5th International/11th Construction Specialty Conference
5e International/11e Conférence spécialisée sur la construction

Vancouver, British Columbia
June 8 to June 10, 2015 / *8 juin au 10 juin 2015*

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

Bader Alsayyar[1] and Ahmad Jrade[2]
[1] PhD Student, Department of Civil Engineering, University of Ottawa
[2] Assistant Professor, Department of Civil Engineering, University of Ottawa

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 facilities. As the North American population is aging Universal Design 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 benefits and costs associated with adopting the concept of sustainable universal design applied for building projects. Therefore, this paper proposes a methodology to develop a model that integrates BIM tools with SUD requirements and strategies (i.e. Energy, material, and indoor air quality and barrier free environment) and to evaluate the associated benefits and costs of proposed buildings at their conceptual design stage. The proposed model consists of three main modules. First, a database module, which is mainly devoted to illustrate items necessary toward SUD approach including: hand rails, entrance slope with its associated material and lighting shapes and specification. All of the mentioned items will be in accordance with the standards (i.e. Canadian National Building Code (CNBC), LEED, international standards). Second, a 3D design module will describe the design components and system used in the different areas in the 3D conceptual design (i.e. living room, toilet, and kitchen). Finally, a cost benefit analysis module that will evaluate the initial cost of each designated area that complies with the needs of aging people who have chronicle health conditions, where the total cost and benefits is calculated accordingly. The effective development of the integrated model will help owners, designers, and developers to evaluate the cost and benefits of adopting sustainable universal buildings. An actual case project is used to test the workability, capability and performance of the proposed model.

1 INTRODUCTION

The sustainable approach is widely adopted in today's construction industry. This notable adaptation of the sustainable approach emphasise its importance 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 building 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 starting from the early stage of its life cycle. It helps designers to visualize their design and their associated materials and technologies before the building physically exists (Bryde, Broquetas, and Volm, 2013). This paper proposes a methodology to integrate BIM with the SUD principles and requirements in order to evaluate the benefits and costs of adopting such type of design over buildings anticipated life.

2 LITERATURE REVIEW

The primary objective at the early stage of building projects is to design and evaluate their budget and 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 ecological 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 involve 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 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 accordingly the proposed model's conceptual design process can be started. The process consists of three 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 method and ending by the validation part. Afterwards, the model's components and architecture are identified.

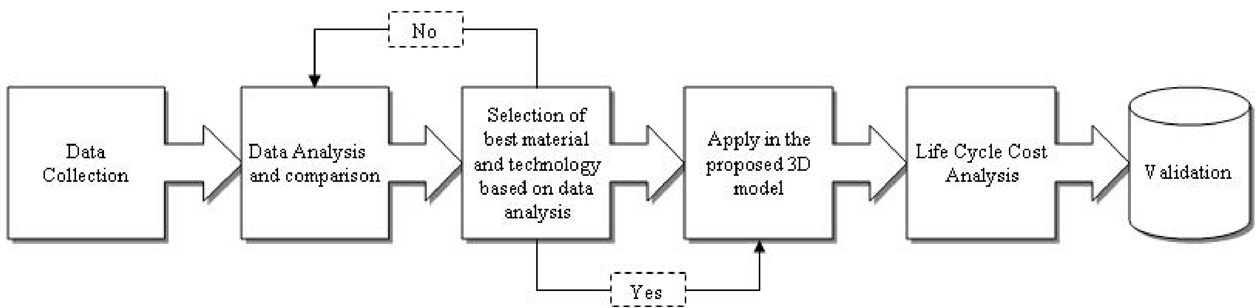

Figure 1: Methodology's approach.

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. The proposed model incorporates the following three modules: a database module; a sustainable and 3D design module; and a life cycle cost analysis module. Figure 2 illustrates the components of the proposed model.

In order to simplify the development process of the proposed model its architecture is created as shown in Figure 3. The analysis section used to examine the input data and its criteria (i.e. SUD strategies, sustainable materials, and energy performance, Masterformat). The analysis is based on the set 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, accumulated LEED credit points and certification level, total cost of the selected materials, total cost of the selected technology, net cost of the project, and life cycle cost analysis.

