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INTEGRATING BUILDING INFORMATION MODELING (BIM) WITH SUSTAINABLE UNIVERSAL DESIGN STRATEGIES TO EVALUATE THE COSTS AND BENEFITS OF BUILDING PROJECTS

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Abstract: Building Information Modeling (BIM) is a well-known innovative approach in project design and construction. The use of BIM enables designers to control project cost from the early stage of its life cycle. The cost impact resulted from the construction of sustainable building is one of the main resources that designers should consider when designing such type of buildings. As the North American population is aging Universal Design (SD) requirements (design that accommodate the needs of human regardless of their ages and abilities) should be considered in conjunction with the sustainable design criteria to achieve sustainable universal design (SUD). The aim of this research is to investigate the environmental and economic benefits associated with adopting the concept of SUD applied for building projects. Therefore, this paper describes the methodology used to develop a model that is able to integrate BIM tools with SUD requirements and strategies (i.e. Energy use, material use, and indoor environmental quality and barrier free environment) and to evaluate the associated costs at the early stage of buildings especially at their conceptual design stage. The proposed integrated model consists of six main components: 1) a knowledge-based module, which is created to establish a database necessary to store the SUD principles and strategies; 2) an expert system (ES) module, which role is to work as an advisory system while designing SU buildings; 3) a 3D BIM module that mainly incorporates predesigned families that are devoted to illustrate items necessary for the SUD, such as hand rails, doors, windows, plumbing fixtures, and their associated materials. All of the mentioned items will be according to the standards (i.e. Canadian national code, LEED, and other international standard, and Unifromat II (WBS)); 4) a life cycle cost analysis (LCCA) module that illustrates the associated costs of the selected materials and components; 5) a life cycle assessment module (LCA) that analyzes the environmental impact of the selected material; 6) a Global Visual Basic Module that aims at linking and transmitting information between all the model's components. The effective development of the integrated model will enable owners, designers, and developers to evaluate the economic and environmental benefits of adopting sustainable and universal buildings.

1 INTRODUCTION

Todays, the sustainability approach is widely adopted by the construction industry. This notable adaptation is based on the economic, environmental and social improvement constraints. Kim and Emily (2007) consider that the visible and measured outcomes from some sustainably designed projects include increased occupant satisfaction, reduced construction and operation-related waste costs, reduced water use, and improved energy performance. While the adaptation of sustainable design (SD) approach in the construction industry is growing, the nation's population is aging as well; therefore, more design strategies should be considered to overcome this issue. Recent studies devoted to guide designers in providing safe and functional facilities for inhabitants who like to age in their living place (Demirbilek and Demirkan, 2004). Universal design (UD) is one of the innovative approaches that have been considered in the construction industry. It has been implemented to help disabled individuals to maintain their daily activities (Hunter et al., 2011). Although, implementing sustainable strategies in buildings (new/existing) showed better economical trend over the long run, its initial associated cost is doubtable. The results of a survey conducted in 2007 by the World Business Council for Sustainable Development found that the costs of sustainable buildings are “overestimated” for an additional cost of 17 percent added to the cost of conventional buildings, which is considered more than triple the actual cost of 5 percent (Hoffman and Henn, 2008). Certainly, it is beneficial for owners, developers, and designers to accurately calculate the cost associated with the construction of Sustainable Universal (SU) buildings at the early stage of the project’s life. In order to evaluate such a cost, designers tend to examine and analyse multiple design criteria at the conceptual stage of projects (e.g. materials, technologies, spaces). Those criteria directly affect the principles, measures and costs of sustainable universal design (SUD). Building Information Modeling (BIM) is an innovative approach that allows designers to control project cost and environmental performance starting from the early stage of its life cycle. It helps designers to visualize and analyse their design and their associated materials and technologies before the building physically exists (Bryde et al., 2013). This paper proposes a methodology to integrate BIM with the SUD principles and requirements in order to evaluate the economic and environmental benefits resulted from adopting such type of design for buildings over their anticipated life.

2 LITERATURE REVIEW

The primary objective at the early design stage of building projects is to evaluate their budget and environmental performance. Critical decisions concerning the profitability and performance can be made at that stage (König, 1995). Bogenstätter and Bogensta (2010) indicate that the conceptual phase of project’s life play an essential role toward sustainable buildings. They suggest that in order to integrate life cycle cost (LCC) and life cycle assessment (LCA) requirements into the conceptual design, building specifications and knowledge about the characteristic values of LCC should be known at that stage. On the other hand, considering the concept of universal design affects the building cost, performance, and occupant’s wellbeing as well. Therefore, designers are expected to apply the universal design strategies at the early stage of designing buildings; this in return will reduce costs, improve designs, and solve usability problems during the design process (Afacan and Erbug, 2009).

