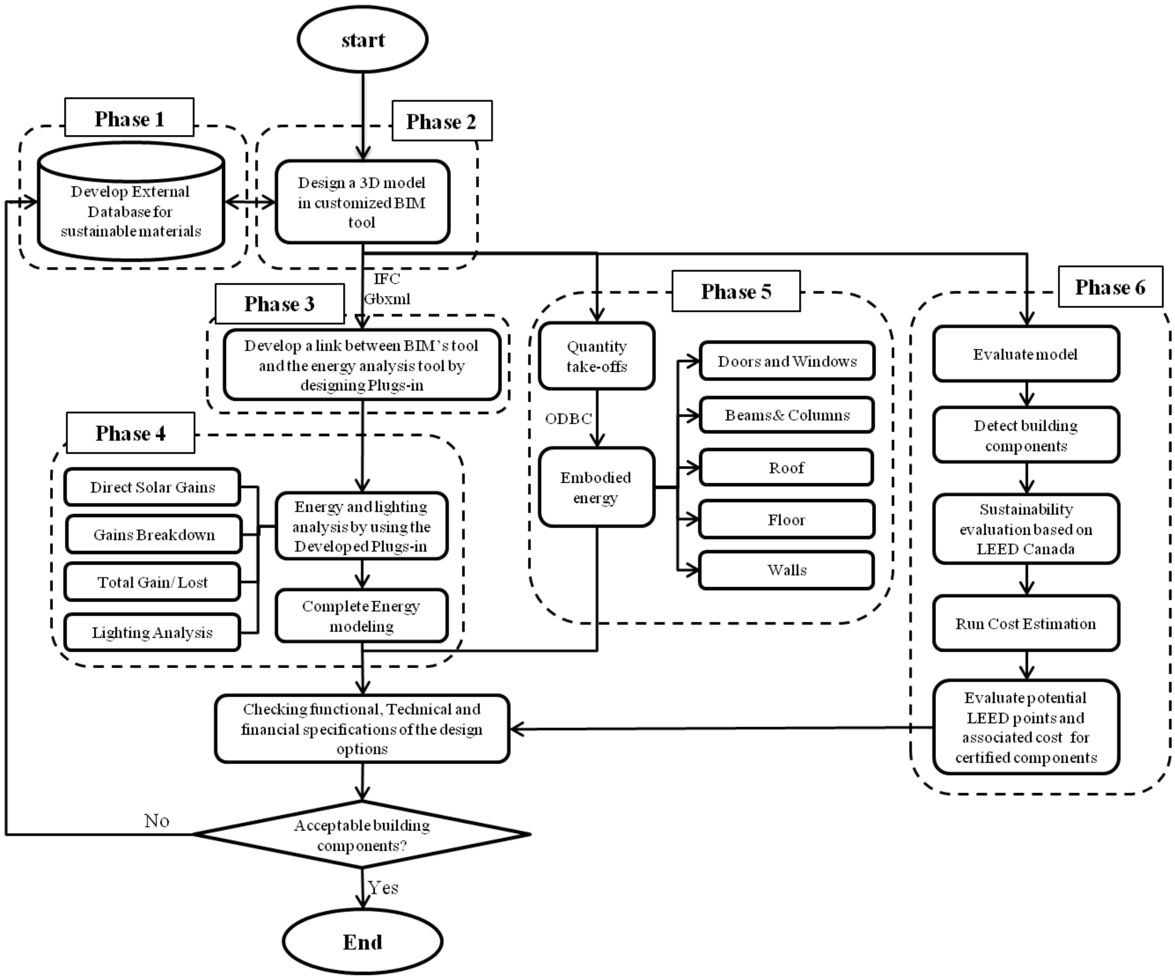

FIG. 2: Flowchart of the integration process

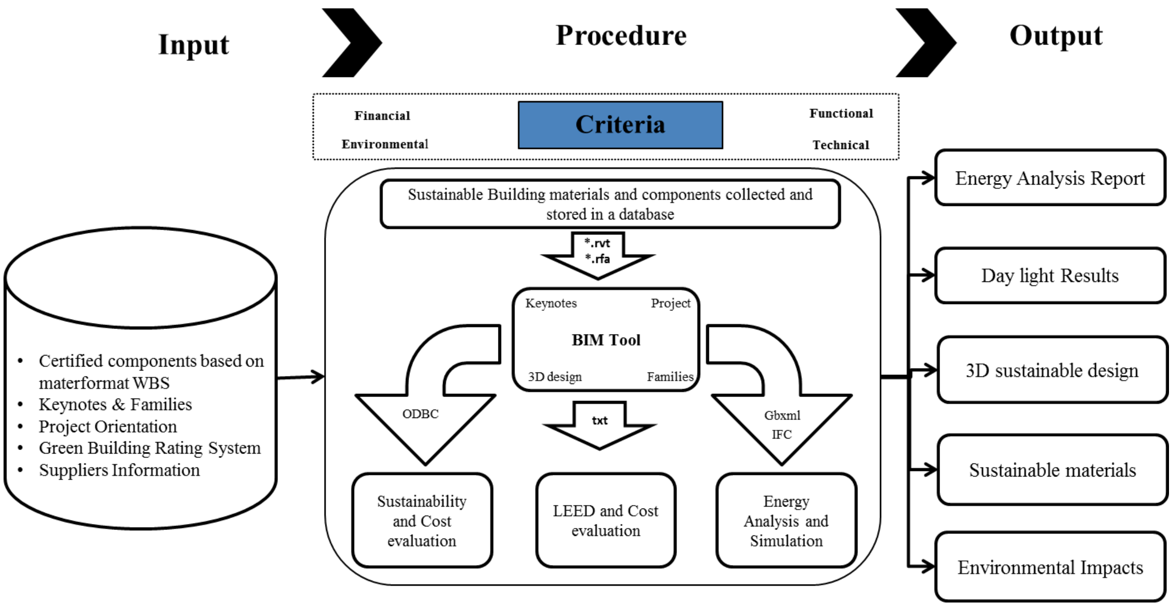

FIG. 3: Model's Architecture

5. TESTING AND VALIDATION

This section tests and validates the capabilities of the developed model. Its performance is examined through the use of an actual eight-floor residential apartment building project that is currently under design in the city of Ottawa. The proposed construction site has a total area of 10,665 ft^2, the building's gross area is 40,810 ft^2 and it has a perimeter of 332 ft. The total number of units in the proposed building is fifteen where the first seven floors have two units each while the eighth one consists of one unit with a gross floor area of 5,130 ft^2. The authors created a conceptual design of the current project where its associated sustainable components and materials were selected from the developed database. The components used in creating the design of the case building had their specifications very close to the ones used in the real design. Every component, such as the floor, walls, roof, and windows has its associated LEED information linked to the families inherited in the BIM tool and are already defined in the database of the sustainability evaluator tool (Ecoscorecard), which includes the manufacturers' web pages and contact information. The developed model will be used to analyse and simulate the energy and lighting of the project's 3D design and to evaluate its sustainability by calculating the accumulated LEED points that can potentially be earned during the conceptual design stage. This process is implemented in four steps, wherein the model's capabilities and performance are measured using the inherited modules.

5.1. 3D Sustainable Design (Step1)

The BIM tool (Autodesk Revit Architecture©) is applied to do the sustainable conceptual design of the case building by using green families and their related keynotes stored in the external database. Once these families' keynote file is linked to the building model, users will select the most appropriate type of certified materials and components for their design. As explained in phase 1, the external database contains detailed information about the suppliers of the green materials used in every family. More than 80% of the components and families used in the case building had their LEED certification points supplied by their manufacturers and stored in the developed external database.

