Integrating BIM with Green Building Certification System, Energy Analysis and Cost Estimating Tools to Conceptually Design Sustainable Buildings

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ABSTRACT

Owners, architects and engineers are more concerned about the sustainability and energy performance of proposed buildings. Evaluating and analyzing the potential energy consumption of buildings at the conceptual design stage is very helpful for designers when selecting the design alternative that leads to a more energy efficient facility. Building Information Modeling (BIM) assists designers assess different design alternatives at the conceptual stage of a building life so that effective energy strategies are attained within the green building constraints. As well, at that stage, designers can select the right type of building materials that have great impact on the building's life cycle energy consumption and operating costs.

The aim of this paper is to propose an integrated method that links BIM, energy analysis and cost estimating tools with green building certification system. The successful development of the proposed method helps owners and designers evaluate different design alternatives taking into consideration the sustainability constraints in an efficient and timely manner. BIM's tool is customized to allow its integration with the energy analysis application in order to identify the potential gain or loss of energy for the building, to detect and to evaluate its sustainability based on the US and/or Canadian Green Building Council (USGBC and/or CaGBC) rating systems and to approximately estimate the costs of construction early at the conceptual design stage. An actual building project will be used to illustrate the workability and capability of the proposed method.

INRODUCTION

Important decisions related to the design of sustainable buildings are made at the conceptual stage of their lives. This practice does not consider the integration between the design and energy analysis processes during early stages and leads to an inefficient way of backtracking to modify the design in order to achieve a set of performance criteria (Schueter and Thessling, 2008). Energy efficiency is an important feature in naming building materials as being environmentally friendly. The ultimate goal in using energy efficient materials is to reduce the amount of artificially generated power that must be brought to a building site (Jong-Jin Kim, 2010). Building Information Modeling tools help users do complete energy analysis and explore different energy saving alternatives during the design stage. This would help owners and designers make energy related decisions that have high impact on the proposed building life cycle cost. Kriegel and Nies (2008) indicate that BIM can aid in the aspects of sustainable design which include: building orientation, building massing (that is used to analyze building form and optimize the building envelope), day lighting analysis, water harvesting (that is used to reduce water needs in a building), energy modeling (that helps reducing energy needs and analyzing how renewable energy options can contribute to low energy costs), sustainable materials (that helps reducing material needs by using recycled materials) and site and logistics management (to reduce waste and carbon footprints). Despite of the advantages of BIM there is a wide gap in the interoperability between its tools and the energy analysis software although new solutions, such as interoperable file formats, have been developed. File formats, such as the Industry Foundation Classes (IFC) and Extensible Markup Languages (XML), are currently promoted by various groups in the construction industry. Hence, this paper proposes a method to integrate BIM and energy analysis tools to help designers do sustainable design of proposed building projects at the early stage of their life. This assimilation will also help owners and designers analyse the day lighting and measure the thermal of such types of buildings. To make this integration, authors customized BIM's tool so users can transfer their design information directly from the BIM model to energy analysis software in order to analyse and evaluate the potential energy consumption at the conceptual design stage of proposed buildings and accordingly to evaluate the sustainability of the design components based on their environmental characteristics.

LITERATURE REVIEW

For the past 50 years, a variety of building energy simulations and analysis tools (i.e., BLAST, EnergyPlus, eQUEST, TRACE, DOE2, Integrated Environmental Solution (IES-VE) and Ecotect) have been developed, enhanced and applied throughout the building industry (Crawley et al. 2005). Grobler (2005) claims 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) and Lam et al. (2004) show that decisions made early in a building project life have a strong effect on its whole life cycle costs. Therefore, 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 conservation targets. The construction industry started to shift its direction toward the use of BIM due to its benefits on all over the project life, starting by the conceiving passing through the design and construction and ending by the operation stages. Using BIM's tools at the conceptual stage to create 3D design models of proposed building projects is very helpful for designers especially when extracting the design data and transferring it to energy analysis software. In this regards, Jalaei and Jrade (2013) evaluated and compared the capabilities of different file formats in transferring information from BIM's tool into energy analysis and simulation applications. The result of this validation showed that gbXML has a simplified schema for energy analysis and accordingly it is a preferred format that can be used during the early design development or the schematic stage. Green building certification systems are useful guides during the design to record performance progress, to compare buildings and to document the outcomes and/or strategies used in the building (N. Wang et al., 2012). 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).