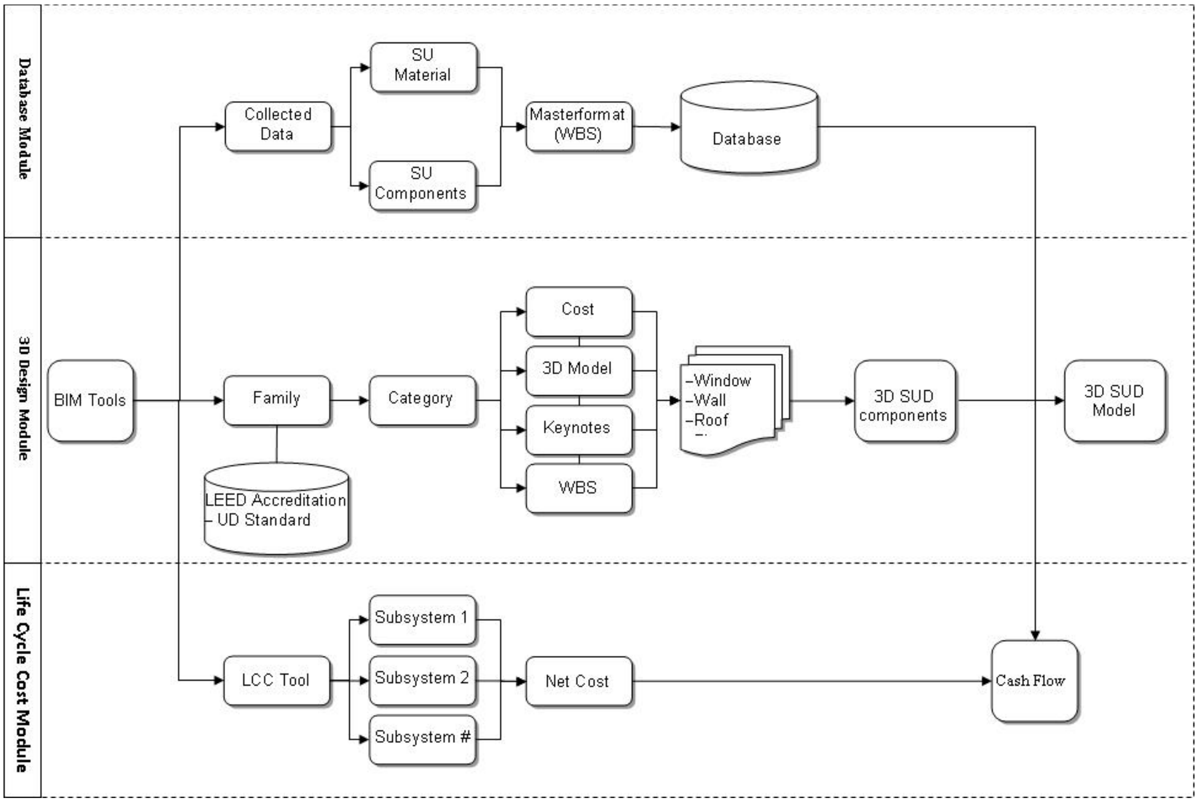

Figure 2: Model's components

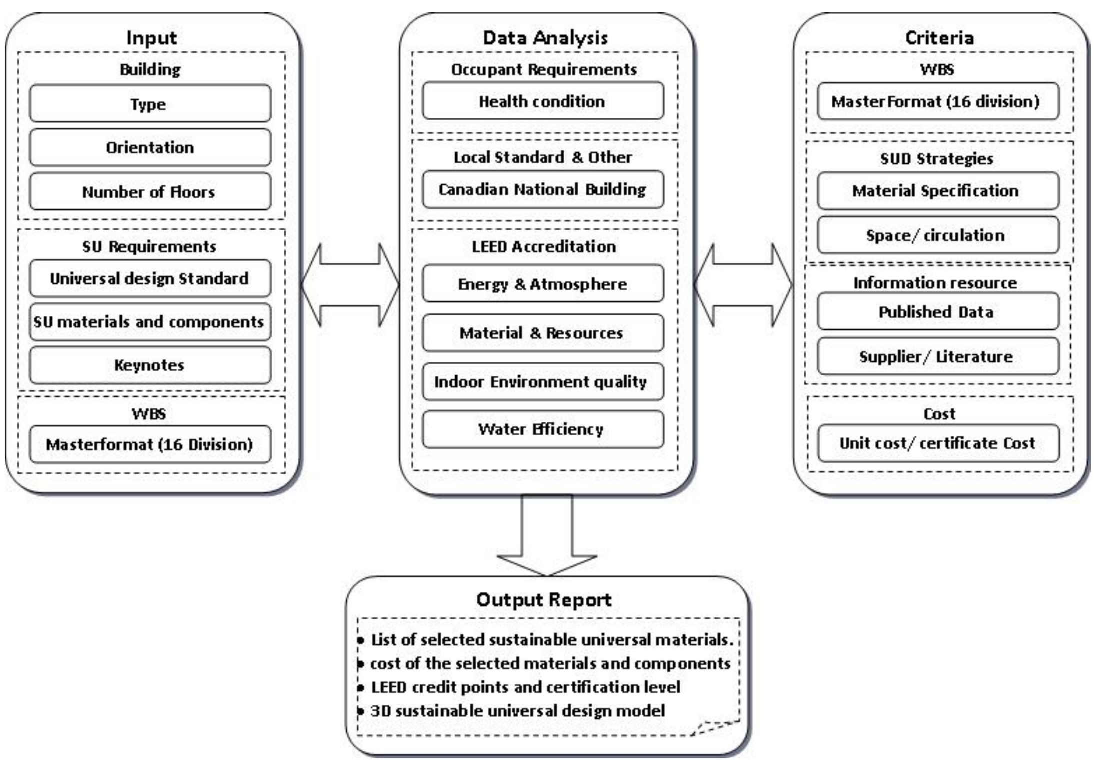

Figure 3: Model's Architecture

3.2 Module 1: Database Module

The module's objective is to establish a database necessary to apply the SUD approach. Set of data were collected form the literature, publishers, and suppliers, which include information related to materials and components used in doing sustainable universal design such as 3D design families for windows, walls, and roofs. This data is analysed and evaluated based on SU strategies and their technical