Green building certification systems provide a guidance to design and operate buildings; it allows to document progress, compare buildings, and record design and operations outcomes and/or strategies (Wang and Fowler, 2012). One of the well-known designs, construction and operation rating system is the Leadership in Energy and Environmental Design (LEED), which was developed in 1994 under the U.S. Green Building Council. LEED is designed to rate new and existing commercial and institutional buildings based on the energy and environmental principles. Sets of criteria are included in the LEED system, where each criterion has its own required points; based on the accumulated points, a building would be awarded either certified, silver, gold, or platinum certification (Dhawade and Harle, 2014). Unlike the sustainable design, universal design has no specific guidance to design and operate buildings. However, many international standards were developed to support the usability of products. When reflecting the concept of universal design to the aging and people with disabilities, there is a wide number of established written documents, which are standards, references and/or norms to guide the design process such as ANSI 1986; BSI 1979; Fair Housing Act Design Manual 1996 (Demirkan and Olguntürk, 2014). Canadian National Building Code is one of the barrier free guidelines; it is a legal document that sets the minimum requirements for design and construction. It first introduced the accessibility requirements in 1965 and continued until 2010. During that period accessibility was mentioned in a several sets of requirements based on the national demand (Jrade and Valdez, 2012).

Researchers highlighted the need of knowledge when doing the integration between different computational tools applied at the conceptual design stage of building projects (König, 1995). Building Information Modeling (BIM) is used to convert the 2D based drawing information systems (i.e. universal material specification, universal components, sustainable universal guides) into 3D object based information systems (Arayici et al., 2009). Multiple efforts were done in the construction industry to find the effective way to integrate BIM with sustainable design and analysis tools (Zhang and Xiao, 2013). Achieving this goal have the ability to remove the construction industry's obstacles, increase its productivity, efficiency, and quality and reach the sustainable development principles (Arayici et al., 2009). This paper proposes a methodology to integrate BIM with the SUD principles and requirements, through Visual Basic interface (VB.NET), in order to evaluate the benefits and costs of adopting such type of design for buildings over their anticipated life.

3 METHODOLOGY

The proposed methodology is routed on an intense literature review related to the benefits of both sustainable and universal approaches. The literature illustrated factors that affect SUD such as: universal design features, sustainable building parameters, type of green materials, and proper technologies used toward SUD principles and strategies. All the information related to these factors is collected and stored in a database; thereafter, the proposed model's conceptual design process can be started. The process consists of five stages as shown in Figure 1. Starting by data analysis and comparison, passing through selecting the best types of materials and technologies that will be applied in the 3D model, then applying the life cycle cost analysis (LCCA) method and Life cycle assessment (LCA) method, and ending by the validation part. Afterwards, the model's components and architecture are identified.

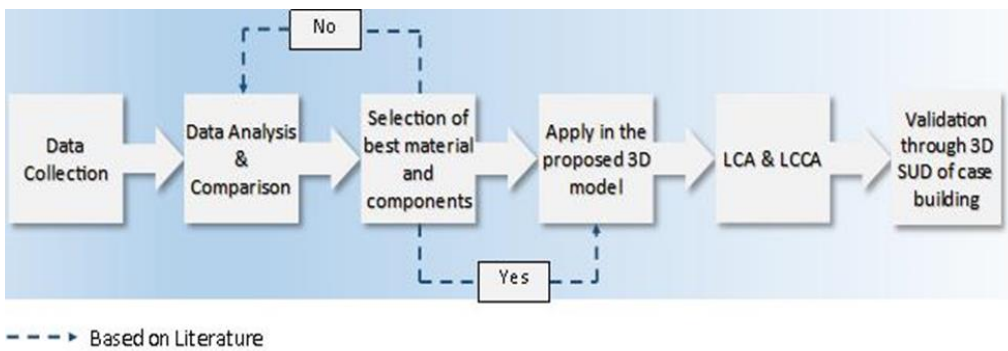

Figure 1: Methodology's approach.

3.1 Model's Components and Architecture

The proposed model consists of different components that are interrelated with each other in a way that data and information is shared in an automatic and efficient way. Figure 2 depicts the proposed model which incorporates the following six modules: 1) a knowledge-based module; 2) an expert system module; 3) a 3D design module; 4) a life cycle assessment (LCA) module; 5) a life cycle cost analysis (LCCA) module; and 6) a Global Visual Basic module.