Integrating all these applications early during the conceptual design stage of proposed sustainable building projects would help the design team to compare and to analyze different energy results (i.e. heat gains/losses, temperature gain comparisons, total annual energy, etc.) for the created BIM model. That team could also evaluate the sustainability of the design based on either the US Green Building Council "USGBC" or the Canadian Green Building Council "CaGBC" certification systems and approximate the construction costs.

METHODOLOGY AND DEVELOPMENT

Since the proposed method integrates the design of sustainable building projects in 3D with energy analysis, certification systems and cost estimating tools, the development will be implemented through the following four phases:

Phase 1 consists of collecting information related to the green materials, such as the materials used in building projects, suppliers' contact data, potential LEED certification points and assembly codes, then store them in a database in the form of predefined 3D design families that can be recognised by BIM's tool. 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 in the database.

Phase 2 focuses on customizing BIM's tool to fit the integration requirements of the proposed method. The first step is to create new unique code for the 3D families that were created in Phase 1. Therefore, an efficient coding system will be the main aspect that represents the relationship between the stored data. Thus, a five-digit code representing the division, subdivision, elements and material names is used in storing the newly created families, which will be linked to the BIM's tool (Autodesk Revit Architecture©). These families consist of different types such as walls, floors, stairs, windows and doors.

Phase 3 concentrates on creating a link between BIM's tool and energy analysis tools. The link will take the form of series of commands that are created in a .NET programming language (C# has been used in this research). The link will extract the data from the designed BIM model in the form of gbXML file format and import it into the energy analysis tool. The energy analysis tool used in this research is Ecotect, which was selected because it can easily create models in a format that includes both the geometry and zones of a building and because it has interoperability potentials with other tools. This interoperability makes Ecotect an ideal tool to import and export 3D models between BIM's tool that generates the geometry of the proposed building and other different advanced energy analysis tools.

Phase 4 includes the design of a green building certification and associated cost module, which is linked with both the BIM and Energy tools. The data retrieved from the BIM model is linked to this module in order to calculate the potential points earned by the selected materials in the 3D design based on various green building rating systems. Authors collected information about sustainable materials and components from the manufacturers and vendors websites and this information is stored in the database linked to the BIM's tool (Phase 1). Therefore, when designers create 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 manually 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 model with the cost module that is linked to a database for green and certified materials. The associated cost of the design in the 3D model is calculated based on R.S. Means published data. Figure 1 shows a flowchart of the integration process for the proposed method.