specifications, LEED and CNBC. After that the collected data is stored and organized in the database based on the Masterformat Work Breakdown Structure (WBS), besides is the associated costs as shown Figure 4.

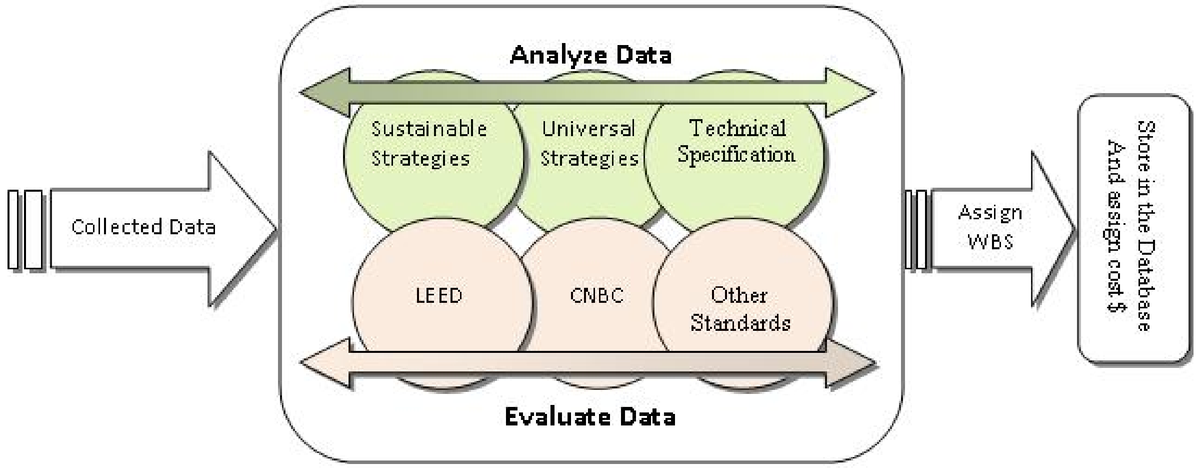

Figure 4: Data collection process of the sustainable universal materials and components.

3.3 Module 2: 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 doing sustainable universal design for proposed buildings. 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 5. 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 the module.

