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Integrating Building Information Modeling (BIM), Energy Analysis and Simulation Tools to Conceptually Design Sustainable Buildings

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Abstract:

It is commonly acknowledged that the energy consumption of buildings is high, therefore owners, architects and designers are required to show more concern about the sustainability and energy performance of proposed building projects. The construction industry is considered to be one of the industries that consume the highest amount of energy in North America. For years, energy simulation tools were used by designers to design energy-efficient buildings. However, most of the time energy analysis for buildings is conducted at the end of the design stage, when building components and elements are already selected and they can no longer be changed or modified. The ability to simulate the energy consumption of a building's components at the conceptual design stage would help designers to make the right decision and to choose the best design alternative that would lead to a more energy efficient project. Building Information Modeling (BIM) offers the design team the ability to assess different alternatives at the conceptual design stage of the project so that ultimate energy strategies and systems are achieved. This will help designers select the right type of materials early during the design stage and, accordingly, will allow them to make energy related decisions that have great impact on the building's life cycle.

The aim of this paper is to develop and improve interoperability between BIM, energy analysis and lighting simulation tools through different formats and compare the workability of each method at the conceptual design stage within the sustainability constraints in an efficient and timely manner. Moreover, to be able to measure the embodied energy of every building components used in the BIM model, a methodology to integrate BIM into Life Cycle Assessment (LCA) is taken into consideration. Successful implementation of the proposed methodology will offer the design team a new way of visualizing and identifying potential gains/losses of energy for the whole building and the embodied energy of each component associated with them. By doing so they will be able to go back and modify their sustainable conceptual design in a more efficient method. A hypothetical building project is used in order to illustrate the workability and capability of the developed model.

1. Introduction

Most effective decisions related to the sustainable design of a building are made at the early design and preconstruction stages. Energy analysis is typically performed after the architectural design and related documents have been produced. This practice does not consider the integration between the design and energy analysis processes at early stages and leads to an inefficient way of backtracking to modify the design to achieve a set of performance criteria (Schueter and Thessling, 2008). Energy efficiency is an important feature in naming building materials 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).

Traditionally, most building energy analyses have been conducted late in design, by specialist energy analysts who are usually mechanical engineers. At that stage, their focus is to design a mechanical system that will cover space conditioning requirements for the final building form. The ability to model different building configurations early in the design process in order to identify energy saving alternatives does not typically occur. This is due to the difficulty and cost of modeling the building and energy systems. Project resources are limited during construction so effort to analyze building energy use is expended in the late stages of design using the current suite of energy modeling tools (Brucker et al., 1996). Presently, Building Information Modeling tools provide the user with an opportunity to explore different energy saving alternatives at the early design stage by avoiding the time-consuming process of re-entering all the building geometry and supporting information necessary for a complete energy analysis.

Using BIM enables owners and designers to make energy conscious decisions early in the design phase when these choices impact building life cycle costs the most. Moreover, BIM has the capability of connecting with Life Cycle Assessment (LCA) to provide users with the required information concerning the embodied energy of every separate building component and enabling them to select the best building components among various suppliers. Said suppliers all offer different types of sustainable products based on the users' requirements and the standard criteria for selecting materials and components. 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 is functionally successful 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 is provided by the manufacturer and contains information about the type, size/dimensions, instalment procedures and other specifications in order to show their capabilities and applications. To be able to meet the requirements of a cost-effective building design, the financial criterion of the selected materials should be taken into consideration. The environmental impact of construction materials is gaining priority within the process by which they are selected. Technically, construction materials should satisfy strength, serviceability and architectural requirements without negatively impacting the environment. (Somayaji, 2001)

Given that BIM's tools are very beneficial, their key strength resides in their interoperability with other programs. However, there is presently a large gap in the aims expected to be made by BIM proponents and what it actually delivers. As a matter of fact, interoperability between BIM's tools and energy analysis software is limited even though new solutions such as interoperable file formats are being developed. Industry groups and practitioners are experimenting with standards in order to establish new means of transferring data that are universally accepted amongst different software packages yet still seamlessly exchange information. Efforts such as Drawing Exchange Format (DXF), the Industry Foundation Classes (IFC) and Extensible Markup Languages (XML) are currently being promoted by various industry groups. Furthermore, using BIM tools to design sustainable buildings necessitates the selection of materials and systems so that their embodied energy can be easily evaluated. The Impact Estimator for Buildings is a stand-alone program that allows users to model their own custom assembly and envelope configurations, and provides flexibility for proposed designs and existing buildings. The Impact Estimator allows the user to input energy simulation results and calculate their operating effects alongside their embodied effects. 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). Therefore, in this paper, the objective is to connect BIM with energy analysis and simulation tools via evaluating and comparing capabilities of different file formats in transferring information when designing sustainable buildings at the conceptual design stage of the project to help owners and designers measure the thermal and day lighting analyses of sustainable building. By taking advantage of the BIM ability to export materials quantity take offs and the potential of BIM to connect to other tools and concepts such as LCA, project teams receive relevant information about the energy consumption of the designed building and that of each component at the conceptual stage, which allows them to be able to determine and modify potential problems.