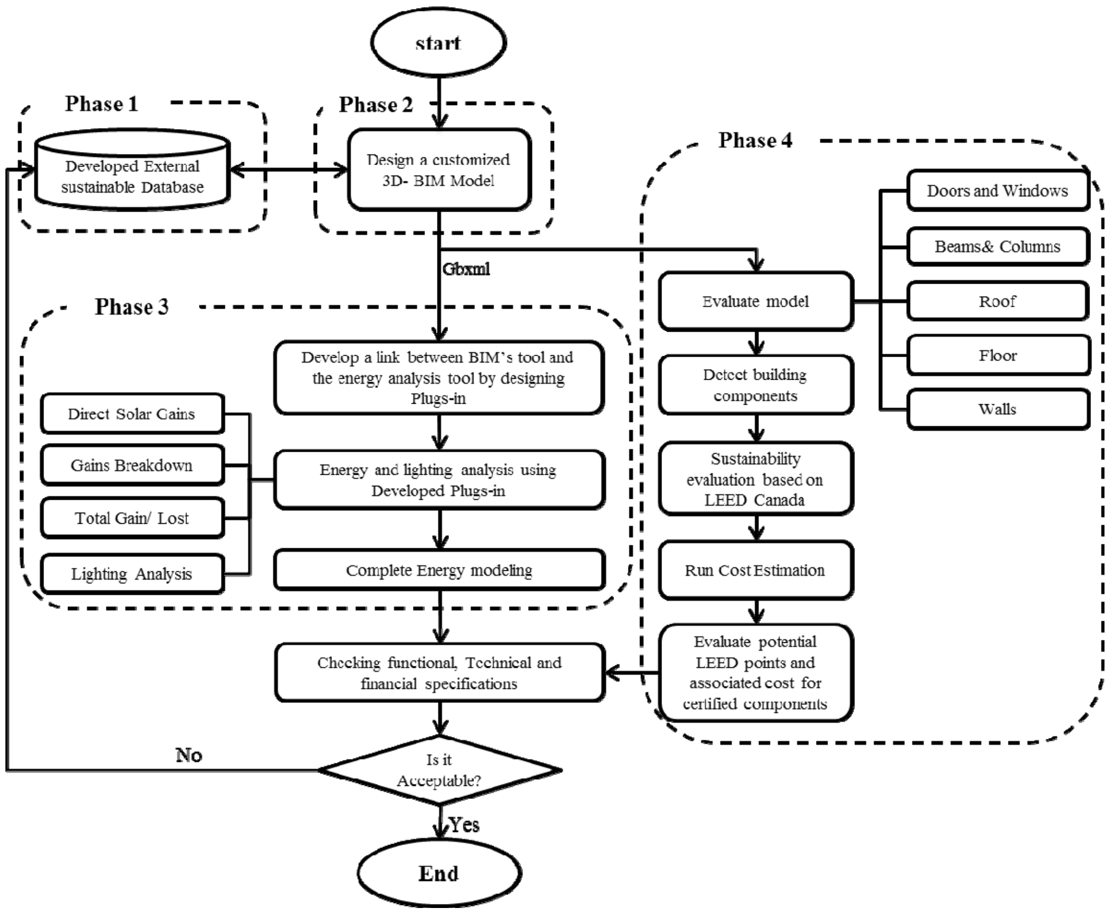

Figure 1. Flowchart of the integration process of the proposed method

Figure 2 illustrates the data flow of the proposed method where the input section includes the project information, sustainable information and Masterformat WBS. 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 3D sustainable design of a proposed building that includes lists of the selected sustainable materials and their environmental impacts as well as the results of the energy and daylight data analysis. The novelty highlighted in this paper describes the model's different modules, which are integrated into each other based on an automated process through creating new plug-ins and improving the functionality of existing plug-ins so that users will be able to start the sustainable design of a proposed building project at the conceptual stage of its life.