5.2. Energy Analysis and Lighting Simulation (Step2)

In order to have an accurate energy analysis of the case building, its created 3D geometric model must be converted into an analytical model. First, we have to convert all the spaces into rooms. In the BIM tool, rooms are considered to be the equivalent of zones that need to be defined. A thermal zone is a completely enclosed space bounded by its floors, walls and roof and is the basic unit for which the heat loads are calculated. The extent of a "room" is defined by its bounding elements such as walls, floors and roofs. Once a "room" is defined for the purpose of analysing the building's energy, these bounding elements are converted to 2D surfaces representing their actual geometry. However, overhangs and balconies, which do not have a room, are considered as shading surfaces. In order to determine whether a room is an interior or an exterior one it is important to define its adjacent in the analytical model. By using the developed plug-in that is loaded in the BIM tool, designers will directly transfer the created model of the building to the energy simulation and analysis tool (Ecotect©) using both the gbXML and IFC formats as shown in Fig. 4. Moreover, by using the IES-VE plug-ins, which is added to the BIM tool, transferring the BIM model into IES-VE is possible using the gbXML format.

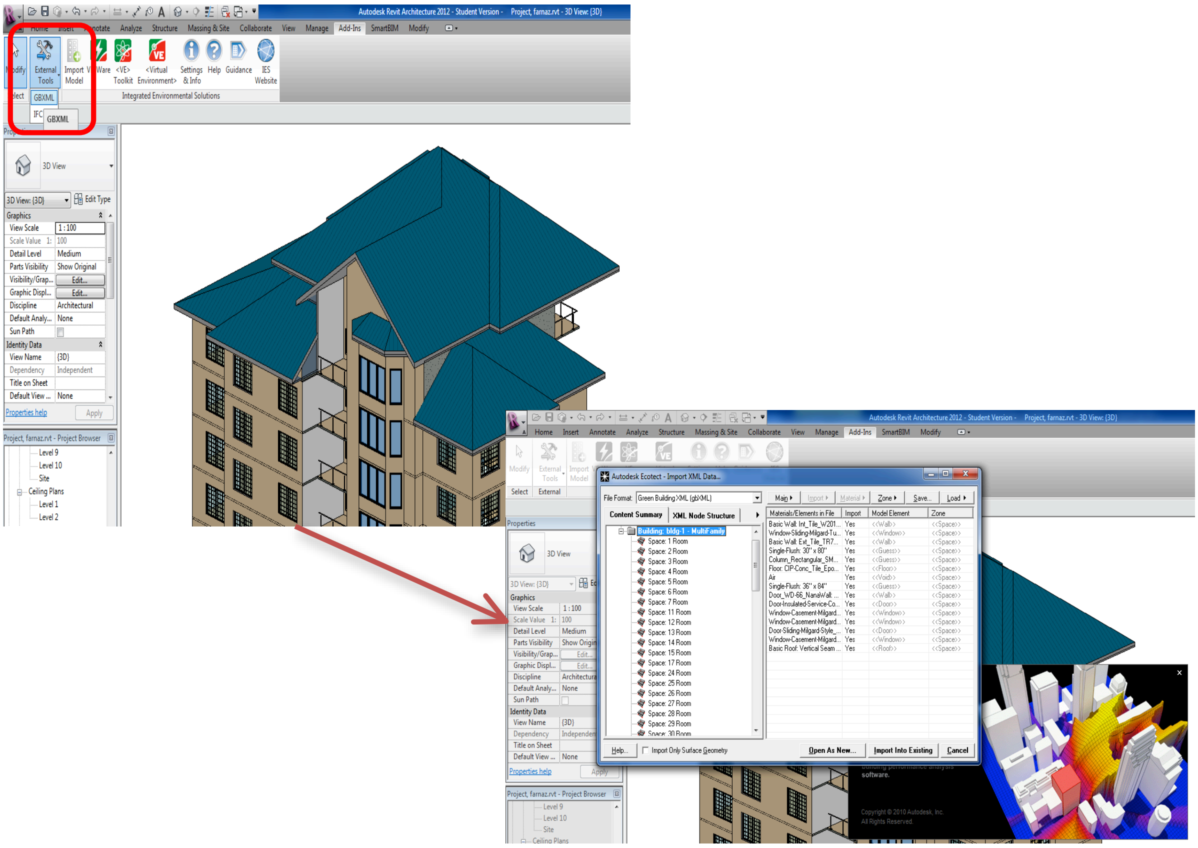

FIG. 4: Snapshot of transferring BIM model directly to Ecotect via the developed Plug-in based on gbXML file format (Same process for IFC format)

In order to test what type of data was included in each of those file formats, a careful comparison will be necessary. The created case building model is tested for building materials, thickness, geometry (area and volume), building services, location, and building type. All the input variables are kept constant in the base case while the testing is done with one alteration at a time.

Fig. 5 shows how wall coordination data is represented in gbXML and IFC by elaborating on the relational and organized data representation in each format. The IFC schema represents the coordinates and dimensions of an IfcWall object. IfcWall is a subtype of IfcBuildingElement. IfcBuildingElement is a subtype of IfcElement, which generalize all the elements that make up a specific component such as walls, windows, or doors.

IfcPlacement has three subtypes: IfcAxis1Placement defines the direction and location in three dimensional space of a single axis. IfcAxis2Placement2D is used to locate and originate an object in two dimensional spaces and to define a placement coordinate system. IfcAxis2Placement3D is used to locate and originate an object in three dimensional spaces and to define a placement coordinate system. A wall gains its geometric position and orientation by virtue of a reference to axis2_placement (IfcAxis2Placement) that in turn references a Cartesian point (IfcCartesianPoint), several directions (IfcDirection) and its starting point (IfcVirtualGridIntersection). IfcCartesianPoint has an attribute called Coordinates, which is a list of 1 to 3 IfcLengthMeasure objects. This is where the coordinates are represented.

In order to compare the IFC approach and the gbXML approach, the same examples are used and evaluated. As mentioned earlier, gbXML is developed based on XML, which captures data information representation but not the relationships among them. Fig. 5 shows a representation of the gbXML geometry information schema. All the geometry information imported from the BIM tool is represented by the “Campus” element. The global child element “Surface” represents all the surfaces in the geometry. There are several attributes defined in a “Surface” such as “id” and “surfaceType.” Every “Surface” element has two representations of geometry, “PlanarGeometry” and “RectangularGeometry.” They both carry the same geometry information. The purpose of this is to double-check whether the translation of geometry from the BIM tool is correct or not. Every “RectangularGeometry” has four “CartesianPoint” elements, which represent a surface. Every “CartesianPoint” is represented by a three dimensional coordinate (x,y,z).

There are only five levels to transverse and to get all the coordinates of an “Exterior Wall” location. It is also easy to add other surfaces according to the schema defined in Fig. 5. In addition, every polyloop, which contains a list of coordinates that makes up a polygon in three-dimensional space, follows a right-hand rule defining the outward normal of a surface.

IFC adopts a comprehensive and generic approach to represent an entire building project. IFC representation was also extended in the building commission domain and implemented in several case studies (Akin, 2004).

However, as it is shown in Fig. 5, gbXML has the ability to carry building environmental sensing information. In terms of geometry, the generic approach of IFC has the ability to represent any shape of the building geometry, while gbXML only accepts a rectangular shape, which is an inherent limitation of the BIM tool in exporting and the energy simulation tool in importing the design information. Furthermore, IFC uses a “top-down” and relational approach, which yields a relative complex data representation schema and a large data file size while gbXML adopts a “bottom-up” approach, which is flexible, open source, and a relatively straightforward data schema. The “top-down” approach can trace back all the semantic changes when one value of the element in the schema changes. However, it is very complex to be programmed and to be implemented in a software application. The “bottom-up” approach has fewer layers of complexity.