2. Literature review

The early design and preconstruction phases of a building are the most critical times to make decisions on its sustainability features (Azhar S. et al., 2009). The focus of designers when doing sustainable design is on the ability to evaluate the environmental impact (EI) of the selected products using available methods and tools. The idea of LCA has emerged as the collection and evaluation of the inputs and outputs and the potential 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, therefore it is very useful to apply it at the conceptual design phase of building projects. For the past 50 years, a wide variety of building energy simulations and analysis tools have been developed, enhanced and applied throughout the building energy community. Examples of these tools are BLAST, EnergyPlus, eQUEST, TRACE, DOE2 and Ecotect (Crawley et al. 2005). Grobler (2005) proposed the notion that building designs (conceptual and detailed) affect most of the life cycle costs of the construction and operation of a building. Several researchers describe energy analysis as a holistic evaluation (Abaza, 2008). Dahl et al. (2005) and Lam et al. (2004) showed that decisions made early in a project have a strong effect on the life cycle costs of a building. A recent innovation in building design and construction, Building Information Modeling (BIM) has received tremendous interest for its impact on sustainable development and provides the opportunity to develop energy analysis software programs for the industry. Yezioro et al. (2008) assessed building performances by using 3D CAD model for energy analysis in the early design stages. Early design energy analysis provides an opportunity to make cost-effective decisions early in the building life cycle and to meet energy conservation targets. At present, the BIM methodology and interoperability are still mostly used by researchers but not widely by practitioners in building projects (McGraw-Hill, 2009). The reason for this is the functional limitation of the available tools, despite the fact that new software packages are becoming more and more available every day. BIM allows for multidisciplinary information to be superimposed within one model thus incorporating structure, mechanics, electricity, plumbing and lighting into a single whole (Tucker, 2010). Hence, an ideal opportunity exists for sustainability measures and performance analysis to be integrated within the BIM model (Azhar & Brown, 2009). Being much more than just the lines and arcs associated with traditional computer-assisted drawing (CAD) tools, BIM includes associated benefits of visualization, built-in intelligence and simulations in addition to intelligent objects of a structure such as spatial data (3D), unstructured data (text), and structured data (databases, spreadsheets). With the addition of building geometry data in a BIM model, the volume can be calculated and energy estimates made based on building envelope characteristics (doors and windows) and building orientation. With programs such as Autodesk Ecotect enabling users to import BIM models, designers can study the performance of interior environments leading to creation of more comfortable, healthy and sustainable spaces for its inhabitants.

AutoCAD DXF is a CAD data file format developed by Autodesk designed to facilitate data interoperability between CAD and other programs. When introduced, it was supposed to be a representation of DWG, which was the native file format of AutoCAD. Certain object types such as solids, regions and blocks are not documented or only partially documented in DXF for commercial developers. The green Building XML schema — commonly referred to as "gbxml" — was developed to facilitate the transfer of building information stored in CAD building information models, thus enabling integrated interoperability between building design models and a wide variety of engineering analysis tools and models available today (Kumur, 2008). It facilitates the transfer of building information including product characteristics and equipment performance data between manufacturer's databases, CAD applications and energy simulation engines. It carries a detailed description of a single building or a set of buildings for energy analysis and simulation. The IFC file format was developed by the IAI (International Alliance for Interoperability) in the hopes of facilitating interoperability and is an open data exchange format that is used by model based applications to exchange data. IFC is an international standard that stores building data in a database, therefore permitting information to be shared and maintained throughout the life cycle of the construction project: that is to say its design, analysis, specification, fabrication, construction and occupancy (Khemlani 2004). The IFC model consists of tangible components such as walls, doors, beams, furniture, etc. as well as the more abstract concepts of space, geometry, materials, finishes, activities, etc.

A methodology that integrates BIM models and LCA systems is needed because it would have the potential to streamline LCA processes and facilitate rigorous management of the environmental footprint of constructed facilities. 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, 3) using parametric formats such as Geometric Description Language (GDL). In LCA terminology, the effects associated with making, transporting, using and disposing of products are referred to as “embodied effects”, a situation wherein the word “embodied” refers to the allocation in an accounting sense as opposed to true physical embodiment. All of the extractions from and releases to nature are embodied effects and there are also embodied effects associated with the production and transportation of energy itself. Although the Impact Estimator doesn’t include an operating energy simulation capability, it does allow users to enter the results of a simulation in order to compute the fuel cycle burdens — including embodied effects — and factor them into the overall results.

It is often difficult to leverage the full potential of BIM due to inadequate data exchange between BIM and energy analysis and simulation programs. Although the potential of using BIM for energy simulation is well known, a systematic approach to share the necessary information is still lacking (Young, et al. 2009). Data exchange between BIM and simulation programs is currently limited to the transfer of 3D geometries of the building projects. Building the data of systems related with HVAC and internal loads such as occupancy and lighting should be included in data exchanges between BIM and energy simulation programs to avoid any repetitive data inputs (Pimplikar et al., 2009). This research concentrates on testing optimized data exchanges between a 3D BIM model and analytical models for energy analysis and lighting simulations using different file formats. One way to pursue this aim is to test different data inputs and outputs using different interoperable formats and optimizing the process by the elaboration of a more workable method. This would provide the project team with the opportunity to compare energy and environmental impacts of every component during design stage so as to allow them to make a well-informed decision in selecting optimum sustainable building components.