In order to simplify the development process of the proposed model its architecture is created as shown in Figure 3. The input section aimed to consider information, based on user input that is necessary to initiate SUD analyses; these information were divided into three elements that have a direct effect on SUD and they are as following: 1) cost; 2) sustainable principles; and 3) universal principles. The analysis section used to examine the input data and its criteria (i.e. SUD strategies, sustainable materials, and energy performance, Uniformat II (WBS)). The analysis is based on the objectives of the research; therefore, the analysis takes into consideration occupants' requirements, building codes and standards (CNBC), and LEED (Leadership in Energy and Environmental Design) system. The output is a list of selected sustainable universal materials along with their cost and economic performance and environmental performance. Furthermore, accumulated LEED credit points and certification level, list of recommended SUD families available in BIM, and cost comparison between conventional and SU design are provided.

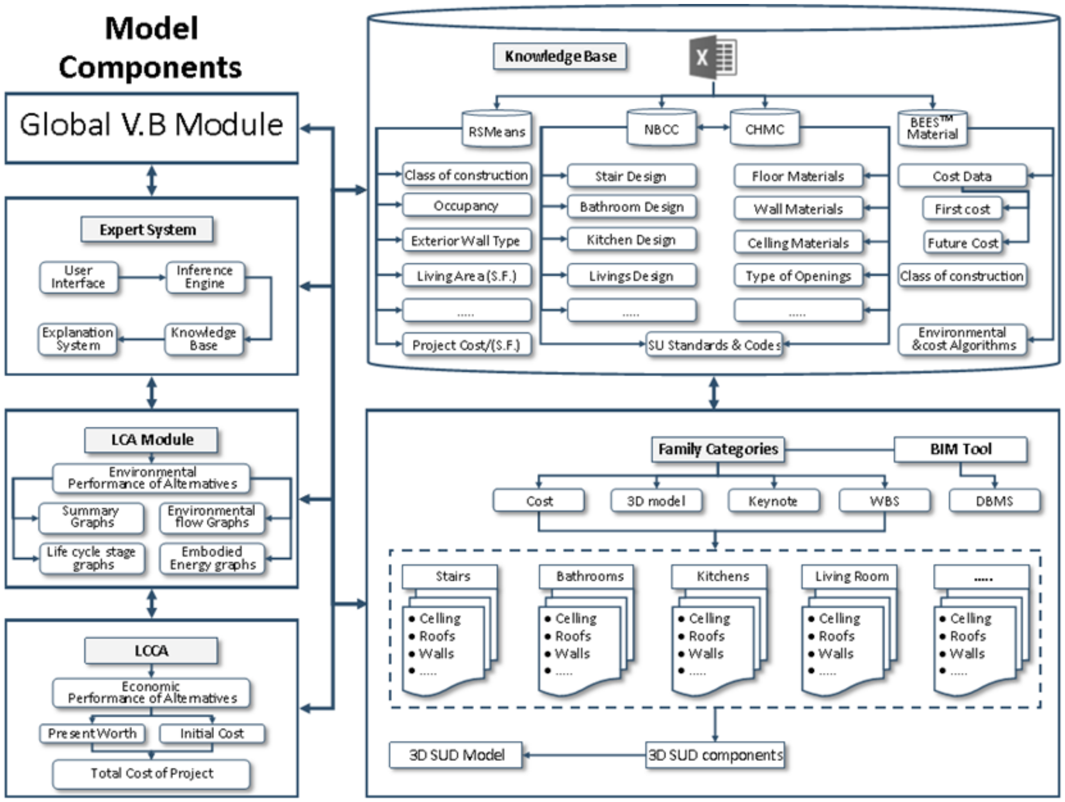

Figure 2: Model's components

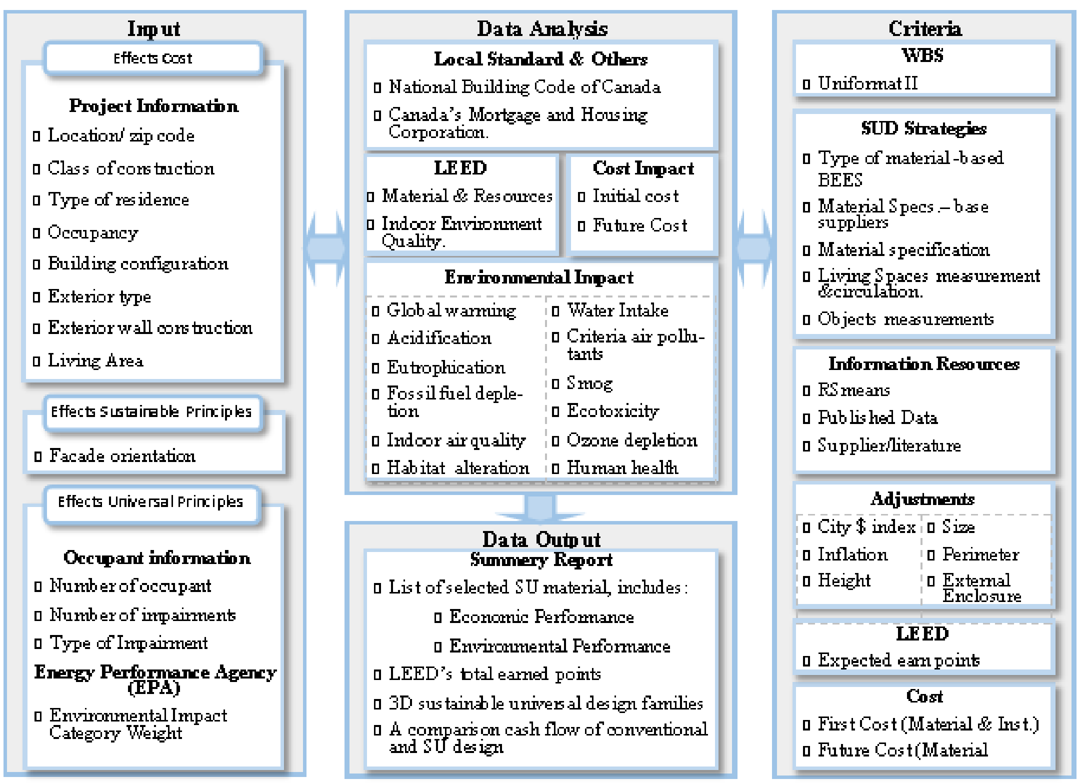

Figure 3: Model's Architecture

3.2 Database Module