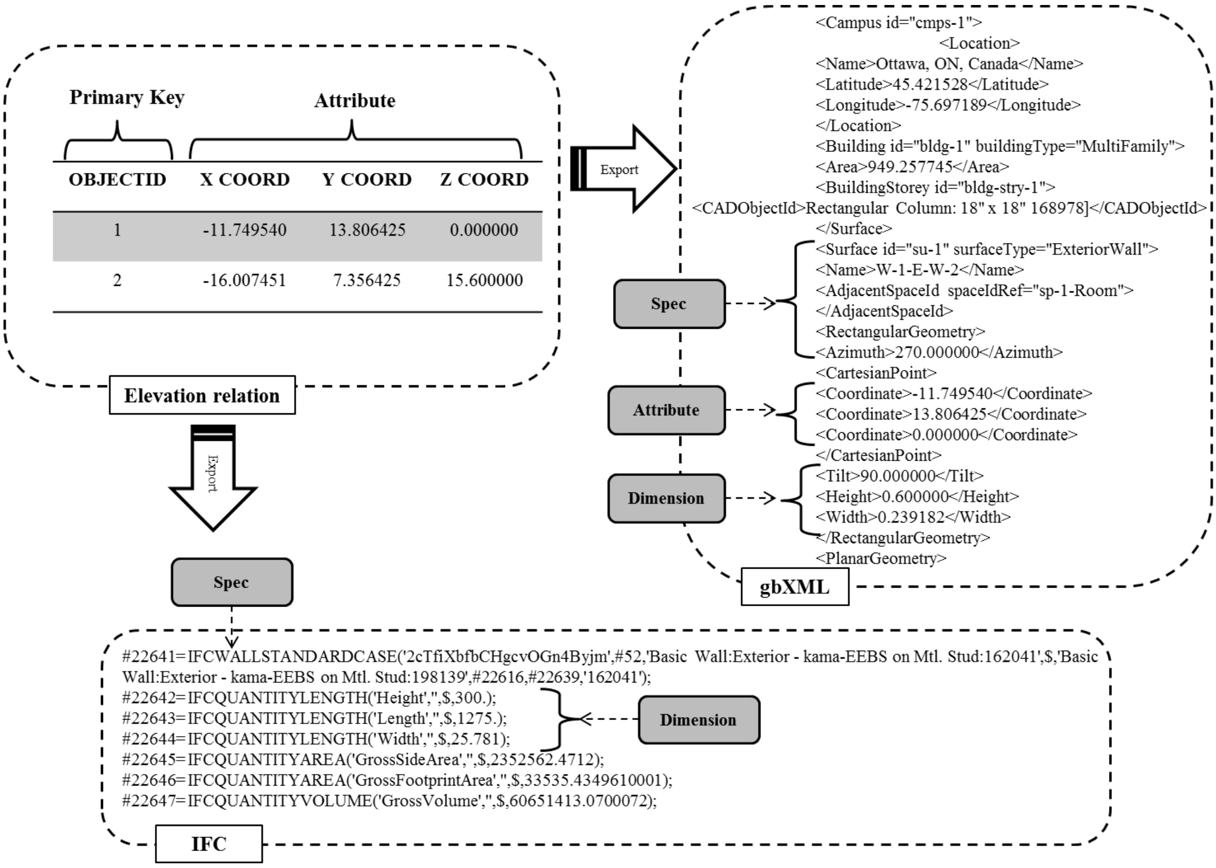

FIG. 5: Example of wall information exchanged through gbXML and IFC file formats

Table 1 shows the result of comparing the information transferred via gbXML and IFC files from the BIM tool. The table also shows that the IFC file contains geometric information such as shapes, areas and volumes but is not populated with other critical information such as location, construction assignments and units. Since the IFC file does not contain all the necessary information, assumptions for lighting, equipment and people loads as well as its air flow data is going to be inferred differently from the data translated into other file formats. However, this is not a limitation of IFC, but is related to the way the design of the case project is modeled in the BIM tool and to what extent that tool supports the IFC standard. The gbXML file, similar to the IFC, contains geometric information such as shape, areas and volumes. However, it is further populated with information about location, and construction assignments. Referring to Table 2, it can be seen that the gbXML file is also able to transfer other information such as building type (residential building) and building services (VAV single duct). Thus, in order to validate the information that is not transmitted, the gbXML file is modified so that it can recognise the information related to the location, building services and construction assignments while executing the transferring process.

The authors realized that missing a single piece of information during the transfer process would have a big influence on the end results. For instance, in this specific case example, the IFC file does not contain the information related to the project location as defined in the created model; hence, when imported into the energy simulation tool (Ecotect), the model would assume the default values for the location given when creating the digital model in Revit. In order to discern that the information related to the selected material used in the model has been completely transmitted over to the energy simulation and analysis tools, a new material is assigned to the 3D model of the case building. The wall's material is changed to a timber frame wall that consists of brickwork (outer leaf), cavity, plywood (lightweight), mineral fiber slab, and cavity and gypsum plasterboard. However, the option selected in the IES interface for the construction assignments (exterior wall) is kept unchanged.

A quick scan of the IES results shows that the data is kept unaltered. This means that the newly assigned material in the model does not have any type of effect on the results. Table 1 also shows that even though a component such as a wall is modeled in the BIM tool with its associated materials, the information transferred to IES is kept unchanged. To clarify this result, in another case, the timber frame wall was modeled as the wall material, and the same option was selected in the IES interface, which is a timber frame wall. The difference in the results indicates that the selection in the Revit-IES interface overrides any selection made when modeling the building in Revit. This is important because it indicates a gap in transferring the information of the building model in Revit and analytical model in IES-VE.

Looking at Table 1 it can be concluded that, for that specific case project, the mapping to the gbXML file format is much more complete than IFC because it transfers the building type and location and provides much more detail in the "results" section of Ecotect. Fig. 6 shows sample results of the day lighting analysis of the created case project that are generated out of both the Ecotect and IES-VE tools and Fig. 7 shows sample of the thermal analysis results generated by these tools. In Fig. 6, day lighting simulation provides a visualization measurement based on gbxml and IFC file formats of the day light that is gained by every single surface inside the building model as well as the building's exterior wall surfaces, which is supplied as a percentage of the solar light each surface can get. For instance, for the fourth floor, the maximum percentage of solar gains for corner areas is around 45% while the minimum percentage is 4.8%, which corresponds to the central areas located far from the openings. IES-VE provides a solar analysis with 3D visualization showing the amount of light, which in this case varies between 59.45 kwh/m² and 1,325.41 kwh/m² for the whole building.

In Fig. 7, a diagram of total gains is based on the outside temperature ranging from -26 ˚C to 32.5 ˚C for the City of Ottawa for all visible thermal zones. The maximum heat loss for the temperature of -26 ˚C is -166 wh/m² and the maximum gain is 108 wh/m² for 31 ˚C. The part of the diagram with condensed points is for the temperature between 0 ˚C to 20 ˚C, which gives an average of -45 wh/m² loss of energy and 10 wh/m² energy gains respectively. Gains breakdown results show the percentage of the overall gains/losses for all visible thermal zones through different colors for Conduction, Solar-Air, Direct Solar, Ventilation, Internal and Inter-zonal for a whole year from January 1st through December 31st. As illustrated, conduction has a maximum overall loss with 64% (around 900 wh/m²) and direct solar has tremendous gains with 70.2% of energy gains (around 500 wh/m²). IES-VE also gives a total annual energy analysis manifesting the total system energy based on power (kw) for the whole year. It also shows that the maximum energy consumption of the building is between November and April with an average of 450 (kw) for the whole system.