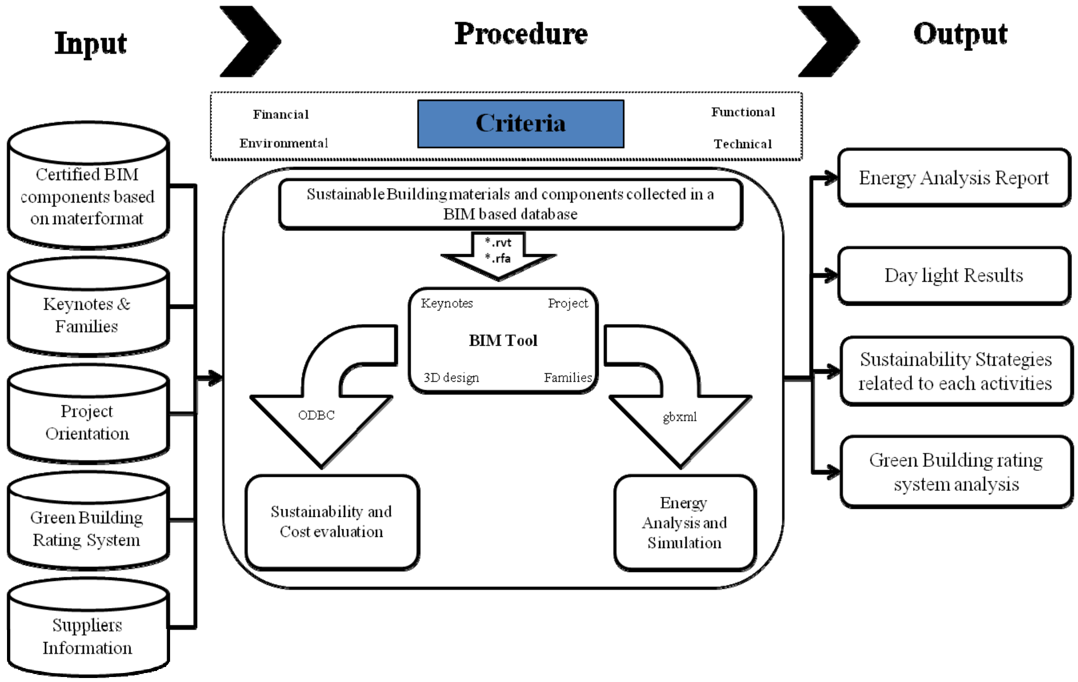

Figure 2. Data Flow of the proposed method

TESTING AND VALIDATION

To test and validate the capabilities of the said method an actual project that is presently under construction is used. The project is located in the city of Montreal, Quebec, Canada and consists of three floor office building project with a conference hall at the fourth floor for a total gross area of 16,862 ft2 and a perimeter of 1,145 ft. Owners are looking to have the project as gold certified. The authors created a 3D conceptual design of the current project where the associated sustainable components and materials are selected from the developed database. Every component, such as floor, wall, roof, and window has its associated LEED information, the manufacturers' web pages and contact information stored in the database that is linked to the BIM's tool as previously explained.

3D sustainable conceptual design (step 1)

BIM's tool (Autodesk Revit Architecture©) is used to implement sustainable conceptual design of the proposed building. The newly created green families stored in the database that is linked to the BIM's tool are used in designing the proposed building. These families are linked to the proposed building model via their unique code permitting users to select the appropriate type of sustainable materials and components for their design. As explained in phase 1, the external green materials' database contains detailed information about the suppliers of the materials used in every family, therefore more than 80% of the components and families used in the example project had their LEED certification points supplied by their manufacturers and stored in the database.

Energy and day lighting analysis (step 2)

In order to have an accurate energy analysis of the proposed building, the 3D physical model should be converted into an analytical model by transferring all the spaces into rooms. Once, a "room" is defined for the purpose of energy analyses for building, the bounding elements such as walls, floors and roofs are converted to 2D surfaces representing their actual geometry. By using the customized BIM's tool, designers are able to automatically transfer the created 3D model in Revit into the energy analysis tool (Ecotect©) using the gbXML format as shown in figure 3.

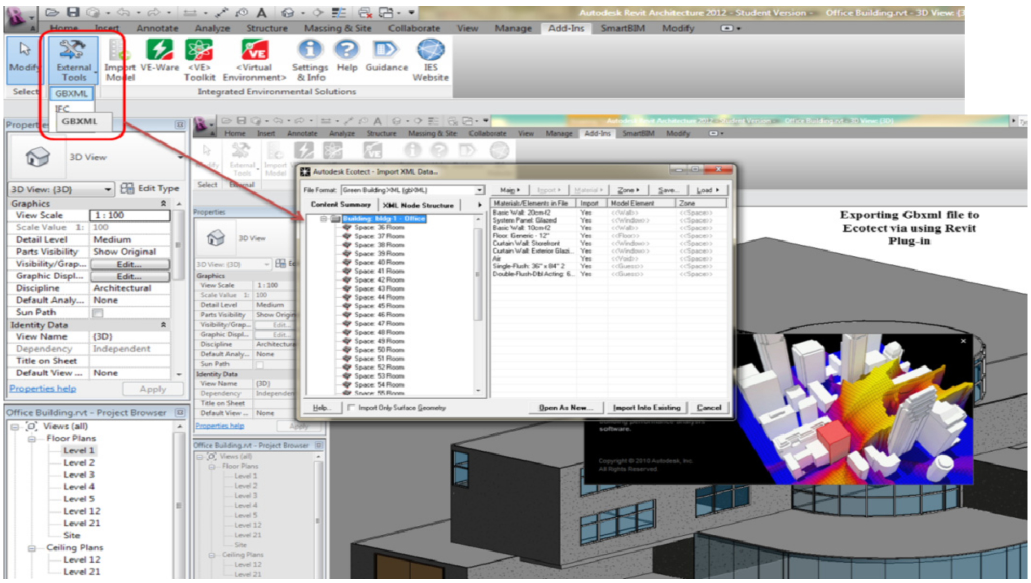

Figure 3. Snapshot of transferring BIM model to Ecotect via developed plug-in in gbXML format

Figure 4 shows snapshots of the building 3D model in BIM's tool and in the energy analysis tools (Ecotect).