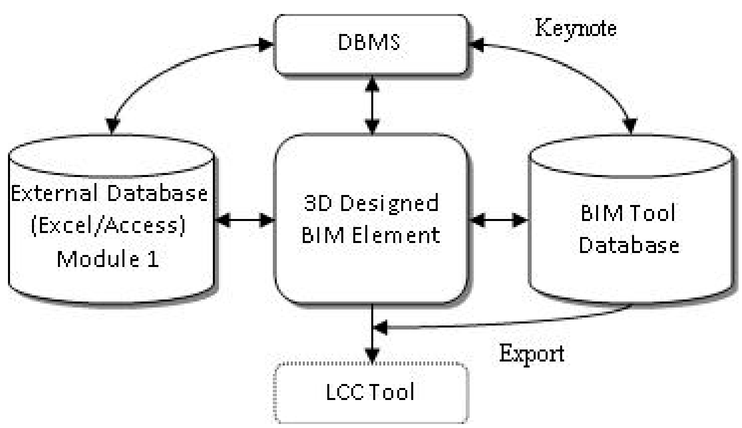

Figure 5: The process to integrate DBMS with BIM tool

3.4 Module 3: Life Cycle Cost Analysis

This module is developed to evaluate the costs and benefits of adopting SUD; accordingly, a cash flow will be generated for analysis and comparison purposes. The module works based on two systems. The first system is to calculate the cost of the elements used in a 3D design of the proposed project by using BIM tool (i.e., Autodesk Revit). The second system is to extract the total cost obtained from "system 1" to calculate the cost benefits and to generate the cash flow accordingly. Figures 6 and7 illustrate the module's process and components.