TABLE. 1: Comparing the information transferred from BIM model and imported as gbXML and IFC formats into different energy analysis tools

	BIM Model	GbXML file imported into Energy Simulation Tool (Ecotect)	GbXML file imported into Energy Simulation Tool (IES-VE)	IFC file imported into Energy Simulation Tool (Ecotect)
Units	Feet and inches	Metres	Metres	Meters
Area	5,130 ft^2	5,130 ft^2	5,130 ft^2	476.59 m^2 (equals 5,130 ft^2)
Volume	359,100 ft^3	359,100 ft^3	359,100 ft^3	10,169 m^3(equals 359,115 ft^3)
Building Components	Basic Wall: Int_Tile_W201E_PermaColorTM_Laticrete	Basic Wall: Int_Tile_W201E_PermaColorTM_Laticrete	4” facebrick with 4” light weight concrete block	-
	Floor: CIP-Conc_Tile_Epoxy_F133A_LATAPOXY-2000_Laticrete	Floor: CIP-Conc_Tile_Epoxy_F133A_LATAPOXY-2000_Laticrete	8” light weight concrete floor deck	-
	Basic Roof: Vertical Seam 12" OC - Solid Substrate	Basic Roof: Vertical Seam 12" OC - Solid Substrate	Sloping roof including loft (2002 UK reg.)	-
	Window-Sliding-Milgard-Tuscany_Series-Horizontal	Window-Sliding-Milgard-Tuscany_Series-Horizontal	Large Double Glazed windows(Reflective Coating	-
	Door-Sliding-Milgard-Style_Line-Patio: 60x80	Door-Sliding-Milgard-Style_Line-Patio: 60x80		-
Building Services	VAV Single duct	VAV Single duct	VAV Single duct	VAV Single duct
Building Type	Residential	Residential	Residential	Residential
Place and Location	Ottawa, ON	Ottawa, ON	Ottawa Macdonald-Cartier Int'	Boston, MA