The design and development of the database is established by considering the critical living areas that affect elderly inhabitants. Critical areas are the ones where most likely the fall would occur when occupied by elderly people (e.g. stairs, bathroom, and kitchen). Each area is then considered as having two types of measurements. The first is the quantitative measurement, which involves numerical values such as: safe circulation dimensions, height of handrails and grips, height of electrical outlets, and height of opening from the floor level. Those dimensions are obtained from the NBCC and CMHC and then analyzed, evaluated and stored based on the needs in each living area. Second is the qualitative measurement, which includes items that influence the quality of indoor environments such as the floor types, walls, and roof materials. The criteria of those items are analyzed based on the sustainability principles as collected from the BEES^{TM} Database. The analyzed data are then modified by adding specific criteria for each material's type, based on the supplier's published data (e.g., durability, color, and glossiness) and then stored in the model's database. The selection process of the SU measurements and dimensions is done from the collected data, which is stored in the database as shown in Fig.4. The data related to the SUD is saved as family files, which can be identified by BIM tools. Therefore, information such as details about the materials, suppliers' contact data, assigned keynote, potential certification points, and assembly codes are stored in the database.

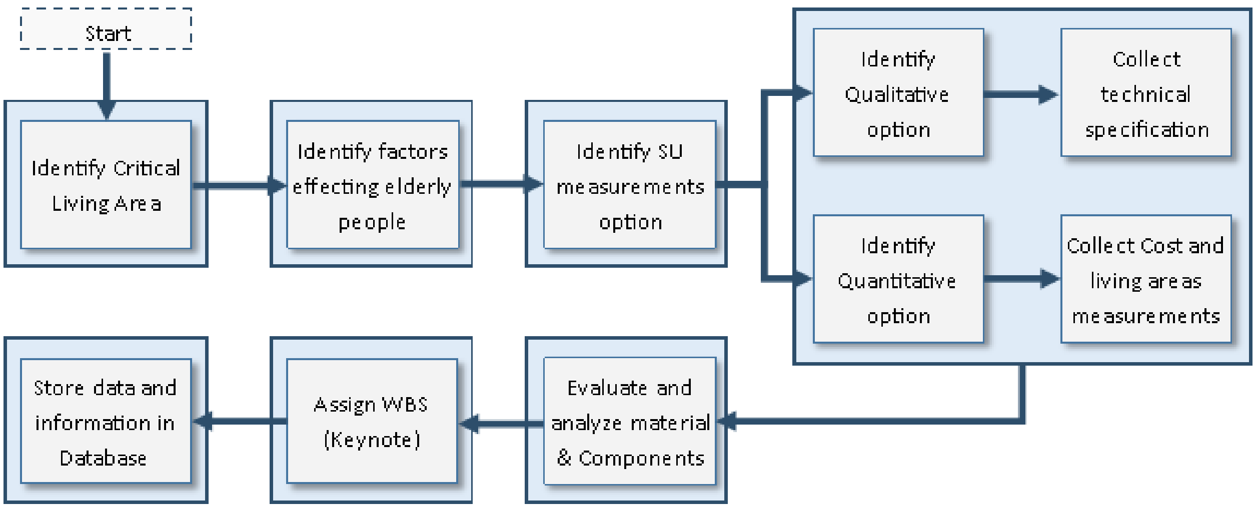

Figure 4: Data collection process for the sustainable universal materials and components.