3. Methodology and Development

The aim is to develop an automated way in which sustainable design in 3D mode would be accomplished and related energy analysis and simulation results and environmental impacts of every component identified. Since the model integrates different applications, as it is represented in figure 1, the development will be carried out through the following four phases:

Phase 1 consists of designing the relational databases of the model needed to design sustainable buildings. The design and development of the databases are accomplished in two steps: conceptual modelling and implementation of the model. First, the problem investigation and user needs are acknowledged based on a literature review. Then the database requirements are identified and the conceptual design is carried out. Second, the data model implementation requires that the transformation process be made from conceptual to logical design, after which the physical design takes over by creating a list of related tables based on the applied WBS to store the collected data. The data related to the green materials are saved as family files that can be identified by the BIM tool. Thus, in the external sustainable database, up to 3,000 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 Masterformat divisions wherein various types of information such as details about the materials used, suppliers’ contact data, assigned keynotes, potential certification points and assembly codes are stored.

Phase 2 focuses on customizing BIM’s tool to fit the modularity requirements of the model. The first step is to design and implement a 3D module capable of storing newly created and added families and keynotes for components employed in residential buildings by using certified green materials. The module is linked to the database developed in phase 1. As an efficient coding system is the main aspect representing the relationship between the stored data it is important to select a unique code for each item, which will then be presented in a separate line in the database. The coding system allows users to accelerate the process of retrieving necessary information. A five-digit number representing the division, subdivision, elements and material names is used in storing the collected data. Creating the families is based on modifying the inherited resources by adding new parameters. Customizing and duplicating an existing family adds an important feature to the model. For instance, the families built in BIM’s tool consist of different types such as walls, floors, stairs, windows and doors.

Phase 3 consists of designing Energy analysis and simulation models by exporting 3D BIM models through IFC, gbxml and DXF file formats, which are the common language between BIM and energy analysis tools. Ecotect, with its imported geometry, is a very strong tool for architectural design studies related to thermal and solar gains. For thermal analysis using zones, Ecotect is also an easy program to use to create or cleanup models in a format that includes both geometry and zones and is even interoperable with most other tools. This interoperability alone makes Ecotect an ideal basecamp to import and export between the architectural programs that generate geometry and the more advanced analysis programs.

Phase 4 consists of designing LCA modules that interconnect the 3D BIM designs with the LCA tool through ODBC exporting format, which directly transfers materials' quantity take offs to an Excel file or other database formats to allow evaluation of its impacts on the environment. This phase concentrates on designing and implementing an LCA module that is linked to an external database, which is in turn associated with BIM's module that could store the extracted quantities from the 3D design and evaluate their embodied energy. The extracted bill of quantity would then be linked to ATHENA® Impact Estimator© via a text file exchange way.

At the final step, by having all results taken from the integrated system, the project team will be able to compare and evaluate each family and their components based on the materials' selection criteria.

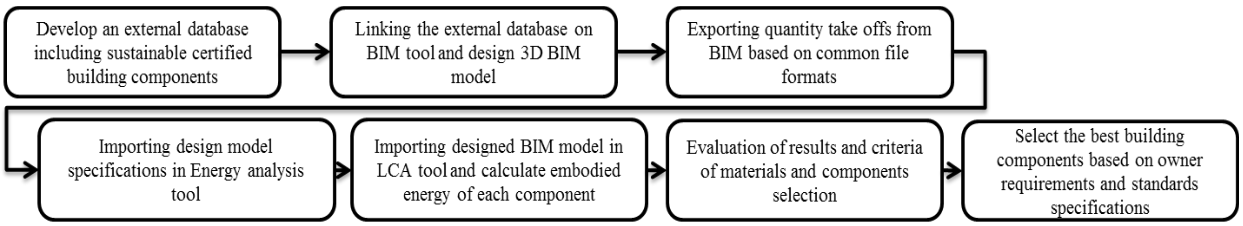

Figure1. Methodology of the integration system

Figure 2 shows the algorithm of the integration which simply shows the procedure of the study. It determines the processes for data analysis considering all criteria and specifications. This analysis will be applied on the selected materials' environmental impacts, divisions, energy efficiency and sustainability issues using input requirements. Figure 3 illustrates the architecture of the integration. The input section includes the project information, sustainable information, Masterformat work breakdown structure with consideration of criteria such as the green building rating system, environmental performance and selection criteria of green materials. The main output of the model will be a 3D-BIM sustainable design of the building containing lists of the selected sustainable materials and their environmental impacts, the energy model and analysis data and daylight simulation of the designed model. The innovation highlighted in this paper describes the model's modules, which are integrated together so that the user will be able to start the sustainable design of a project at the conceptual stage of its life.

