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Framework for Evaluating the Sustainability of Buildings' Design in Saudi Arabia Using Building Information Modeling

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***Abstract*—Building information modeling (BIM) and green building are currently two major trends in construction industry. This study aims to develop a sustainability assessment framework for buildings' design in Saudi Arabia using BIM technology in extracting data needed for determining the level of sustainability from the digital building model. The sustainability-BIM framework helps designers in accommodating sustainability goals and making more informed decisions at the early design stage. The framework can be used also to improve the sustainability of existing buildings through sustainability assessment and adopting modifications and improvements to achieve more sustainable building. The first phase of this study has been devoted to develop a national rating system for sustainability assessment through identifying the evaluation criteria and their measurement methods and relative weights. The next phase of study includes interpreting the rating system requirements and identifying the BIM functionalities. The credit estimation for the sustainability criteria can be determined through the integration between the rating system requirements and the BIM functionalities. The third phase of this study is developing the sustainability –BIM framework based of previous phases results. This phase includes developing the rating system template in the BIM model and then programing new BIM functionalities (inclusion the calculation formula for criteria) through Revit API (Application Programming Interface) provided by Autodesk using Visual Basic/ Visual C#. The last phase of study includes the validation process of the developed framework and perform the necessary modifications and improvements.**

***Keywords*—sustainability, BIM, rating system, building, Saudi Arabia**

I. Introduction

Resources scarcity and environmental challenges lead to increase the importance of adoption of more sustainable life style (Ljungberg 2007). One of the major consumer of nonrenewable resources and also responsible for a huge portion of waste production is construction (Bakhoum and Brown 2012). Generally, the building sector in the developed countries are responsible for 40% of carbon emissions and consumes about 30% of total produced energy (IPCC 2007). More specifically, in United States buildings are responsible for 40% of the national energy consumption, 72% of electricity consumption, 39% of carbon emissions, 30% of waste output, and 13% of water consumption (USGBC 2009; 2012). The resource consuming increases in the countries that suffering from extreme environmental conditions such as Saudi Arabia especially water and energy consuming. In Saudi Arabia, about $133 billion has earmarked by Saudi government for various water and energy projects over the next decade (The Economic Times 2013). To minimize the construction negative environmental impacts, there is critical need to take actions to ensure obtaining sustainable and green buildings (Abdallah et al. 2013). Many countries are devising policies to promote green and sustainable developments. With the increasing the consciousness of environmental issues, many countries are devising policies to promote sustainable developments (Cheung 2013).

Building information modeling (BIM) has been a growing development in the construction industry. BIM can be used to construct virtual building prior to construction of the actual building. This helps in achieving more efficient design that optimize energy usage and reduce the waste of resources (Bynum, et al. 2013). Creating integration between the BIM and the sustainability rating systems helps in assessment the sustainability of building's design in early design stage and selecting the best design alternatives. The main objective of this paper is to develop a sustainability assessment framework for buildings' design in Saudi Arabia using BIM technology in extracting data from the digital building model needed for determining the level of sustainability. This framework helps the designers to evaluate the sustainability for the building in design phase and making the necessary modifications to achieve sustainable design. The framework can be used also to evaluate the sustainability of existing buildings that can be modified to be more sustainable.

II. Background

The environmental issues has become a great concern among professionals in the construction industry in trying to minimize the environmental impact and achieving sustainable construction. Of the most common ways to achieve sustainable buildings is sustainability rating systems. In worldwide, more than 600 sustainability rating system that can be used to evaluate the sustainability of buildings through set of sustainability criteria such as LEED, BREEAM, Green

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Globes...etc. (BRE 2008). The sustainability criteria and their importance weights usually differ of the country to another. This variation comes from the differences in environmental requirements and weather conditions. In Saudi Arabia, there is a critical need to develop a national sustainability rating system that suits the hard weather conditions and satisfy the construction industry needs for sustainable constructions.

Adoption of BIM in construction has revolutionized the construction industry which made the design and execution process more efficient and less costly. BIM is a digital representation of characteristics of any built object which forms a reliable basis for evaluating the alternatives and making decisions (ISO Standard 2010). This approach provides the data needed for analysis and evaluation the building performance (Nguyen and Gao 2010). There is misconception among many of practitioners in construction industry that BIM just a software for 3D geometric drawing. BIM can be used for many purposes including; 3D visualization, fabrication/shop drawings generation, cost estimating, construction sequencing, conflict, interference, and collision detection, forensic analysis, and facilities management (Azhar, 2011). Using BIM in construction industry helps in achieving more effective construction and provides accurate information and geometrical representation of the building elements. Stanford University's Center for Integrated Facilities Engineering, studied the impact of using BIM among 32 major projects and they concluded that using BIM in these projects reduced the change orders, increased the accuracy of cost estimation, reduced the time for cost estimation, saved the cost through fixing the clash detections, and reduced the projects time (CRC Construction Innovation 2007).