3.3 Expert System module

The approach is to integrate an expert system (ES) and multi-criteria decision method (MCDM) in order to create a system that is able to advise decision makers (designers). This system should be compatible with BIM tool. The ES works as a filter that is capable of extracting specific information, from the database related to decision maker requirements. The filtration process is based on expert's knowledge that is available in the database module; and it is based on four steps: 1) identification step; 2) advisory step; 3) screening step; and 4) evaluation steps. Fig.5 illustrates the four steps of the proposed approach.

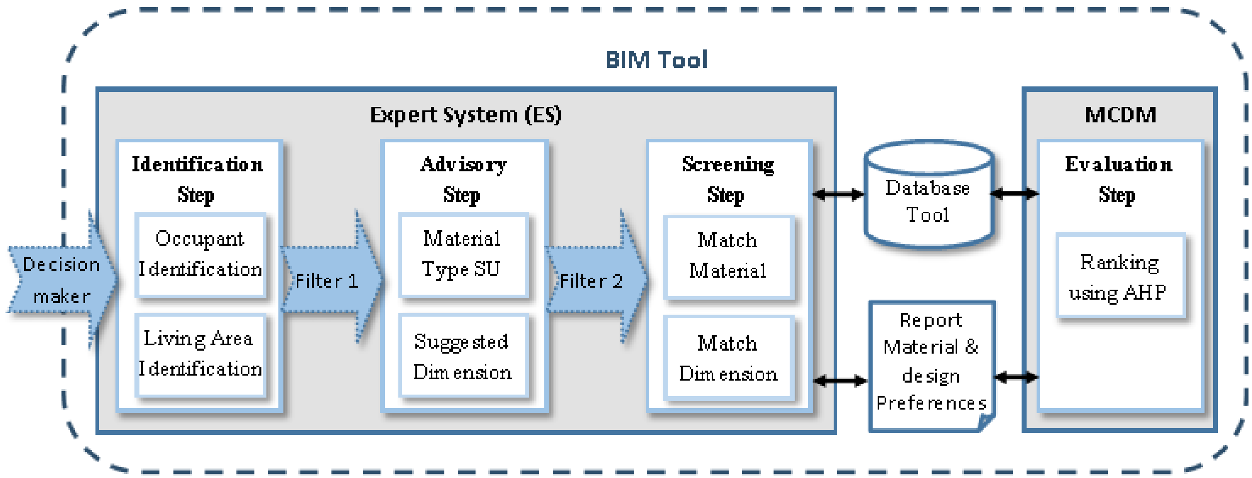

Figure 5: Steps of the proposed approach

3.4 3D Design Module

This module incorporates 3Ddesign families that are created in accordance with the sustainable and universal design requirements. These families are made of different green elements and their associated information such as cost, keynotes, specification, description and comments. These elements are created to have them handy whenever designers are consulting ES (Module 2) and while doing sustainable universal design for proposed house. Once the 3D design is done, the information related to the 3D project components can be exported to an external database using a Database Management System (DBMS) to calculate the project's life cycle cost as illustrated in Figure 6. LEED accreditation system and UD design standard for each component (i.e. door width, height of handrails, height and width of the kitchen sank) will also be incorporated within this module.