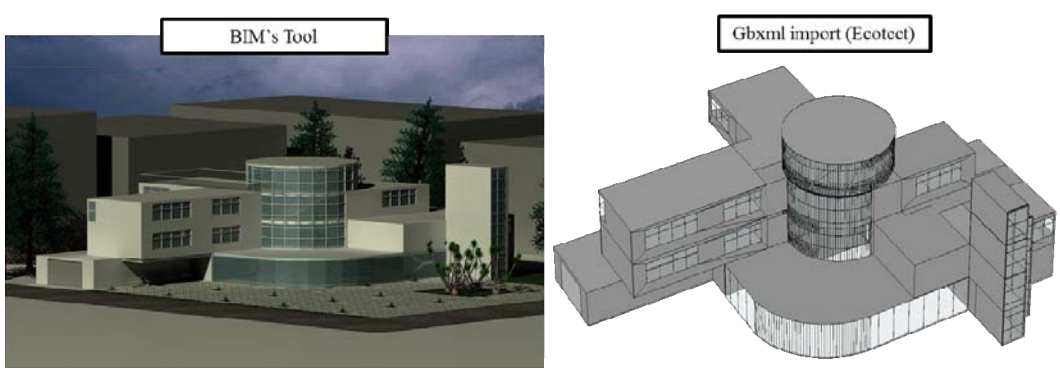

Figure 4. Snapshot of the designed green building and its converted 3D views in Ecotect via gbXML format

Figure 5 shows sample of the day lighting and the energy analysis results generated by the Ecotect for the example project. In figure 5, day lighting analysis provides a visualization measurement of the day light that is gained by every single surface inside the building's 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, at the second floor, the maximum percentage of solar gains is for central areas surrounded by glazed curtain walls with 72% while the minimum percentage is 12%, which corresponds to corner areas located far from openings. Furthermore, a diagram of the total heat gains is based on outside temperature ranging from -26 ˚C to 32.5 ˚C for the City of Montreal for all visible thermal zones. The maximum heat loss corresponding to -26 ˚C temperature is -166 wh/m² and the maximum gain is 54 wh/m² correspond to 32 ˚C. The part of the diagram with condensed points is for the temperature between 0 ˚C to 26 ˚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 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 – December 31st. As illustrated, conduction has a maximum overall loss with 69.4% (around 840 wh/m²) and direct solar has tremendous gains with 51.7% of energy gains (around 420 wh/m²).

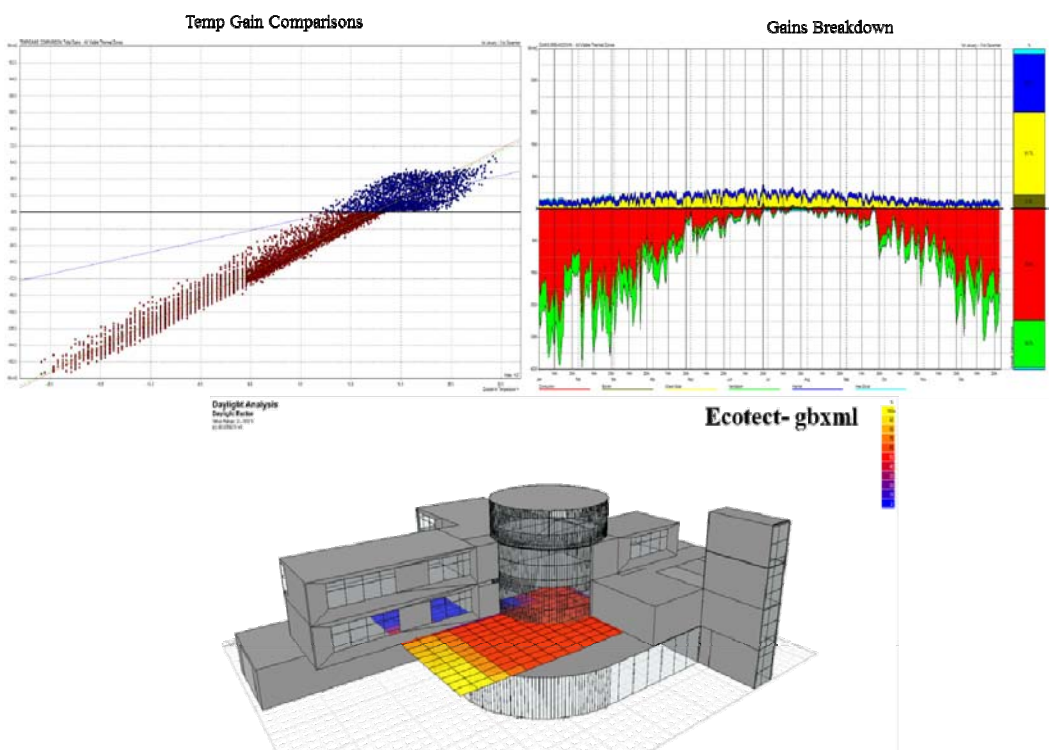

Figure 5. Snapshot of the sample day lighting and energy analysis in Ecotect

Environmental Evaluation and calculation of the potential LEED points (step 4)

Once the design is finished using the customized BIM's tool, designers are able to evaluate the model based on different green building rating systems. The result shows that 52.9% of the model's components are compiled from sustainable materials and families that are already defined in the BIM's tool database. In this paper, LEED® Canada New Construction v1.0 is used to evaluate the designed model. In this case, the authors are able to identify the potential points earned by the 3D design.