Developing sustainable analysis tools helps designers to make better informed decisions in the early design process. Some of BIM applications. Some of BIM applications such as, Green Building Studio (GBS) and Ecotect from Autodesk evaluates some of sustainability aspects such as energy and water consumptions. However, these applications does not provide sustainability assessment according to holistic rating system. Wu, and Issa, (2010), studied the feasibility of integrating BIM and LEED (Leadership in Energy and Environmental Design) certification process. Their research proposed and demonstrated that the BIM-LEED integration was feasible with considerable constraints. Wu, (2010), developed a "Design Assistance" module that integrated between BIM software and LEED rating system using the Autodesk Revit API to facilitates more accurate implementation of BIM in green building certification and ensure the design was LEED-oriented. Nguyen and Gao (2010), developed a sustainability assessment framework for buildings design using BIM technology in extracting data from the building model to determine the level of sustainability based on the LEED Green Building Rating System, a widely accepted national standards for sustainable building design in the United States. Moakher and Pimplikar (2012), also integrated BIM with some of sustainability aspects. They highlighted how BIM can be used to accurately analyze daylight in buildings. Similarly, Cho, et al. (2012), used BIM to evaluate the design of energy efficient building. Azhar, et al. (2011), presented a case study that was conducted on Perdue School of Business building in Salisbury University to demonstrate the use of BIM for the LEED certification process and achieving sustainable design. In conclusion, most of previous studies tried to integrate BIM with some of sustainability aspects according to LEED rating system. This study attempts to achieve a holistic integration between BIM and sustainability based on Saudi sustainability rating system.

III. Sustainability –BIM Framework

The sustainability-BIM framework aims to evaluate the sustainability of buildings in Saudi Arabia through integrating the BIM technology with the national sustainability rating system. To develop this framework, the following phases must be carried out:

- Develop a national rating system for evaluating the sustainability of building in Saudi Arabia. The Saudi sustainability rating system includes; identifying the key criteria for sustainable buildings, identifying appropriate measurement methods for sustainability criteria, and identifying relative importance weights for sustainability criteria.
- Identify the rating system requirements through analysis all system criteria and interpret them into qualitative or quantitative data requests.
- Review the BIM functions to assist in achieving the rating system requirements.
- Integrating the requirements of the developed rating system with BIM functionalities. This integration helps in identifying how to satisfy each of system requirements within BIM functionalities.
- Develop the rating system template in BIM model that include all system groups and criteria, relative importance weights, and points information.
- Enhance the current BIM functionalities with new functionalities that help in estimating the sustainability score for system criteria.
- Validation processes and performing the necessary modifications and improvements. Figure 1 shows the main components of sustainability-BIM framework.

A. *Sustainability Rating System*

There are many rating system for evaluating the sustainability. However, each rating system designed to suit the environment conditions in specific area. In order to develop a sustainability rating system suits the extreme weather conditions and the differing requirements in Saudi Arabia, this phase of study involves the following steps (shown in Figure 2).

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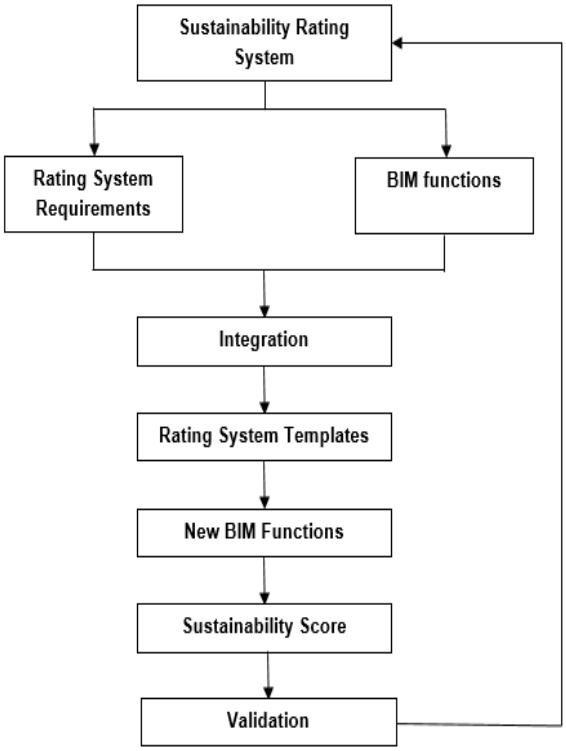