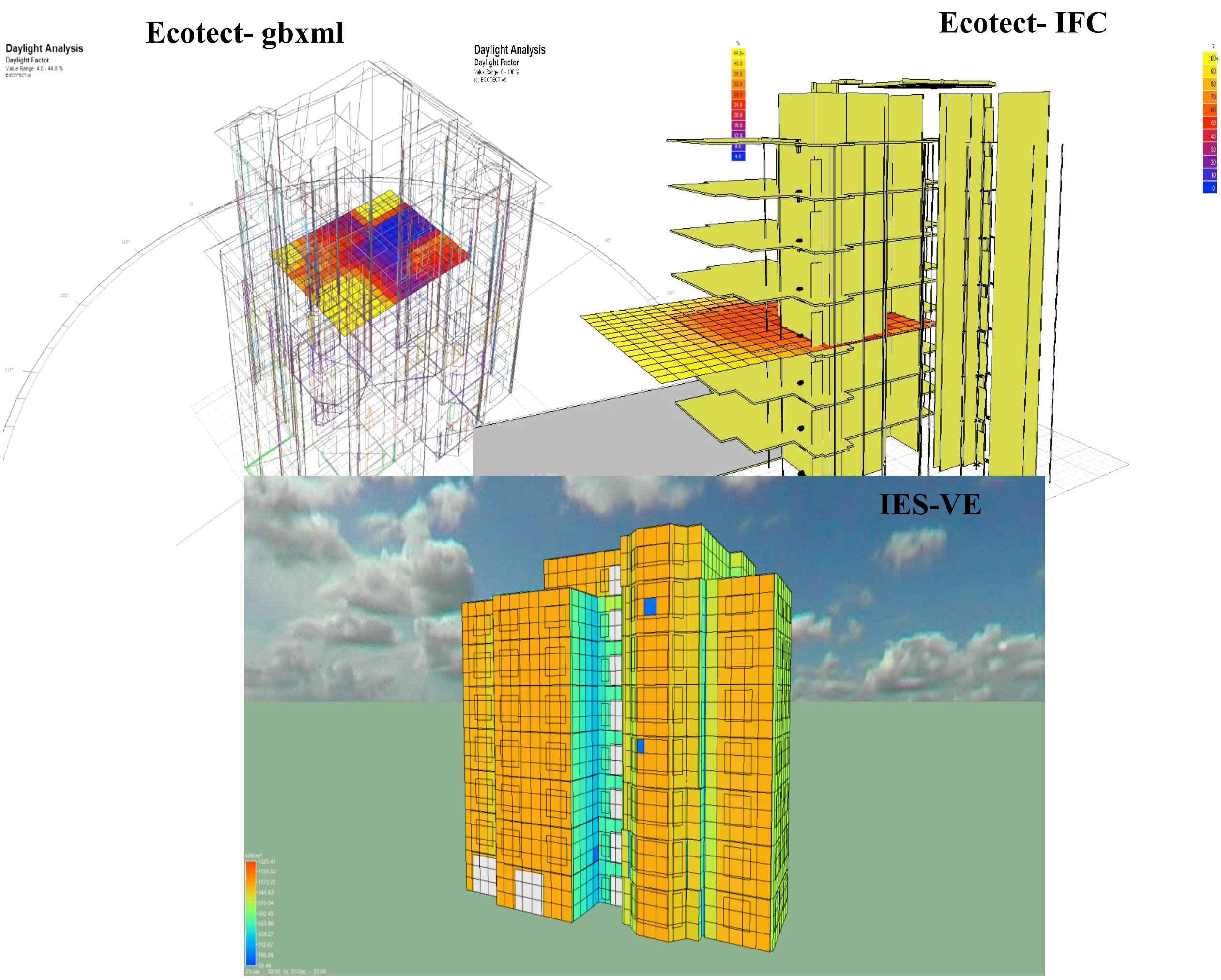

FIG. 6: Snapshot of the sample day lighting simulation in Ecotect and IES-VE

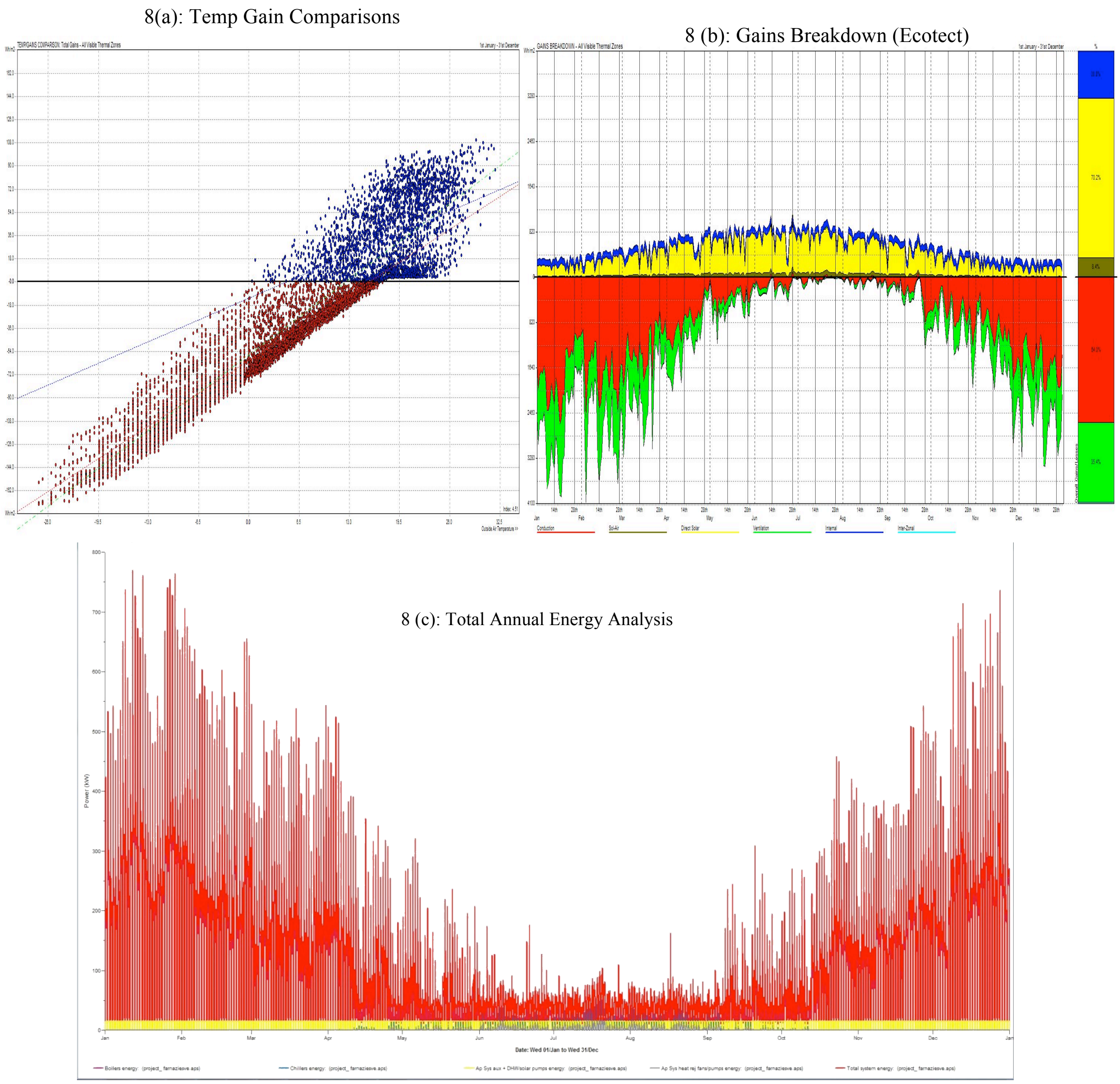

FIG. 7: Snapshot of the sample thermal energy analysis in Ecotect and IES-VE

5.3. Embodied Energy Analysis of the Building Components (Step 3)

Once the conceptual design is finished and the energy is analyzed, the building is assessed and analyzed based on the sustainability requirements using the LCA module and its associated tool (ATHENA® Impact Estimator©). Using the Impact Estimator (IE), users can calculate the primary operating energy including the embodied energy (the energy used to extract, refine and deliver energy) and the related emissions to air, water and land over the life cycle of the case building. Furthermore, users can compare the life cycle of the operating and embodied energy and other environmental effects of the design created for the case building and they will better understand the inherent trade-offs associated with the increase of the envelope materials (e.g., insulation), which can reduce the operating energy consumption.

Transportation embodied energy is dependent on the type and number of trucks, the travel distance between suppliers and construction site, and material properties (i.e. size and weight). In order to demonstrate the model's capabilities, four different types of trucks (as listed in Table. 2) are taken into account when identifying the required number of trucks. In this study, a gross vehicle weight (GVW) is considered as the maximum weight value of a vehicle that includes weight of a vehicle and cargo and a payload is defined as the total weight of all cargo that a vehicle carries. Also, the size of the load in the truck bucket is limited to 53×13.5×8.5 ft (L×H×W) (Irizarry et al, 2013). Using the properties identified above and quantity of material for a given order, the required number of trucks can be determined as it is shown in the algorithm flowchart represented in Fig. 8. The proposed algorithm selects a combination of trucks based on the minimum value of fuel consumption. Then, the fuel consumption value is calculated according to the distance traveled per unit of fuel used in miles per gallon (MPG). The distance measurement can be done by using the geospatial method used by the BIM tool that specifies the geographic location for the project. It uses an Internet mapping service to visualize the project location by searching its street address, or the longitude and latitude of the project.

TABLE. 2: Descriptive attributes for each type of trucks selected for the case building

Truck Type	GVW (lb)	Payload (lb)	Fuel Consumption (MPG)	MPG for empty truck
1	36,300	25,300	-0.0246W+6.63	6.62
2	60,600	40,800	-0.0258W+6.285	6.26
3	80,000	55,750	-0.0255W+6.205	6.18
4	92,000	66,200	-0.0263W+5.885	5.86

W=Total Weight of Load (1000xlb).

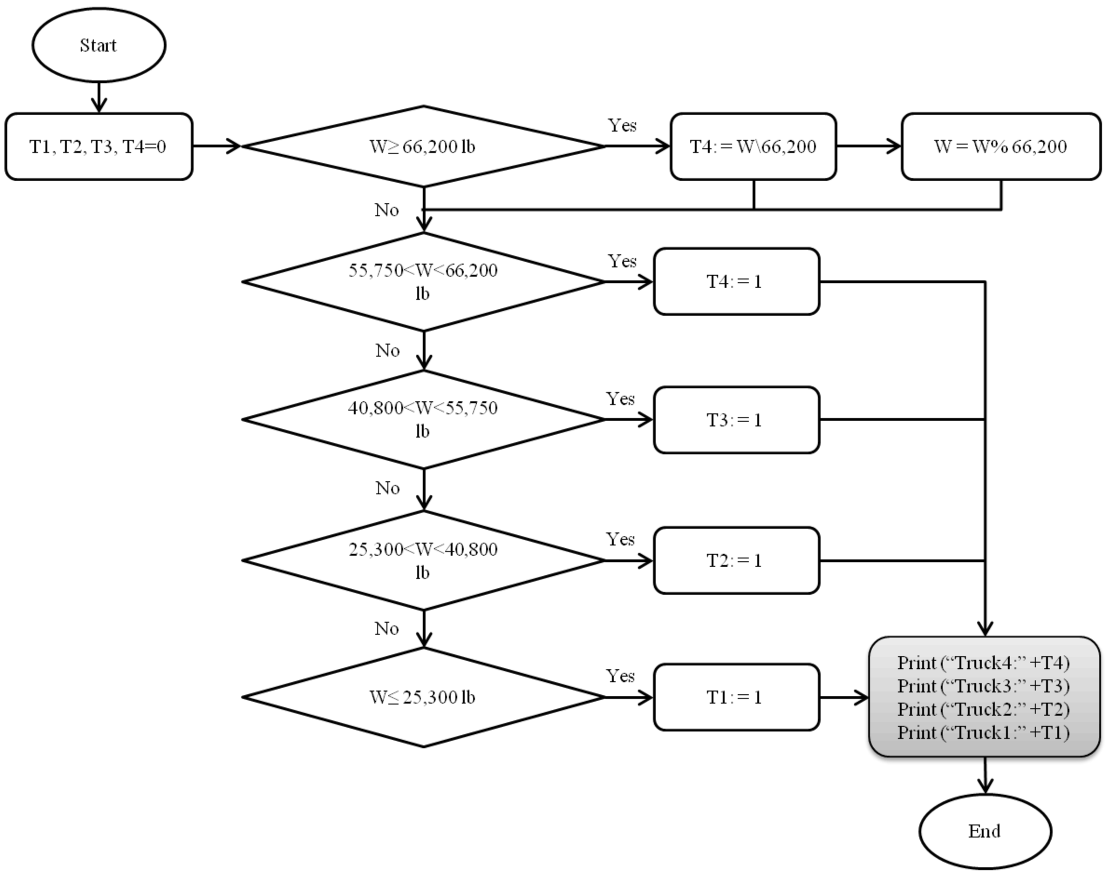

FIG. 8: Algorithm’s flowchart to select the number of trucks based on the weight of building materials and components

First, we input the necessary information such as geographic location, building life and occupancy/type and, if desired, annual operating energy values into the ATHENA IE. Second, the exported bill of quantities extracted in Step 1 is imported as a text exchange file format 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. The embodied energy of every building component is calculated and its result is generated and supplied as shown in Fig. 9. IE takes into account the energy used to construct the structural elements of the building, the emissions to air, water and land associated with the on-site construction activity as well as the energy used to transport the materials and components from the manufacturer to a national distribution centre and from that centre to the building construction site. As illustrated in Fig. 9, in the case building, it is obvious that the wall materials have the highest embodied energy consumption with a total of 15,456,764 MJ based on different types of energy description. Beams and columns have the second highest embodied energy consumption (8,355,880 MJ), especially in the case of natural gas. Furthermore, 22,112,368.4 MJ of the energy consumed in this building is operating fossil fuel energy while 23,736,933.5 MJ is embodied fossil fuel energy.

