A Framework of Building Knowledge Representation for Sustainability Rating in BIM

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ABSTRACT: Recently, sustainable building design, a growing field within architectural design, has been emerged in the construction industry as the practice of designing, constructing, and operating facilities in such a manner that their environmental impact, which has become a great concern of construction professionals, can be minimized. A number of different green rating systems have been developed to help assess that a building project is designed and built using strategies intended to minimize or eliminate its impact on the environment. In the United States, the widely accepted national standards for sustainable building design are known as the LEED (Leadership in Energy and Environmental Design) Green Building Rating System. The assessment of sustainability using the LEED green rating system is a challenging and time-consuming work due to its complicated process. In effect, the LEED green rating system awards points for satisfying specified green building criteria into five major categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality; and sustainability of a project is rated by accumulating scores (100 points maximum) from these five major categories. The sustainability rating process could be accelerated and facilitated by using computer technology such as BIM (Building Information Modeling), an innovative new approach to building design, engineering, and construction management that has been widely used in the construction industry. BIM is defined as a model-based technology linked with a database of project information, which can be accessed, manipulated, and retrieved for construction estimating, scheduling, project management, as well as sustainability rating. This paper will present a framework representing the building knowledge contained in the LEED green building criteria. The proposed building knowledge framework will be implemented into a BIM platform (e.g. Autodesk Revit Architecture) in which sustainability rating of a building design can be automatically performed. The development of the automated sustainability rating system and the results of its implementation will be discussed.

Keywords: Knowledge Representation, Building Information Modeling (BIM), Sustainability, Green Buildings, Green Rating Systems, and LEED

1. INTRODUCTION

It has been a long time since the sustainable development has been recognized as the unique solution to heal the negative impact of the industrial evolution on environment by humankind [1]. On the other hand, nowadays, the 3D modeling applications have the capability of designing a complex product in many industries including AEC (Architecture, Engineering & Construction) industry. Furthermore, by the help of Industry Foundation Classes (IFC), the new concept of sharing information has been introduced to modeling products. The BIM models is an example of the tools that has been developed based on the sharing information concept.

Another important issue in the AEC industry is the sustainable development [2]. Despite the necessity of sustainability, the level of its implementation into the AEC industry is low. Through the survey from over 200 engineers, Chong et al. (2005) finds that the organizations, where participant to survey has been working at, have implemented the sustainability in their project at extremely low levels. The green building evaluation systems can play a major role in improving the sustainability level of construction projects. The key for adding sustainable concept into a project is to define the goal at early stage of design and persuade that goal through different stages of a project.

The current building models are all explicitly providing component, attributes of component and relationships between them. However to provide a product model that be useful to evaluate sustainability ratio, we need to add the features to the existing product models to make them capable of determining the sustainability ratio of a project. This rate can help us to realize how sustainable and green a building is, even at its early stages of design. By providing such a capability for product models, not only we can reduce the cost and save time, but also we add the

potential of improving the overall sustainable ratio to a project. For achieving such a goal, the feature framework that is presented in this paper provides the base and path for transforming design-focused product models into feature-based product models that support the extra features for rating the sustainability of buildings. This framework has project independent base to make it possible for using it for variety of projects.

2. BACKGROUND

2.1 Building Information Modeling (BIM)

Since the introduction of the BIM, as a super ordinate concept, the AEC industry has seen a rapid growth of modeling in different section from architectural section to MEP and structure. Beside the advanced graphic environment that BIM product model provides, it offers an essential advantage: a platform that users can access, control and modify information of a shared model. With the help of BIM-based management environment, users can share all information during the different stages of the project progression from pre-design to occupancy. The BIM software generally consists of two sort of informations:1- building elements and attributes and 2- the relationship between the elements. This capability makes the BIM software a suitable platform to implement the sustainability rating system.

2.2 Why sustainability?

In order to recuperate the industrial revolution outcome on the environment, sustainable development is the unique path that can help environment, preserve natural resources, improve the indoor environment quality, reduce the overall energy consumption of the buildings, reduce the level of harmful substance in the air and improve the productivity during the construction phase. One of the ways for reducing the negative impact of construction activity on environment is aligning the design and construction activities with the sustainability goal [4].