Figure 1. Sustainability-BIM framework components

1. Sustainability criteria

This step aims to identify the key sustainability criteria for buildings' design in Saudi Arabia. For this purpose, set of international and regional rating systems has been reviewed such as LEED, BREEAM, Green Globes, GPRS, and Pearl. Through this review, a list of initial criteria can has been identified and classified within seven main groups including; sustainable sites, water efficiency and conservation, energy efficiency and conservation, material selection and recycle, indoor environmental quality, innovation and regional priority , and design and management. Sustainable sites groups and their criteria deals with the impact of the building site on environment, reducing environmental damage, pollution due to building construction. Water efficiency and conservation group deals with reducing water usage and pollution. Energy efficiency and conservation group deals with improving energy efficiency within buildings. Material selection and recycle group deals with selecting sustainable materials and studying the other life cycle issues associated with the manufacture, transport, and installation. Indoor environmental quality group deals with reducing indoor pollutants and providing a healthy indoor environment. Innovation and regional priority group deals with encouraging the use of innovative environmental design with considering the cultural and regional practices. Design and management group deals with improving management and design practices to maximize the environmental benefits and minimize the negative impacts. Based on initial criteria, a questionnaire has been designed and used to identifying the appropriateness of initial criteria for Saudi rating system through set of experts and practitioner engineers working in Saudi construction industry. Using severity index (SI) for data analysis, list of key criteria has been identified within the seven main sustainability groups mentioned above. According to SI analysis results for the sustainability groups, the water efficiency and conservation and energy efficiency and conservation groups achieved highest SI score with 98% and 95% respectively. While innovation and regional priority and design and management groups achieved lowest SI score with 74% and 69% respectively.

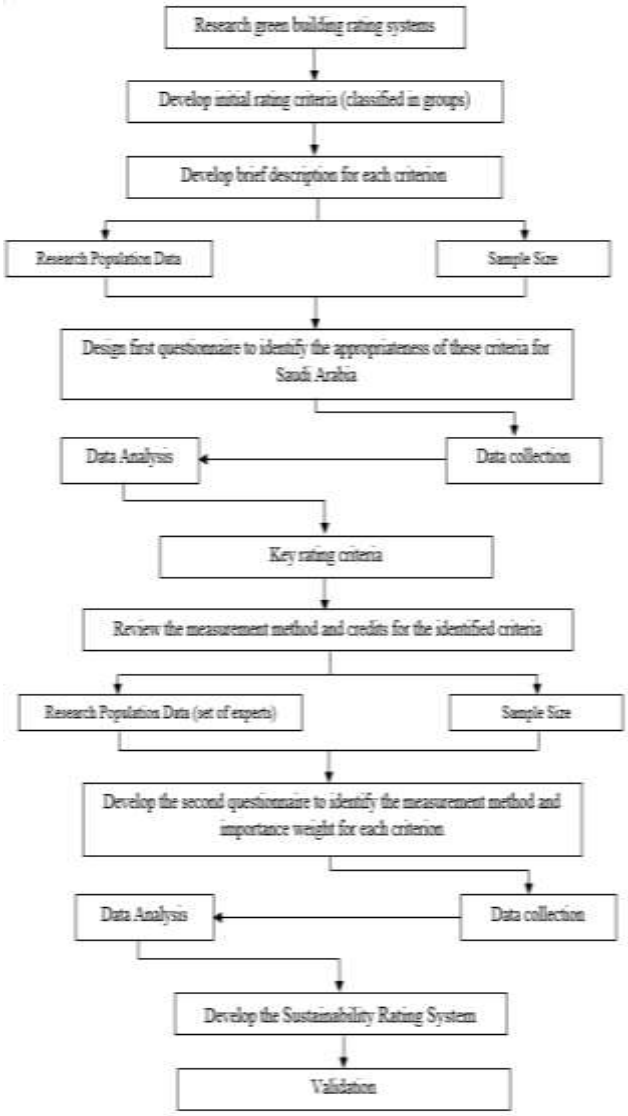

Figure 2. Process of developing rating system

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2. Measurement methods and weights for criteria

There is no standard method for measuring the numerical value for criteria in literature. In this step, set of measurement methods for criteria has been identified through literature. These methods represent the base for designing the second questionnaire that aims to standardize measurement methods of criteria. The differences in weights of criteria should be considered when using these criteria to estimating the sustainability score for buildings. Identifying the relative weights for criteria needs a numerical comparing technique. This technique should define the importance of each factor in relation to other factors. Several techniques can be used to achieve this step of study such as Analytical Hierarchy Process (AHP) and Simos. AHP developed by Thomas L. Saaty in the 1970s (Sun 2005). It has been extensively used and refined since then. AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales. It is originally a structured technique for organizing and analyzing complex decisions (Saaty 2008). Simos (1990a, b) proposed a technique allowing any DM to express the way in which he wishes to hierarchies the different criteria of a family F in a given context. This procedure also aims to communicate to the analyst the information he needs in order to attribute a numerical value to the weights of each criterion of F (Roy and Mousseau, 1996; Roy and Bouyssou, 1993).