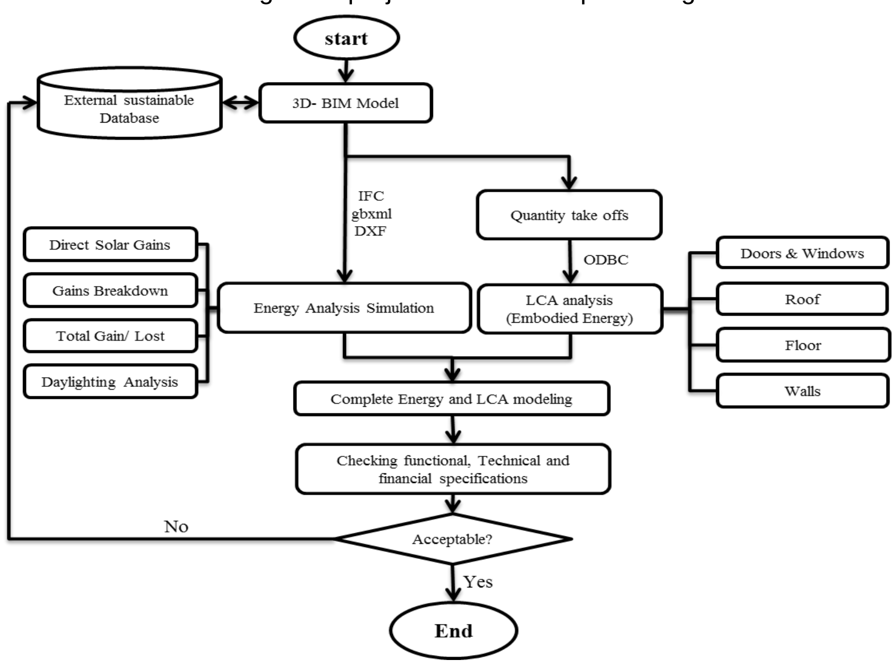

Figure 2. Algorithm of the integration

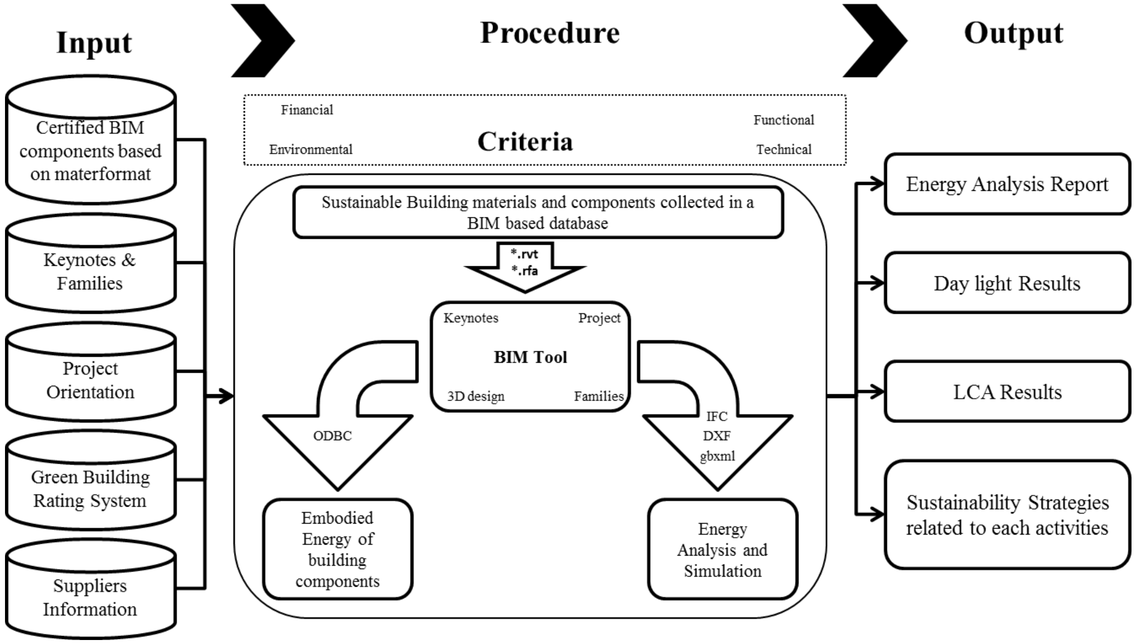

Figure3. Architecture of Model

4 Testing and Validation

The preceding paragraphs explored in detail the methodology followed in developing the integrated model. This section validates the capabilities of said model. Its performance is examined through designing a hypothetical six floor apartment building project in the city of Ottawa. The proposed construction land has an area of 7,500 ft^2 and the building consists of six units, one on each floor with an area of 1,610 ft^2 per floor for a total gross area of 9,660 ft^2 as well as a perimeter of 180 lft. The model's capabilities and performance are measured using the developed modules. The process is implemented in three steps. Figure 4 shows a snapshot of the green proposed building in Autodesk Revit and imported views through different file formats conversion based on following development processes previously described.