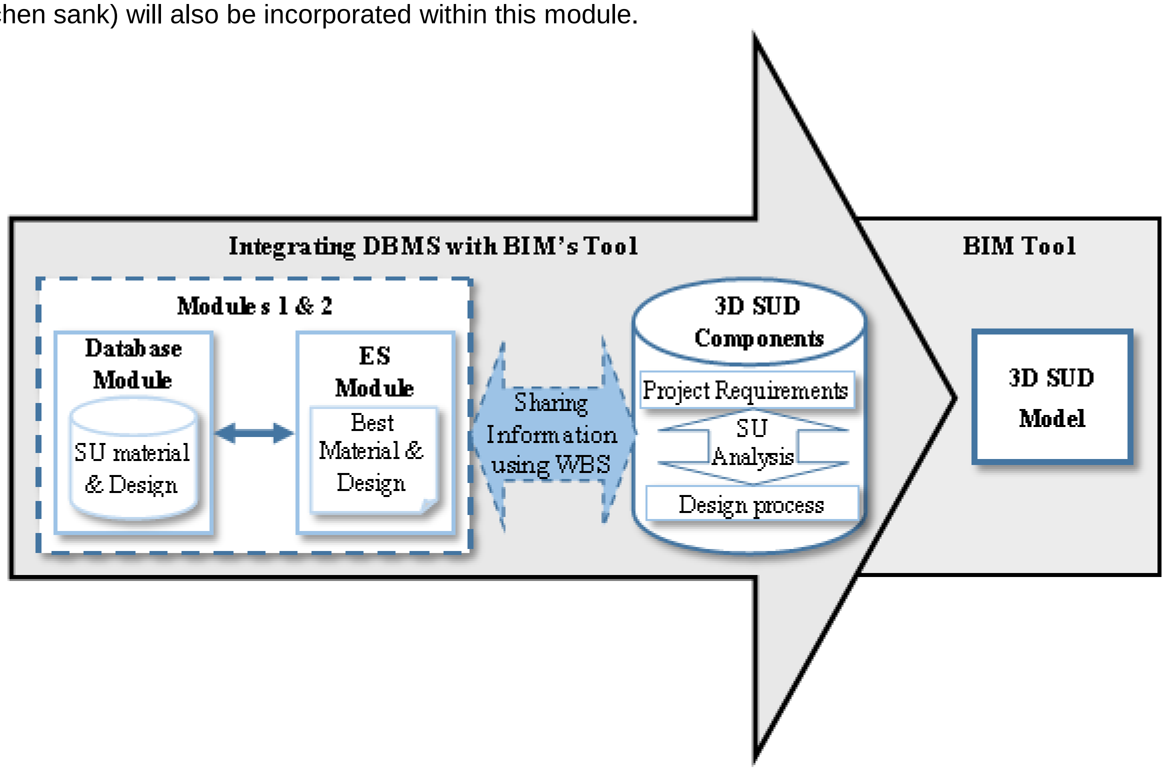

Figure 6: The process to integrate DBMS with BIM tool

3.5 Life Cycle Assessment (LCA) Module

The purpose of this module is to achieve an occupant's environmental satisfaction with the designed project. LCA evaluates the environmental impacts of Material/Components, selected based on ES Module, throughout its entire life cycle. It evaluates the material's life cycle with respect to different environmental aspects (e.g., energy, emission, and waste). As shown in figure7; the aim of this module is to link LCA tool (BEES™) with the 3D designed model`s database stored in BIM tool by using Microsoft VB.NET environment. Figure 7 depicts the integration process of the LCA module.