To calculate the transport energy, the algorithm receives the weight of every building component (lb) and implements the truck selection procedure. Then, the distance calculator which is integrated into Revit uses the API of Google Maps to calculate the distance between the location (origin) of the materials' suppliers and the location of the project site (destination) once the required postal codes are entered by the user. When all the required data (i.e. weight of the material, postal codes of origin and destination) is entered, the algorithm calculates the transportation energy of every building component (MJ) as well as the number of trucks and their types. For example, by considering the walls' materials in the case building and by assuming a unit weight of 55 lb./SF and a calculated total surface area of 16,250 SF for all the walls, the total weight of the wall material will be around 893,750 lb. Using the developed algorithm shows that a combination of one truck of type 2 and thirteen trucks of type 4 is a proper option for transporting the materials. While the fuel consumption for truck 4 and truck 2 are 4.14 MPG and 5.43 MPG respectively, entering the postal code of the origin and destination would lead to an approximate measurement of the distance to be 422 miles, thus the consumed embodied energy for transporting the wall's material is calculated to be around 1,402.83 G (184,836.88 MJ). The same processes are applied for the rest of the building components and accordingly the total transportation energy for that case building would be calculated to be around 15,641,600.88 MJ.

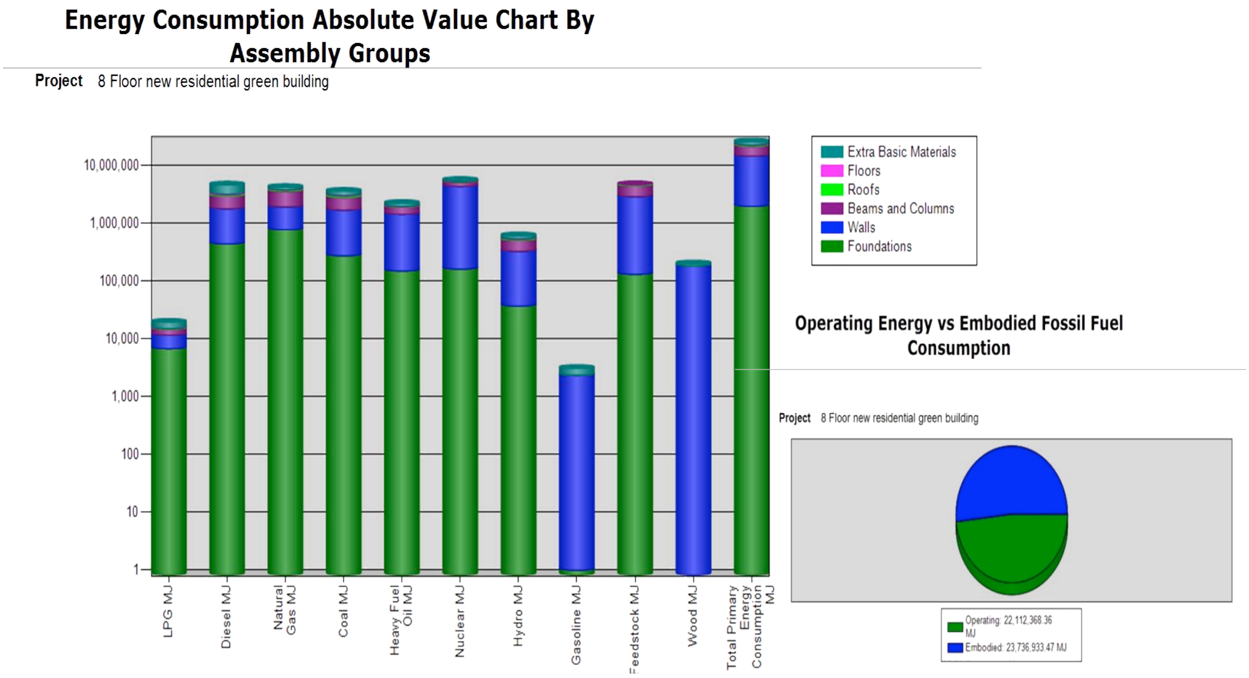

FIG. 9: Embodied Energy analysis of each building component in the designed model

5.4. Environmental Evaluation and Calculation of the Potential LEED Points (Step 4)

By running the sustainability evaluator plug-in (EcoScorecard) loaded into BIM tool, one can evaluate the created case building model based on different green building rating systems as previously described. The result of the EcoScorecard is shown in Fig. 10, where 54.2% of the cases building model's components are compiled from sustainable materials and families that are already defined in the Smart BIM database and detected by the EcoScorecard. By selecting the desired green building rating system and clicking the "evaluate" button, we are able to see the analysis results in detail and save them as a PDF file. LEED® Canada New Construction v1.0 is used to evaluate the designed model for the case building. Thereafter, users are able to identify the potential points earned by the design based on the information provided by the EcoScorecard.