3. Develop and validate the Sustainability Rating System

Sustainability rating system can be developed based on the results of previous steps in this phase of study. This system can be validated through set of real case studies.

B. *System requirements and BIM functions*

This phase of study aimed mainly to identify the rating system requirements and the BIM functions and then integrating the system requirement with BIM functions. Identifying the rating system requirements come through analysis all system criteria and identifying their requirements and interpret them into qualitative or quantitative data requests. This step helps in identifying the credit estimation plan for each criteria. Identifying the BIM functionalities aims to review the functionality that BIM applications possess to assist in achieving the rating system requirements. The BIM applications include Revit suite, Ecotect, Green Building Studio, etc. After identifying the system requirements and the type of data associated, it is time to match up these requirements with the identified BIM functionalities.

C. *Generating new BIM functions*

This phase of study started with developing the rating system template in BIM application and then generating new BIM functions to calculate the sustainability score. In BIM application, the project template can be developed and customized according to project requirements. This feature helps in developing the rating system template in BIM application. Accordingly, the sustainability criteria can be created and stored as parameters in BIM application (Figure 3). Most of rating system requirements are not available in current BIM functions. Accordingly, new BIM features must be generated to satisfy all requirements of the national rating system. Through these functions, the sustainability score can be calculated for each criteria and also the total sustainability score for the building which can be used for evaluating the sustainability of building's design. Revit API can be used to create and insert external applications into the Revit platform (Wu, 2010). API developers can; gain access to the graphical and parameter data in the model, create and edit model elements and integrate external applications into Revit products such as sending model data to an analysis application or linking an external database to Revit (Autodesk 2009). The Revit API is compatible with many programming language including Visual Basic, C#, and C++. Validation process for the developed framework can be performed on some case studies through comparing the framework results with manual calculation and also comparing the results with the other international rating systems. Modifications and improvements can be performed according to the validation results.

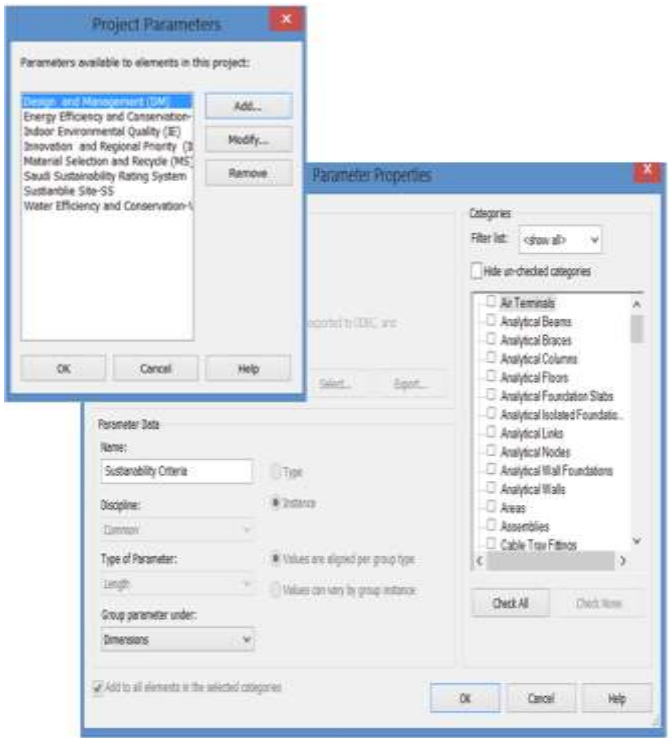

Figure 3. Creating the sustainability criteria in Revit

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IV. Conclusion

With the growing the impact of buildings on environment and resource limitation, many construction industry sectors began giving more attention to develop sustainable buildings. The most common method for assessing the sustainability of buildings is the use of rating systems. The conventional use for these system consumes a lot of time and efforts. Accordingly this paper integrated between the rating system and BIM technology to make the evaluation processes faster, convenient and more accurate. The sustainability- BIM framework developed in this study depended on national rating system suits the requirements and hard weather conditions in Saudi Arabia. This system consists of seven main groups. The water and energy groups' achieved the highest importance among the other sustainability groups due to the high temperatures, which cause higher consumption of water and energy. The framework extracts the data from BIM model to satisfy the rating system requirements and then calculates the sustainability score. Accordingly, the sustainability evaluation can be performed in the early stage in design process which helps the designer to modify the design to be more sustainable.

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