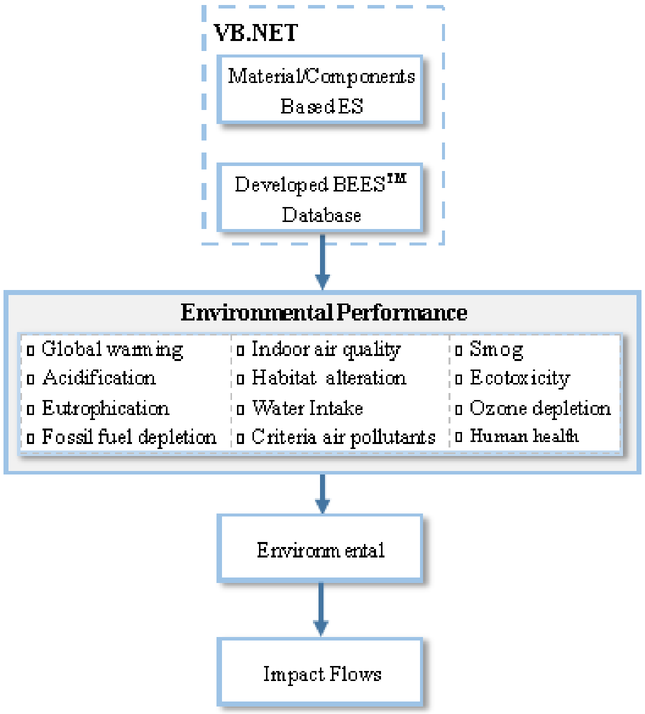

Figure 7: LCA integration process

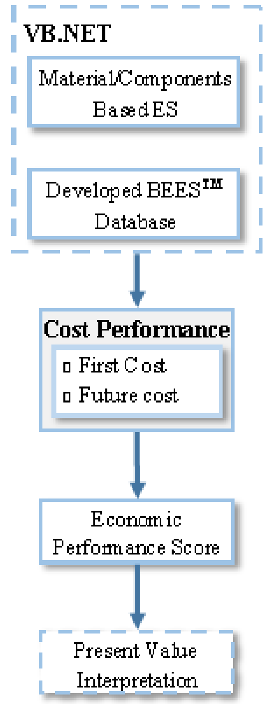

Figure 8: LCCA integration process

3.6 Module 5: Life Cycle Cost Analysis (LCCA) module

Similar to the approach adopted in the LCA module, the concept in the LCCA module is to extract the quantities of materials from the 3D designed model and send them to the LCCA tool (BEES™) in order to perform an economic analysis. In this module, the required cost of materials/components are retrieved from BEES™ and its performance is calculated based on decision taken in the ES Module within VB.NET environment. Figure 8 depict the LCCA integration process.

3.7 Module 6: Global Visual Basic Module

The purpose of this module is to control, organize, perform, and displays the overall information of the whole model's components. All the required estimates and calculations of the SU economic and environmental performance are performed within this module through the integration to the other modules for data retrieval. Thus, this module has the ability to interconnect with all the modules to perform all necessary calculations based on the decision maker preferences. Furthermore, it acts as the interface (shell) for the overall modules. In order to perform the said interconnections, a proper programming language is used to exchange information between database and BIM tool by using IF-THEN rule.

4 VALIDATION

The developed model should be validated to test its capability and workability; therefore, an eight floor case building project is used for that purpose. The project has an area of 11,320 S.F. First, 3D sustainable universal design of the case building is created by using BIM tool, which is Autodesk Revit in this case. Second, the selected materials and components associated with the created 3D design chosen from the database module.

4.1 3D Model Design

The families created in accordance with sustainable and universal design requirements are implemented into the 3D designed model of the case building. They are imported with their associated information (cost, keynotes, assembly code, specification and description), which are stored in the database module. The process of customizing BIM families is done by duplicating the existing family and adding the necessary parameters as illustrated in Figure 9.