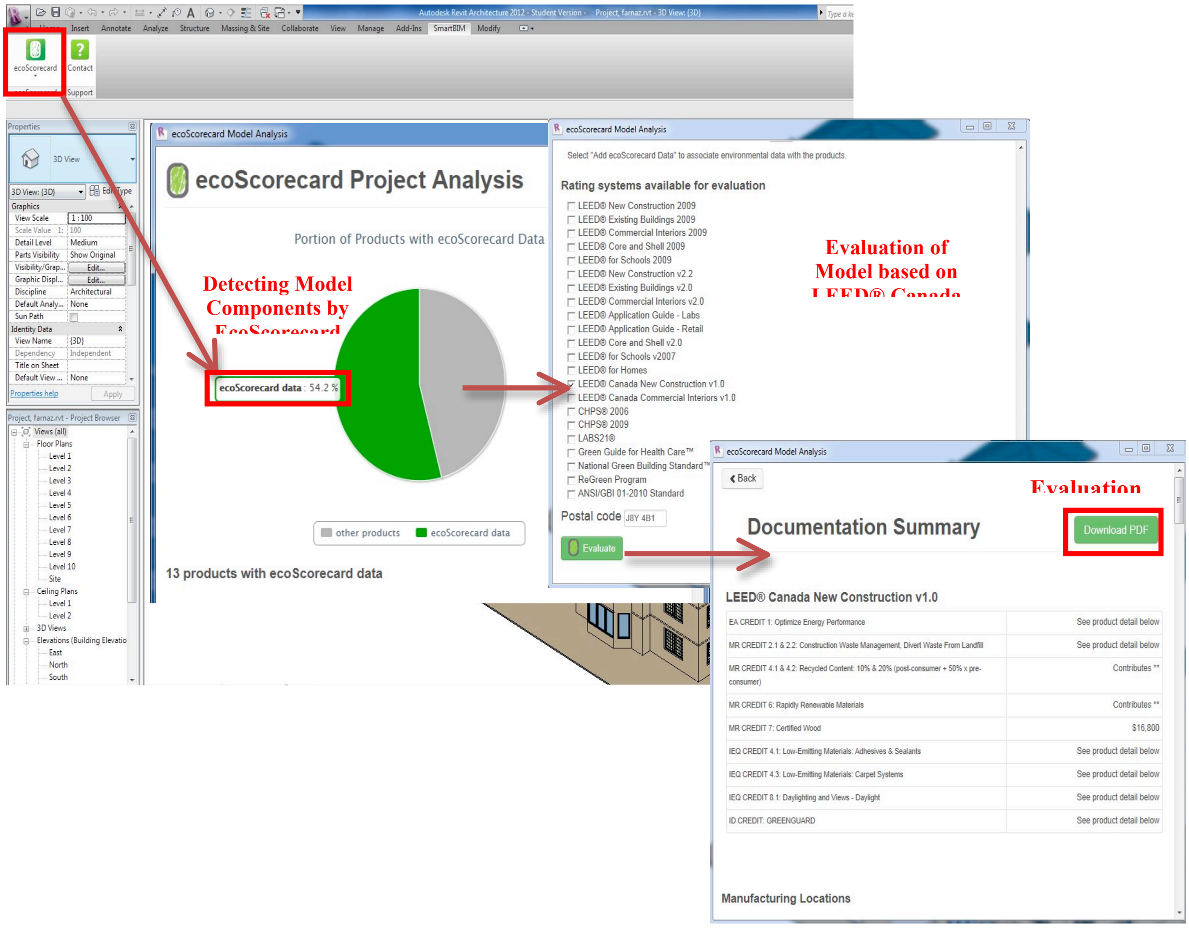

FIG. 10: Snapshot of using Ecoscorecard plug-in in Autodesk Revit to detect and evaluate model components based on LEED (CaGBC)

Table 3 shows information related to the materials and their associated potential LEED points as well as the actual points earned by the design of the case building done in Step 1 based on the results of the EcoScorecard LEED evaluation. As shown in Table 3, the detected components used in the design gets a total of 41 LEED points based on the CaGBC rating system. This is an approximated number of the LEED points that are earned by the designed case building since the focus of this study is at the conceptual design stage, which means the calculated points do not necessarily reflect the final number that can be earned when the building design is completed. The intent is to simply generate an idea about how many potential LEED points the proposed building might earn if a decision is made to continue the project.

TABLE. 3: 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	
LEED Credit	**Credit Description**	**LEED Points**	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	3,5										
SSc3	Brownfield Redevelopment	1										
SSc4.1	Public Transportation Access	3,6										
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										
SSc6.1	Storm water Design: Quantity Control	1										
SSc6.2	Storm water Design: Quality Control	1										
SSc7.1	Heat Island Effect: Non-Roof	1										
SSc7.2	Heat Island Effect: Roof	1										
SSc8	Light Pollution Reduction	1										
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							*	1point		
EAp3	Fundamental Refrigerant Management	Required										
EAc1	Optimize Energy Performance	1-19										
EAc2	On-Site Renewable Energy	1-7	*	6 points			*	8 pts			*	10 pts
EAc3	Enhanced Commissioning	2										
EAc4	Enhanced Refrigerant Management	2										
EAc5	Measurement and Verification	3										
EAc6	Green Power	2										
Materials & Resources												
MRp1	Storage and Collection of Recyclables	Required										
MRc1.1	Building Reuse: Maintain Existing Walls, Floors, and Roof	1-3										
MRc1.2	Building Reuse: Maintain Interior Non-Structural Elements	1										
MRc2	Construction Waste Management	1-2										
MRc3	Materials Reuse	1-2	*	1 point	*	1point	*	1point	*	1point		
MRc4	Recycled Content	1-2	*	1 point								
MRc5	Regional Materials	1-2	*	1 point	*	1point	*	1point	*	1point	*	1point
MRc6	Rapidly Renewable Materials	1										
MRc7	Certified Wood	1							*	1point		
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										
EQc3.1	Construction IAQ Management Plan: During Construction	1										
EQc3.2	Construction IAQ Management Plan: Before Occupancy	1										
EQc4.1	Low-Emitting Materials: Adhesives and Sealants	1					*	1point				
EQc4.2	Low-Emitting Materials: Paints and Coatings	1										
EQc4.3	Low-Emitting Materials: Flooring Systems	1			*	1point						
EQc4.4	Low-Emitting Materials: Composite Wood and Agrifiber products	1										
EQc5	Indoor Chemical and Pollutant Source Control	1										
EQc6.1	Controllability of System: Lighting	1										
EQc6.2	Controllability of System: Thermal Comfort	1										
EQc7.1	Thermal Comfort: Design	1										
EQc7.2	Thermal Comfort: Verification	1										
EQc8.1	Daylight and Views: Daylight	1	*	1 point			*	1point	*	1point		
EQc8.2	Daylight and Views: Views	1										
Innovation & Design Process												
IDc1	Innovation in Design	1-5										
IDc2	Accredited Professional	1										
Regional Priority												
RPc1	Durable Building	1										
RPc2	Regional Priority Credit	1-3										

Subtotal	10 points	3 points	12 points	5 points	11 points
Total	**41 Points**				
PEP: Potentially Earned Points			**EPM:** Earned points by the Model		

Table 4 includes selected components used in the BIM model based on the functional, technical and financial specifications of the sustainable families collected from the manufacturers' web pages. 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 one shown in Table 4 is 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. Furthermore, it shows the most applicable criteria for the elements that have environmental friendly options. The information provided shows that the selected materials used in creating the sustainable families meet the elaborated functional, technical and financial specifications and take into consideration the environmentally friendly aspects.

Since not all suppliers provide the cost of products on their website, authors used RS-Means cost data to prepare preliminary cost estimate for the case building as shown in Table 6. In this table, the total estimated cost of each building component is calculated using the R.S. Means Green Building Cost database. In this database the unit cost of each family is calculated based on the year 2013 national average value and adjusted for the city of Ottawa. To prepare the cost estimate, materials with specifications similar to the quantity take off extracted from the developed 3D design are selected from the R.S. Means database. However, as illustrated in Table 5, the preliminary cost estimate of the building components using the proposed method is calculated to be \$1,621,834.79 while the actual estimated cost was calculated to be \$1,889,186.39 for the year 2013 which reflects a 17% difference in the values, which is acceptable for the conceptual stage where little information about the project is known.

6. CONCLUSIONS

The intent of this research at the conceptual stage is to help decision makers generate a better idea about the project while making important decisions related to the continuation or dismissal of that project. Though the level of accuracy of the available information at that stage is low, nevertheless decisions have to be made. Thus, any additional information would be an asset and helpful to support the decision. The novelty highlighted in this paper describes the model's different modules, which are integrated into each other based on an automated process by creating new plug-ins and improving the functionality of the existing ones so that users will be able to start the sustainable design of a proposed building project at the conceptual stage of its life in a timely and cost-effective way. Using a BIM integrated platform moves the design decisions forward at the early stage especially when comparing different design alternatives, which is considered to be an attribute of this research.

The developed model enables users to compare and select different materials and components, which are stored in the external database, to be used in their design based on energy and sustainability specifications and costs. This accelerates the process of modifying building components early in the conceptual design stage in the case that the selected ones do not meet owners or designers requirements. The BIM model created is successfully imported into ECOTECT with gbXML and IFC file formats by using the developed plug-in in Revit. The mapping to gbXML is shown to contain more of the data needed for energy analysis and in this project is the preferred format to use during the conceptual design stage. Furthermore, the developed database was designed based on collected information that contained a limited number of certified components, all of which are designed and provided by the manufacturing companies. This is a limitation for the model because it does not cover all the existing green elements and, as was previously mentioned, only 54.2% of those materials and components were detected and defined in the Ecoscorecard database. This means that there are several green families that need to be designed, converted to BIM file format and added to the database. Missing information during the transformation process from the BIM tool to the other tools (i.e., energy analysis and simulation) includes the information required as input by different software. Some information needs to be entered manually by the user after the transfer process, while other types of information are automatically assumed by the software itself (i.e. information about the type of materials when transferring from Revit to Ecotect or IES-VE).