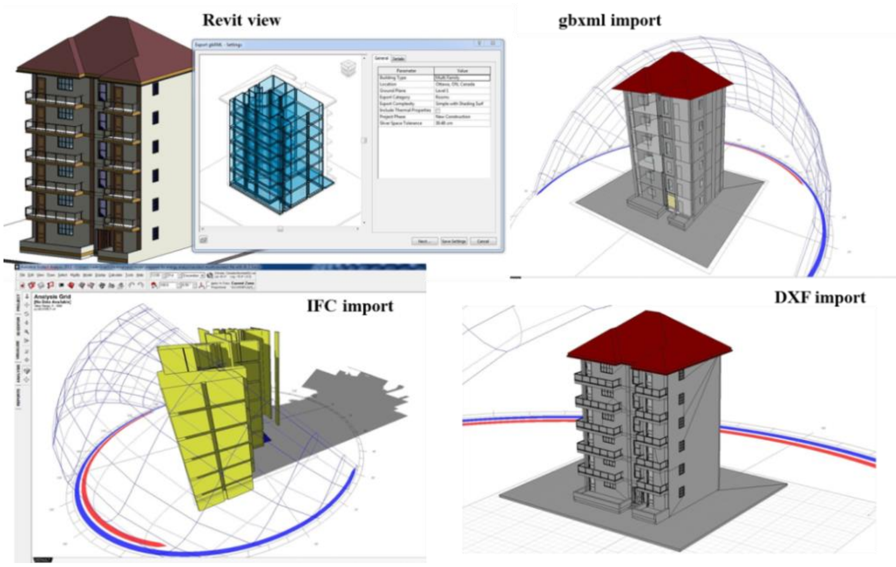

Figure 4 Snapshot of the designed green building and its converted 3D views in Ecotect via different converting formats.

Once the design is finished, the building is assessed and analyzed based on the sustainability requirements using the LCA module and its associated tool ATHENA® Impact Estimator©. This user-friendly tool provides quick results in clear tables and graphs. The Impact Estimator allows users to change the design, substitute materials and make side–by–side comparisons. It also lets users compare similar projects with different floor areas on a unit floor area basis. The IE affords the user the option to input the building's estimated annual operating energy by fuel type. It is then able to calculate primary operating energy, including 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 building. The software can subsequently compare and contrast the life cycle operating and embodied energy and other environmental effects of the building design, thus allowing the user to better understand the inherent trade-offs associated with adding more envelope materials (e.g., insulation) with reductions in operating energy use.

First, users input the necessary information such as geographic location, building life and occupancy/type and, if desired, annual operating energy values into ATHENA. Second, the exported bill of quantities extracted in step 1 is imported as a text exchange file into ATHENA® Impact Estimator©, as shown in figure 5. Pre-set dialogue boxes prompt users to describe the different assemblies, such as entering the width, span and live load of a floor assembly.

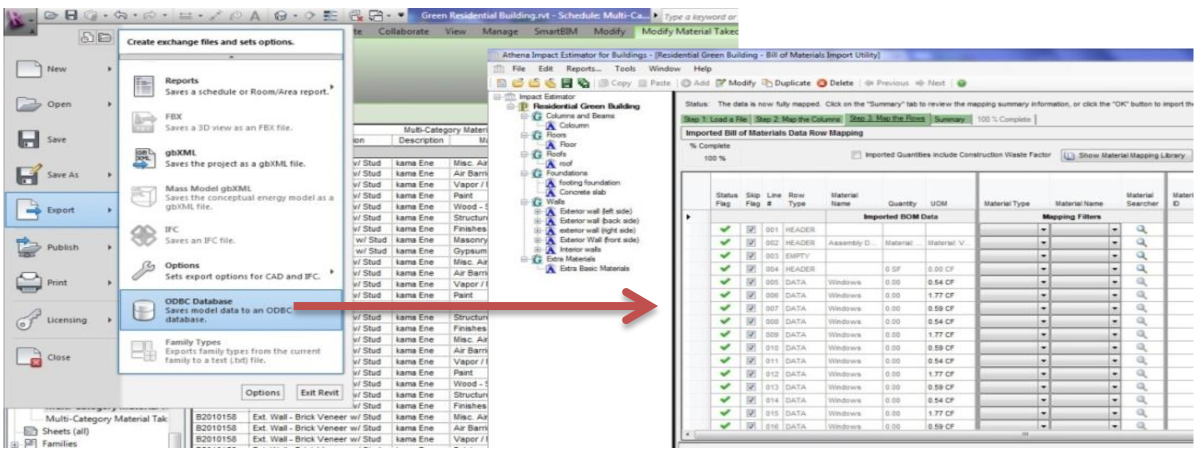

Figure 5 the procedure of exporting materials quantity take offs from BIM tool to LCA tool.