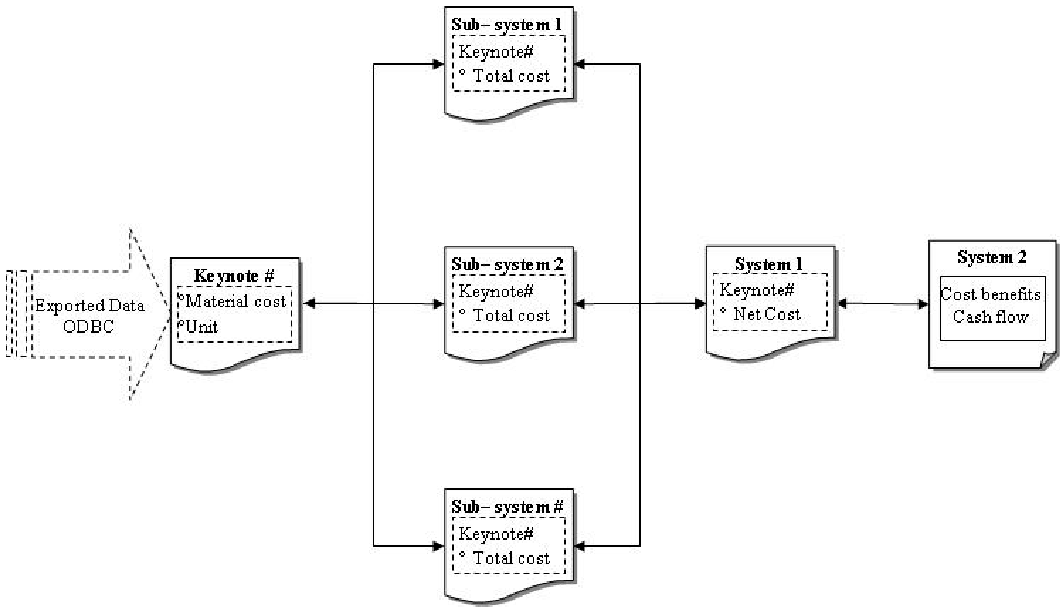

Figure 6: Module's system Process

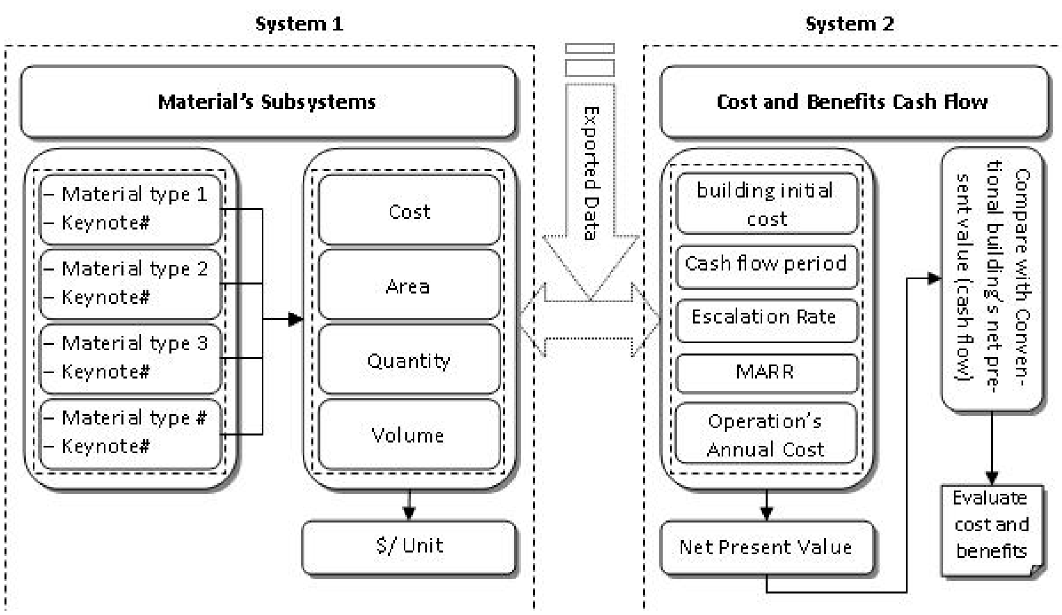

Figure 7: Cost benefits analysis module's components

4 VALIDATION

The developed model should be validated to test its capability and workability; therefore, a one floor case building project is used for that purpose. The project has an area of 8,089 ft^2. First, 3D sustainable universal design of the case building is created (using BIM tool, which is Autodesk Revit in this case, as shown in Figure 8). Second, the selected materials and components associated with the created 3D design chosen from the database created in module 1. The cost of a similar conventional building was obtained from RSMeans© Cost Data in order to compare it with the cost of the created 3D SU design.

Figure 8: 3D sustainable universal model

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 of module 1. The process of customizing BIM families is done by duplicating the existing family and adding the necessary parameters as illustrated in Figure 9.