TABLE. 4: Functional, technical and financial specification of sustainable materials used in the 3D BIM Model

Green Families used in the BIM sustainable model	Windows	Roof/ Ceiling	Floor	Wall	Door
Functional Criteria	-Recyclable packaging materials, -SmartTouch® Hardware PureView® Window Screen -3D®/3D MAX® Energy Packages -EdgeGar/ EdgeGard MAX™ Window Spacers -SunCoat®/SunCoat MAX® Low-E Insulating Glass -Quiet Line™ Sound Countrol Windows -Positive Action Lock	-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	-Products manufactured regionally within a 500 mile radius of the Project -Adhesive products must meet or exceed the VOC limits of South Coast Air Quality Management District (SCAQMD) Rule #1168 and Bay Area Air Quality Management District (BAAQMD) Reg. 8, Rule 51. - 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	-Products manufactured regionally within a 500 mile radius of the Project -Adhesive products must meet or exceed the VOC limits of South Coast Air Quality Management District (SCAQMD) Rule #1168 and Bay Area Air Quality Management District (BAAQMD) Reg. 8, Rule 51. - 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,	-Deliver superior energy efficiency -Help protect furniture from damaging ultraviolet (UV) rays with SunCoat® or SunCoatMAX® -Durable vinyl frames won't absorb moisture and will never need painting -State-of-the-art door rollers allow for effortless operation and adjustment of door panels -Award-winning SmartTouch® Handle - SunCoat® Low-E glass standard - EdgeGard™ spacer standard - Constructed of Recycled-content materials and contain insulating core material that does not contribute to ozone depletion.
Technical Specifications	-Exposure Category: 2000 (pa) - Air Permeability: Not more than 16m^3/h/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.	- Finishes: PVDF (Kynar 500), MS Colorfast45®, and Acrylic Coated Galvalume® - Gauges: 24 ga standard, 26 ga and 22 ga optional - 12", 16", or 18" panel coverage, 13/4" rib height -Concealed clip (0.050" thick) designed to accommodate thermal movement -Architectural/structural integral standing seam panel -Applies over open framing or solid substrate - Factory applied side lap sealant -Snap together panel system - Minimum roof slope is 1:12 for solid substrates and 3:12 for open framing. - Reuse or salvage of ballast, Energy Guard™ roof insulation, and membrane - Material diverted from the waste stream during the manufacturing process, - Low-E glass for energy efficient performance	- Moisture Sensitive Tile or Stone-Epoxy Thin Bed with LATICRETE SpectraLOCK PRO Premium Grout -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. - Concrete or Masonry Wall (Exterior)-Thick Bed Over Metal Lath with LATICRETE PermaColorTM Grout	- Provide aluminum top track, side jambs, and vertical struts: White powder coated or clear anodized or dark bronze anodized or powder coated select from range of RAL powder coated finishes available from manufacturer. -Light to Solar Gain Ratio: 2.0 - Solar Heat gain Coefficient: 0.15 - Visible Transmittance: 0.54 - PEFC™ Certified: 70.0% - ISO 14001 Voluntary Environmental Management Systems - ENERGY STAR® Listed - National Fenestration Rating Council Certified -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.

TABLE. 5: Associated cost of the selected components based on R.S. Means cost data

Description (Green Building)	Unit	Quantity	Total Unit Cost ($)	Total Item Cost ($)	Description (Typical Building)	Total Unit Cost ($)	Total Item actual Cost ($)
Windows							
Windows, wood, sliding, vinyl clad, premium, double insulated glass, 6'-0" x 5'-0", incl. frames, screens & grill	Ea.	100	$1,078.00	$107,800.00	Windows, aluminum, awning, insulated glass, 4'-5" x 5'-3"	$58.64/ SF	336,300.4
Windows, wood, casement, average quality, builder's model, double insulated glass, 2'-4" x 6'-0" high, incl. frame, screens and grilles	Ea.	48	$ 431.65	$20,719.00			
Roof							
Wood shingles, white cedar, 3/4" thick x 16" long, 5" exposure on roof	Sq.	777	$303.79	$236,044.83	Wood shingles, white cedar, 3/4" thick x 16" long, 5" exposure on roof	$386.92	300,636.84
Floor							
Resilient Flooring, cork tile, standard finish, 5/16" thick	S.F.	40,849	$12.43	$507,760.00	Floor, concrete, slab form, open web bar joist @ 2' OC, on W beam and wall, 25'x25' bay, 26" deep, 75 PSF superimposed	$14.91	609,058.59
Doors							
Doors, glass, sliding, vinyl clad, 5'-0" x 6'-8" high, 1" insulated glass	Ea.	8	$1498.88	$11,991.04	Door, aluminum & glass, with transom, narrow stile, double door, hardware, 6'-0" x 10'-0" opening	$7.72/ ft^2	$72,500.00
Doors, glass, sliding, aluminum, premium, 5/8" tempered insul. glass, 6'-0" x 6'-8"	Ea.	15	$1567.58	$23,513.70			
Walls							
Precast wall panel, smooth, gray, un-insulated, high rise, 4' x 8' x 4" thick, 3000 psi	S.F.	16250	$37.62	$611,325.00	Brick walls,13.5 brick per square foot, 8" thick wall, includes mortar, 8% brick waste and 25% mortar waste, vertical reinforcement and grout, excludes scaffolding & horizontal joint reinforcement	$29.97	487,012.5
Railing & Stairs							
Stair, shop fabricated, steel, 3'-6" W, including picket railing, stringers, metal pan treads, excl concrete for pan treads, per riser	Riser	158	$519.83	$82,133.14	Stairs, steel, cement filled metal pan & picket rail, 16 risers, with landing	$5.27/ ft^2	83,678.06
Railing, pipe, steel, primed, 3 rails, 3'-6" high, posts @ 5' O.C., 1-1/4" diameter, shop fabricated	L.F.	453	$45.36	$20,548.08			
Approximated Construction Cost	**$ 1,621,834.79**			**Actual approximated cost**		**$ 1,889,186.39**	

In this research, different energy tools have been used and their results have been compared. While Ecotect gives annual thermal consumption and peak loads for worst-case times, the IES Apache Simulator gives comprehensive information about the total annual energy consumption and room loads. The variation in Ecotect in terms of the heating and cooling loads is due to the calculation method used by this tool. Ecotect uses the worst design annual load case while the ASHRAE load calculator built into IES uses the worst monthly scenario (January) for heating loads and a five-month long (May-September) scenario for cooling loads. The discrepancy in the results between Revit, IES and Ecotect was expected to occur because of the different load calculation techniques, calculation engines, and variation in the materials types and their associated values found in these tools.

In the developed model, multiple design alternatives are compared through the economical aspect. The results generated by the different modules are evaluated based on diverse economical perspectives. Energy analysis results are good feedback to the design team about the potential energy that can be gained or lost within a year by the proposed building. Using these data can ease the way of estimating the energy cost which is a major part of the operation cost for any building. Compared to the traditional way of making building estimates, Life Cycle Cost can take environmental impact and the energy aspect into account, which will have a big effect on future capital variable. Along with the obvious environmental advantages, LEED-certified buildings cost less to operate and are more desirable for commercial and residential occupants. In the integration platform, the process of having this information is done in a timely manner and it is done easily by clicking on the developed plug-ins and using the connected database.

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