After running Thermal and Day lighting analysis by importing different file formats from Revit to Ecotect, it is taken into consideration that earlier formats such as DXF were files designed to carry geometric information and were designed specifically for use with AutoCAD files and as such most of its data is stored as layers. At the beginning of the study, it is assumed that the geometric information carried by the DXF would be good enough for a day lighting analysis, but it did not prove to be so. Even though DXF carried over the geometry, there was no meaning attached to the lines. For instance, when a DXF model was imported into Ecotect, it did not automatically convert rooms into zones and ended up converting certain layer types into zones instead. Consequentially, the user had to redraw the building and the use of DXF is largely limited to importing 2D plans that become a sort of foot print, from which the building has to be generated again.

However, with the advent of the gbxml file schema and the IFC formats, it was possible for additional comprehensive building information other than geometry to be carried by these files. The gbxml schema was quite effective in organizing file information. Building data is sorted into levels (buildings, zone, space, surface, openings and construction type) each of which is able to carry information about material-related parameters such as U values, absorbance, reflectance, roughness, construction type and so on. Similarly, the IFC model consists of tangible components such as walls, doors, etc. as well as the more abstract concepts of space, geometry, activities, etc.

It was found that even if the files were not carrying a single piece of critical information, it would still affect the result. For instance, the IFC was not able to carry the location information as defined in the Revit file and, when imported into Ecotect, the model would assume default values for the location given when creating the digital model. As indicated in table 1, all three file formats are able to carry over geometric information and material thicknesses. However, DXF was unable to carry the building zone definition and the gbxml file scored better in comparison with the IFC in that it was able to carry building type and location and gave much more details in the "results" section. A sample of some thermal and day lighting analysis results users can get from the software is shown in figure 6. Sample thermal analysis results are related to thermal gains breakdown, direct solar gains and total gains for all visible thermal zones. Day lighting simulation visualizes the measurement of day lighting each surface potentially earned in the building (Example: 2nd floor of the building for each importing file format). Furthermore, the result of the embodied energy of every building component, which is calculated by the Athena impact estimator, is shown in figure 7. It takes account of the energy used to construct the structural elements of the building and the emissions to air, water and land associated with the on-site construction activity as well as the energy used to transport materials or components from the manufacturer to a notional distribution centre and from the distribution centre to the building site.

Table1. Comparison of the information carried by different file formats

		DXF	IFC	gbxml
Building Type		×	×	✓
Location		×	×	✓
Building Materials		×	×	×
Material thickness		✓	✓	✓
Drawing units		✓	×	✓
Zone definition		×	✓	✓
Geometry	Shape	✓	✓	✓
	Area	✓	✓	✓
	Volume	✓	✓	✓