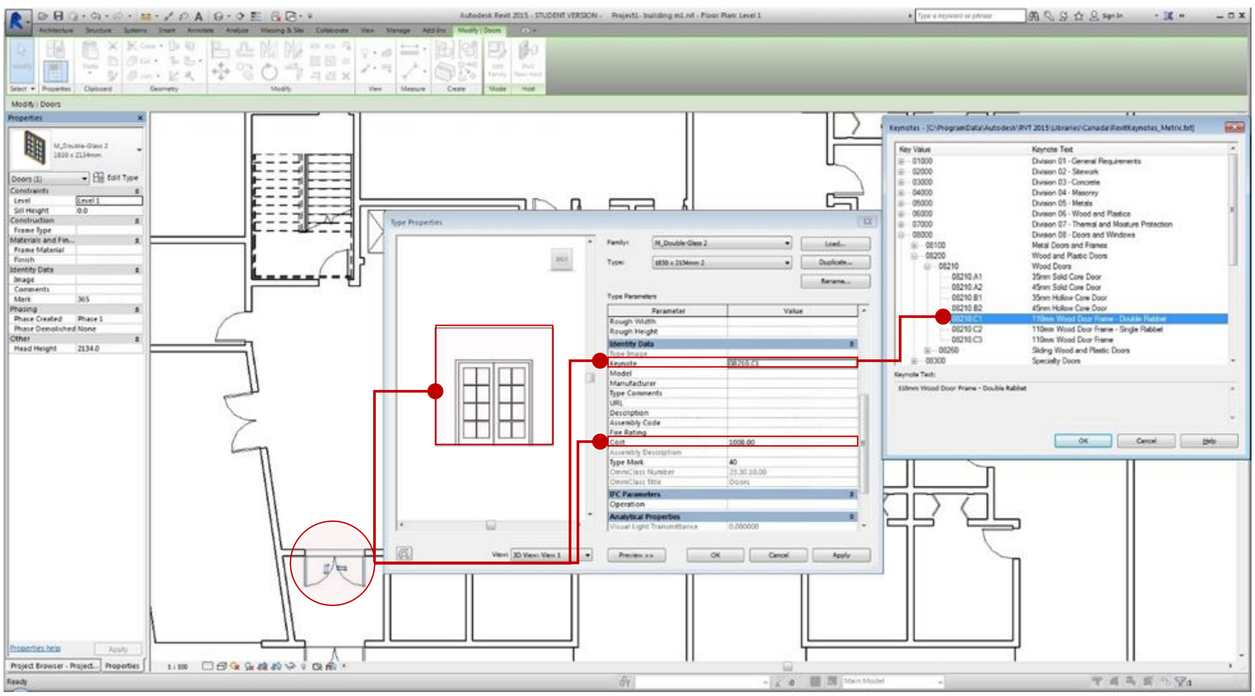

Figure 9: Snapshot of customizing BIM families

4.2 Interface Development

In order to demonstrate how the proposed model can assist decision makers while doing the design in BIM tool, the developed interface is illustrated in this section. The development of the interface considered the interoperability between two main environments: 1) BIM environment and 2) Microsoft environment. Fig. 10 illustrates the relation between the two environments. First, the BIM environment is where the plug-in is created in order to perform the interface role while designing the project in BIM tool (Revit). Second, the Microsoft environment which its role is to act as mean between BIM and Microsoft software (e.g. MS Excel, and MS VB.NET); accordingly, it perform all necessary tasks to retrieve, calculate, and provide all necessary information based on user (designer) desires.

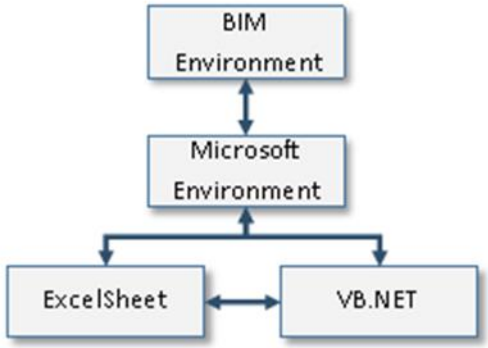

Figure 10: The relation between BIM, and Microsoft environments

4.3 Using Revit's SUD Plug-in

This section illustrates the sequences that a designer faces when using the SUD plug-in. Fig. 11 shows the steps that the designer should go through in order to consult the SUD plug-in. The four main step (identification, advisory, screening, and evaluation), which are illustrated in the ES module, are implemented in this interface; each step shown in the interface guides the designer prior to start the consultation. After defining the preferred parameters in each step, a SUD report can be generated. Fig. 12 depict sample of the report generated by the developed plug-in.

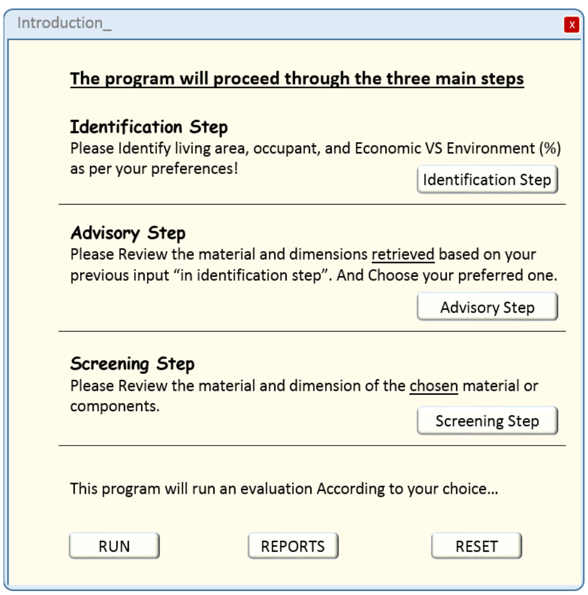

Figure 11:The four main steps to consult SUD plug-in.

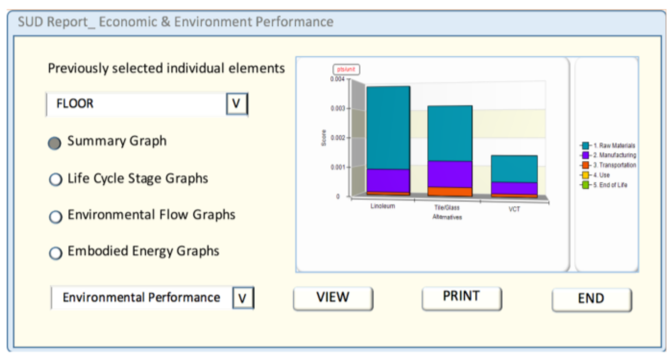

Figure 12: Sample of the report generated by the developed plug-in

5 CONCLUSION

The paper emphasised the importance of considering sustainable universal design strategies at the early stage of buildings' design. The model was developed in order to integrate BIM with SUD principles in order to evaluate the costs and benefits of adopting this type of building projects. Outputs of the developed model consist of a list of the selected SU materials and components along with their LCA and LCCA reports, in addition, their associated LEED accreditation level; list of the associated universal design standards and suggestion; and list of 3D SUD families. Having such a model helps designers, owners, and developers evaluate and compare the benefits of adopting the design and construction of sustainable universal buildings.

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