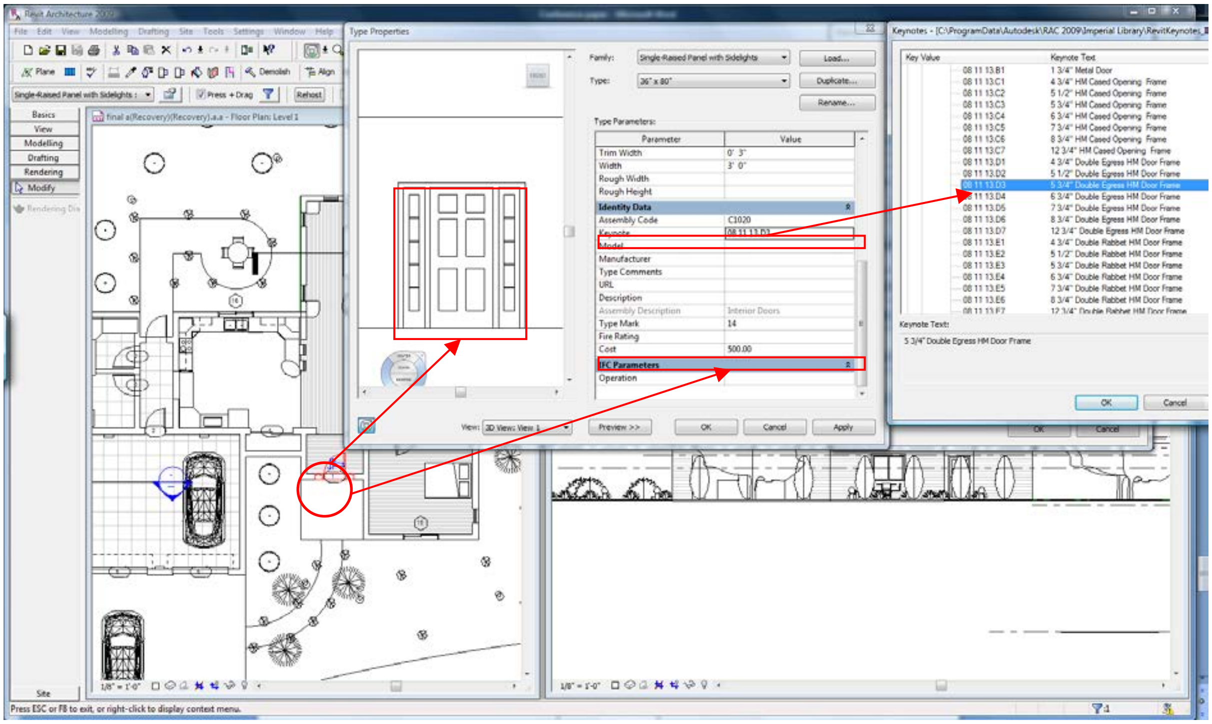

Figure 9: Snapshot of customizing BIM families

4.2 Cost Benefits

This section presents the final result of the LCCA module that recognises the selected design elements by their keynotes. Therefore, after exporting the information of the 3D SU design model of the case building, the costs of these elements are automatically extracted from the external database based on their associated keynotes. Accordingly, the cash flow is generated for analysis and comparison as shown in Figures 10 and 11.