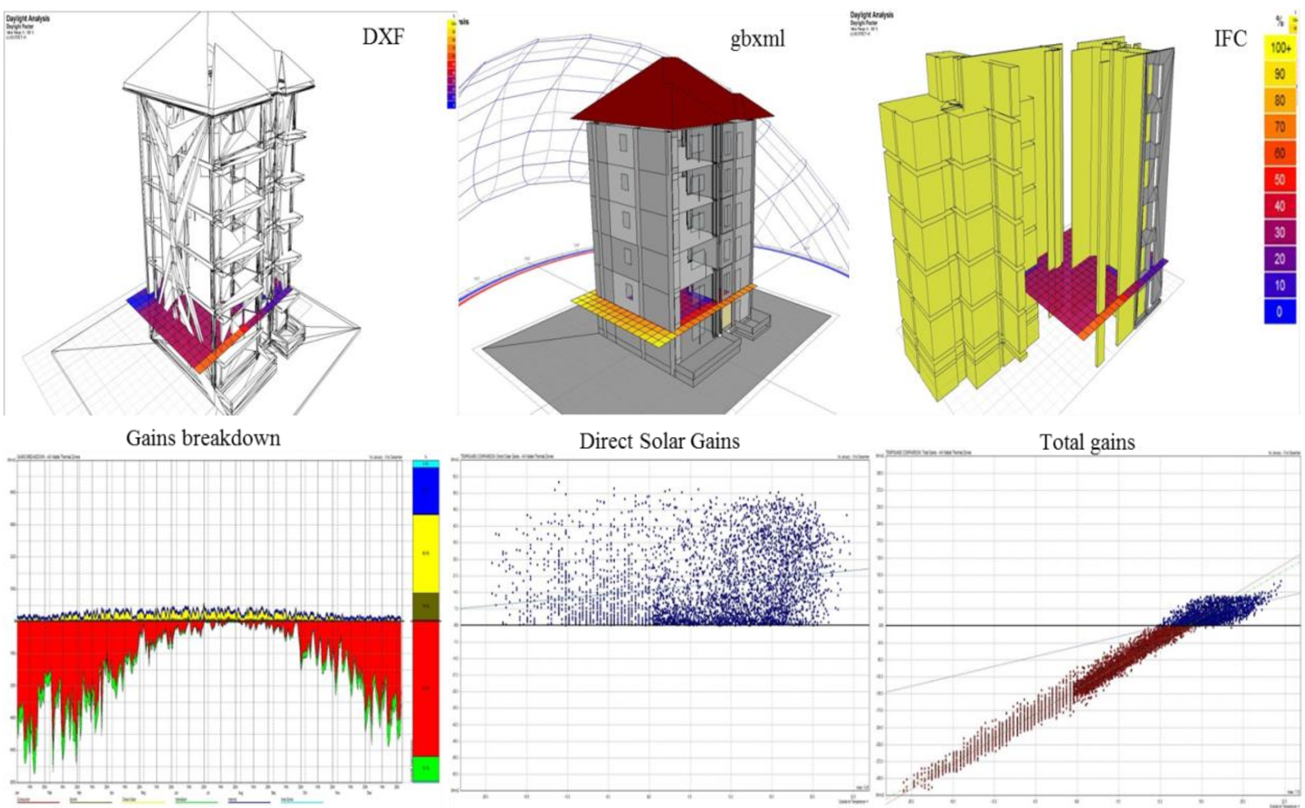

Figure 6 snapshots of the sample thermal analysis and day lighting simulation

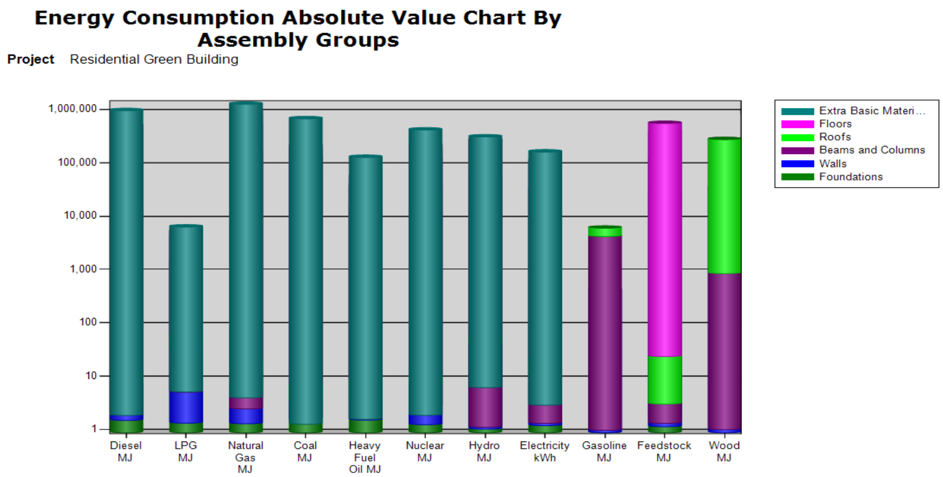

Figure 7 Embodied Energy analysis of each building component in the designed model

Table 2 shows selected components used in the BIM model based on the functional, technical and financial specifications of sustainable 3D families collected from the manufacturers' web pages. Furthermore, it shows the most applicable criteria for those elements that have environmentally friendly capabilities. The provided information shows that the selected materials used in creating sustainable 3D families meet the functional, technical and financial specifications elaborated and take into consideration the environmentally friendly aspects.

Table 2 functional, technical and financial specification of sustainable materials used in the 3D BIM Model

Green Families used in the BIM's sustainable model	Windows	Roofing Systems	Floor	Wall	Door
Functional Criteria	-Recyclable packaging materials, -Products are certified by Scientific Certification Systems (SCS) to contain pre-consumer recycled content, which includes glass cullet and wood fiber in Fibrex® material,	-To divert construction and demolition debris from landfills and incineration facilities. -Redirect recyclable resources back into the manufacturing process. -Redirect reusable materials to appropriate sites. - Use materials with recycled content such that post-consumer plus ½ pre-consumer is at least 10% or 20%.	- Resource Reuse - Recycled Content -Regional Materials	- Framing, Off-Site Fabrication of the structural systems. - Utilize proprietary fabrication techniques for limiting waste in a controlled factory environment. - Enables resource efficiencies that can often eliminate on-site waste, - Reduced assembly time and smaller construction crew,	- No Added Urea Formaldehyde requirement, - 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)	- Asphalt shingles, Thermoplastic polyolefin (TPO) and Poly-Vinyl Chloride (PVC) membranes, Ethylene Propylene Diene Monomer (EPDM) membranes, poly Iso insulation, extruded or expanded polystyrene insulation, gypsum board, mineral fiber board, ballast, metal flashings, metal roof panels, and clean wood.	- 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.	- The system allows for construction waste per home built being less than 2.5 pounds (or 0.016 cubic yards) or less of net waste per square foot of conditioned floor area. -Contain recycled content at a minimum of 25% postconsumer and 50% post-industrial for at least 90% of the building component.	-Rigid foam plastics and fiberglass are typically used as insulation core, -Interior doors are typically constructed of wood products (veneer, core materials, and styles) and synthetic wood products (plastics),
Financial Investments	Minimise disturbance of the existing structure and internal finishes to a minimum, thereby reducing the cost of making good.	This roof was selected because of its engineered cooling attributes for a cooler roof and a projected cooling cost saving of 20%.	Lowers maintenance costs a minimum of 10% (based on cost) of the total material value	Benefits accrue well beyond the design and construction budget through energy savings, a reduction in the contributory costs of the built environment to global warming	The cost is higher than for conventional doors. Such cost increases are dependent on the sustainable features specified.