In order to approximate the costs of the designed project, authors used RS-Means cost data to preliminary estimate the cost as shown in Table 1. In this Table, the total estimated cost of each building component was 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 2013 and adjusted for the city of Montreal. To prepare the preliminary cost estimate, materials with specifications similar to the quantity take off extracted from the developed 3D model are manually selected from R.S. Means database. However, as illustrated in Table 1, the preliminary cost estimate of the building components using the proposed method is calculated to be $1,131,303.43 while the actual estimated cost was calculated to be $1,527,259.63 for year 2013 that reflects a 35% difference in the values, which is acceptable for the conceptual stage because little information about the project is known. As shown in Table 1, the selected materials and components compiled a potential number of 44 LEED points based on the CaGBC rating system. This is an approximated number of the LEED points earned by the designed example project therefore it does not reflect the final number that can be earned when the building final design is completed. At the conceptual stage, owners and designers do not have detailed information about the project, yet this integration will help them generate an idea about the potential LEED points the designed 3D model can earn. Moreover, the earned LEED points derived from the integrated method are based only on Energy and Atmosphere (EA), Materials and Resources (MR) and Indoor Environmental Quality (IEQ) criteria of the LEED system.

Table 1. LEED points and associated cost of the selected green components based on R.S. Means cost data compared to the actual conventional office building components

Earned LEED points	Description (Green Office Building)	Unit	Total Item approximated Cost ($)	Description (Typical Office Building)	Total Item actual Cost ($)
13 points					
	Insulating glass, 2 lites, clear, 3/16" float, for 5/8" thick unit, 15-30 SF	S.F.	$ 45,282.09	Windows, aluminum, awning, insulated glass, 4'-5" x 5'-3"	$322,500.00
	Frames, steel	Ea.	$55,246.94		

10 points					
	Structural insulated panels	S.F.	$82,196.80	Roofing, asphalt flood coat,	$62,000.00
		S.F.	$16,006.40	Roof, steel joists, beams,	$17,000.00
3 points					
	Resilient Flooring, cork tile, standard finish, 5/16" thick	S.F.	$186,077.1	Floor, concrete, slab form, open web bar joist	$131,000.00
9 points					
	Doors, glass, sliding, vinyl clad, 6'-0" x 6'-8" high, insulated glass	Opng.	$4,620.96	Door, aluminum & glass, with transom	$42,500.00
	Doors, wood, paneled,	Ea.	$7,765.56		
9 points					
	Precast wall panel, smooth, gray, un-insulated, high rise, 4' x 8' x 4" thick, 3000 psi	S.F.	$615,463.2	Brick wall, composite	$923,259.63
	Stair, shop fabricated, steel	Riser	$49,903.68	Stairs, steel, cement filled metal pan & picket rail, 16 risers, with landing	$29,000.00
	Railing, pipe, steel,	L.F.	$20,548.08		
Total: 44 points	**$1,131,303.43**		**$1,527,259.63**		

CONCLUSIONS

This paper presented a method to partially automate the procedures of implementing sustainable design for building projects at their conceptual stage by integrating BIM, energy and day lighting analysis, LEED and cost estimating tools. The method is intended to assist owners, architects and engineers to run conceptual design for sustainable building projects, analyse their energy as well as evaluate the environmental impacts at early stages. Furthermore, users can identify the potential LEED points that can be earned based on the selected certification system. Authors aimed to automate the whole integration process so users can evaluate LCA, energy analysis, LEED and cost estimation during the conceptual design, however some procedures require users to do some manual input, which makes the method as partially automated. This is an ongoing research and its authors are currently focused on enhancing the databases in addition to striving to achieve a fully automated integration between the different design and analysis tools needed to design sustainable building projects at the conceptual stage.

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