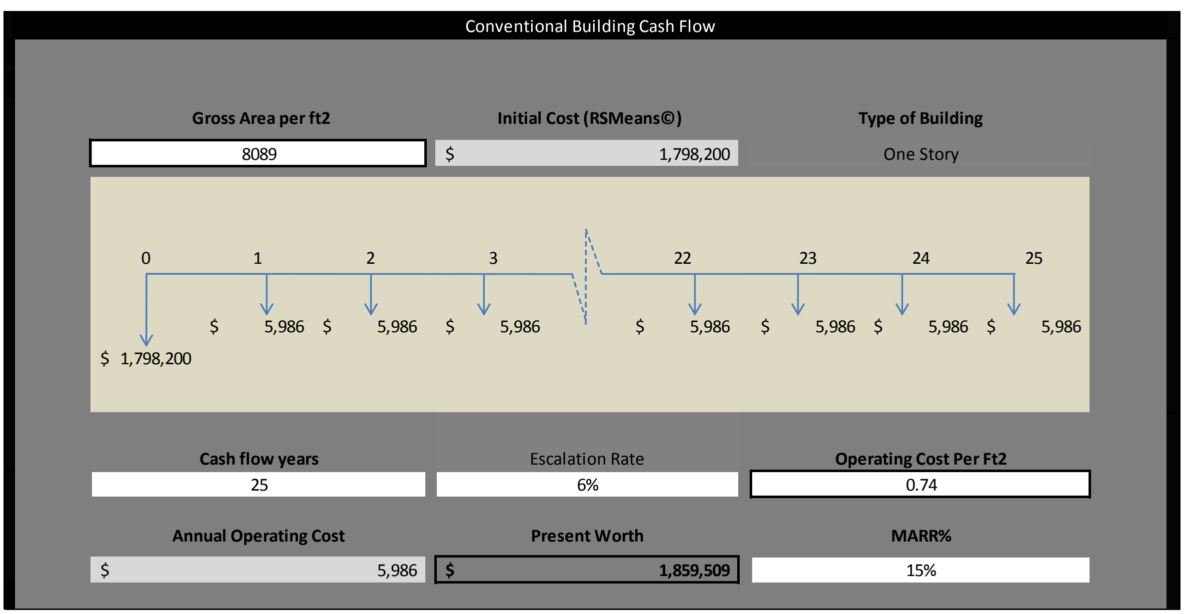

Figure 10: Conventional building's cash flow

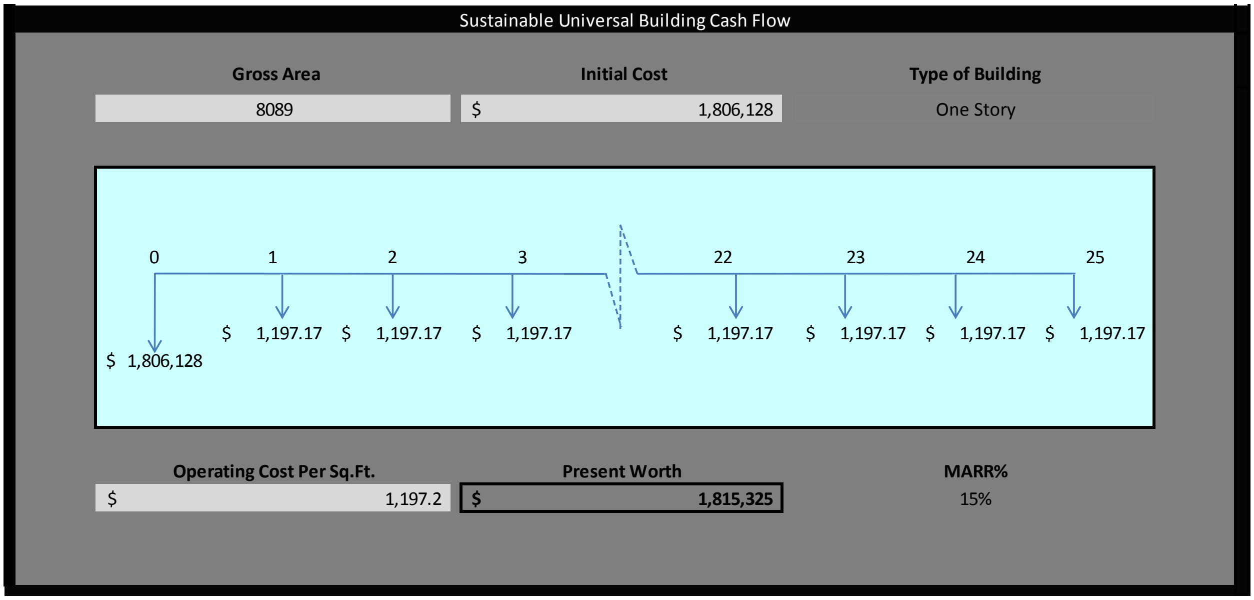

Figure 11: Sustainable universal building's cash flow

5 CONCLUSION

The paper emphasised the importance of considering sustainable universal design strategies at the early stage of designing buildings. The paper 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, their associated LEED accreditation level; list of the associated universal design standards and suggestion; and a LCCA report presented in the form of cash flow that is automatically generated. Having such a model helps designers, owners, and developers evaluate and compare the benefits of adopting the construction of sustainable universal design buildings.

6 REFERENCES

Afacan, Yasemin, and Cigdem Erbug. 2009. "An Interdisciplinary Heuristic Evaluation Method for Universal Building Design." *Applied Ergonomics* **40** (4). Elsevier Ltd: 731–44.

Arayici, Y, SP Coates, LJ Koskela, M Kagioglou, C Usher, and K O'Reilly. 2009. "BIM Implementation for an Architectural Practice.

Bogenstätter, Ulrich, and Ulrich Bogensta. 2010. "Prediction and Optimization of Life-Cycle Costs in Early Design Prediction and Optimization of Life-Cycle Costs in Early Design," no. February 2015: 37–41.

Bryde, David, Martí Broquetas, and Jürgen Marc Volm. 2013. "The Project Benefits of Building Information Modelling (BIM)." *International Journal of Project Management* **31** (7). Elsevier Ltd and APM IPMA: 971–80.

Demirbilek, Oya, and Halime Demirkan. 2004. "Universal Product Design Involving Elderly Users: A Participatory Design Model." *Applied Ergonomics* **35**: 361–70.

Demirkan, Halime, and Nilgün Olguntürk. 2014. "A Priority-Based ' Design for All ' Approach to Guide Home Designers for Independent Living" **57** (2): 90–104.

Dhawade, S M, and S M Harle. 2014. "Green Technology- A Review," no. **3**: 51–55.

Hoffman, A. J., and R. Henn. 2008. "Overcoming the Social and Psychological Barriers to Green Building." *Organization & Environment*.

Hunter, Rebecca H., Kathy Sykes, Sarah G. Lowman, Richard Duncan, William a. Satariano, and Basia Belza. 2011. "Environmental and Policy Change to Support Healthy Aging." *Journal of Aging & Social Policy* **23** (January 2015): 354–71.

Jrade, Ahmad, and Paola Zurro Valdez. 2012. “Integrating Building Information Modeling with Universal Design Requirements for High Accessible Homes.” *Construction Research Congress 2012 © ASCE 2012*, 1291–1300.
König, C. 1995. “Computing in Civil and Building Engineering.” *THE SIXTH INTERNATIONAL CONFERENCE ON COMPUTING\rIN CIVIL AND BUILDING ENGINEERING*, 1179–84.
Wang, N, and K M Fowler. 2012. “Green Building Certification System Review,” no. March.
Zhang, Shaojie, and Tieqiao Xiao. 2013. “Building Information Modeling and Sustainable Architecture Design Analysis.” *Proceedings of the 2013 International Conference on Advanced ICT*, no. Icaicte: 758–62.