5. Conclusions

A study to this end shows how early design decisions, increased compatibility with energy analysis software and increased energy analysis functions within BIM could have an impact on green design that would make its claims to an impressive interoperability that much more persuasive. The model is successfully imported into ECOTECT with DXF, gbxml and IFC file formats despite the fact that there still seems to be some problem with the exterior wall and roof placements. This could be partly caused by the model or transfer of gbxml files in Ecotect. Usually components which bind or shade the space can be correctly transferred while other components such as columns, overhang, tiles, and curtains walls were assigned to the layer of external shading and mistakes such as dislocation, overlap and loss of these components may occur. Windows and walls were separated, therefore extra work permitting the successful application of incidences like opening windows and adding roofs needs to be done. The imported IFC file produced a faulty model in Ecotect caused the floor and roofs to be disclosed. Part of reason for this is that IFC support is only at the beta stage in this release of Ecotect, therefore IFC space-related data and complex curves may not transform correctly. Based on the analysis of pros and cons of IFC and gbxml, it is relatively simple to develop building application prototypes for the latter without understanding all the elements in the whole schema. Gbxml is a simplified schema for energy analysis and as preparing an analytical model from BIM designed for gbxml import can be time-consuming for large and complex projects, hence it is a preferred format during design development or the schematic stage.

6. References

Abaza, H. (2008), “An interactive design advisor for energy efficient building”, Journal of Green Building

Azhar. S, J. Brown, (2009), BIM for sustainability analyses, International Journal of Construction Education and Research 5 (4) 276–292.

Brucker, B., and Stumpf, A. (1996), “Applying collaborative engineering to the facility delivery design”, USACERL Technical Report 98/32

Crawley, D., Hand, J., Kummert, M. and Griffith, B. (2005), “Contrasting the capabilities of building energy performance simulation programs”, Joint Report, Version 1.0

Dahl, P., Horman, M., Pohlman, T. and Pulaski, M (2005), “Evaluating design-buildoperate- maintenance delivery as a tool for sustainability”, Construction Research Congress

Grobler, Francois. (2005), “A Practical Guide to IFC or Surviving in the BIM Economy: What you need to know”, AEC-ST, Orlando, FL

Guinée J. B., Heijungs R., Huppes G., Zamagni A., Masoni P., Buonamci R., Ekvall T., Rydberg T. (2011). Life Cycle Assessment: Past, Present, and Future, Journal of Environmental Science and Technology. Vol. 45. No. 1. pp: 90 – 96

Häkkinen T., Kiviniemi A. (2008). Sustainable Building and BIM. Proceedings of World Sustainable Building Conference (SB08). Melbourne. Australia.

Jeong, K.-S., Lee, K.-W. and Lim, H.-K. (2010). Risk assessment on hazards for decommissioning safety of a nuclear facility. Annals of Nuclear Energy, Vol. 37, No. 12, 1751-1762.

Khasreen M. M., Banfill P. F.G., and Menzies G. F. (2009). Life-Cycle Assessment and the Environmental Impact of Buildings: A Review. Journal of Sustainability. pp: 674 – 701

Khemlani, L 2004, The IFC Building model: a look under the hood, AEC Bytes, accessed 14 September, 2007, http://www.aecbytes.com/feature/2004/IFCmodel.html

Kumar, Sumedha, (2008), Interoperability between Building Information Modeling (BIM) and energy analysis programs, MSc thesis, University of southern California, USA

Lam K.P., Wong, N.H., Mahadavi, A., Chan, K.K., Kang, Z., and Gupta, S. (2004), “SEMPER-II: an internet-based multi-domain building performance simulation environment for early design support”, Automation in Construction V. 13

McGraw-Hill Construction, 2010. The Business Value of BIM in Europe. Getting Building Information Modeling to the Bottom Line in the United Kingdom, France and German. ISBN: 978-1-934926-27-7

Pimplikar, S.S, Esmaeili, P, 2012, Building Information Modeling (BIM) and Sustainability – Using Design Technology in Energy Efficient Modeling, IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE), PP 10-21

Schueter, A., and Thessling, F. (2008). “Building Information Model Based Energy/Exergy Performance Assessment in Early Design Stages”. Automation in Construction Volume 18, Issue 2, March 2009, Pages 153-163

Somayaji S. (2001). Civil Engineering Materials. Prentice Hall. Second Edition

Tucker P., Newton W., 2009, ‘Carbon Emissions from Domestic Built-in Appliances’, Environment Design Guide, DES 74, November

WBDG (Whole Building Design Guide). (2012). Evaluating and Selecting Green Products. Available: http://www.wbdg.org/resources/greenproducts.php. Accessed 08 June 2012.

Yezioro, A., Dong, B., and Leite, F. (2008), “An applied artificial intelligence approach towards assessing building performance simulation tools”, Energy and Buildings