Also the sustainable building can benefit their owners by saving on the overall energy consumption of the building compare to non-green buildings. Based on the energy use analysis of 100 Leadership in Energy and Environmental Design (LEED) certified buildings, LEED buildings on average use 18-39% less energy per floor area than their conventional counterparts [5].

2.3 Sustainability Rating Systems

Around the world there are hundreds of rating systems that focus on sustainability. Just by March of 2011, 382 rating systems have been registered that deal with evaluating the level of energy saving, energy efficiency, use of renewal energy and sustainability of the buildings [6]. Among all those systems, there are a few numbers of systems that provide a recognizable set of standards for evaluate the sustainability ratio of a building and here is the list of 5 most popular and technical and advance rating systems[6].

1-Building Research Establishment's Environment Assessment Method (BREEAM), is developed in the UK in 1990.
2-Leadership in Energy and Environmental Design (LEED) is developed in the USA in 1998.
3-Comprehensive Assessment System for building Environmental Efficiency (CASBEE) is developed in Japan in 2001.
4-HK-BEEM is developed in Hong Kong in 1996.
5-GREEN STAR is developed in Australia in 2003.

Among all rating systems, the LEED rating system has the highest rate in user-friendliness and LEED and BREEAM has the highest rate in popularity and applicability [7].

There are several sustainable rating systems in the USA. Each of those systems have their own methods to rate a project based on their criteria and scoring systems. Nowadays, the LEED rating system not only becomes popular in the US, but also it finds a good place for itself in the world. There are seven rating systems in the world that are based on LEED: LEED Canada, LEED India, LEED Mexico, SPiRiT (Sustainable Project Rating Tool), MSBG (The State of Minesota Sustainable Building Guideline), Calabasas LEED and CEPAS (Comprehensive Environmental Performance Assessment Schem). The LEED rating system is one of the five sustainable rating systems that provide the whole building evaluation and can rate all types of buildings (commercial, residential). . The other four systems are: BREEAM (Building Research Establishment's Environmental Assessment Method), CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), Green Globes US and GBTools. Only LEED and Green Globes US have the US specific version and Green Globes US is the modified version of Green Globes Canada. The most important feature of LEED is it uses measurable characteristics of building to evaluate the rate of sustainability of a project

Since 2000, that the US Green Building Council (USGBC) has introduced the Leadership in Energy and Environmental Design (LEED) building rating system to the AEC industry, many buildings was awarded one of the four certification level of LEED: bronze, silver gold, and platinum. The scoring system in LEED is based on the measurable pre-defined criteria which relates to both design and construction phases of a project. The maximum of 100 point is the top score a building can get and 40 points is the minimum score for getting the LEED certification (bronze). LEED rating system gained a significant record by certifying more than 14,000 building in the US and 30 countries over 99 billion cubic meter of development area from 2000 till 2006[8]. In order to earn the LEED certification, a process of continues check and documentation should be done during the four stages of lifecycle of a project: 1- pre-design, 2-design, 3-construction and 4-post construction. Also all the stakeholders (owner/s, architecture/s, designer/s, engineer/s, construction manager/s or general contractor/s in addition to the major subcontractors (MEP), glazing and etc.) play a role in the process of obtaining the LEED certification. As the result, earning the LEED certification

for a building is a complex, time consuming and challenging process for any project. In order to get the LEED certification, two major tasks are needed to be done explicitly: 1- satisfying the LEED rating system's requirement and 2- submitting a comprehensive documentation that shows that all the compliances between the submitted documents and real work that has been perform at the project. To facilitate the process of obtaining the LEED certification, USGBC introduced a web base platform (LEED ONLINE) that mainly is allocated to the second part: documentation [9].

This research focuses on the first part and for the purpose of this paper, LEED 2009 has been used.

2.4 Other research

A wide variety of building simulation systems have been developed during the past 55 years. Many of them have been used to optimize the energy saving, improve the sustainability of construction projects and minimize the negative effect of the AEC industry on environment. The example of the tools are BLAST, energy plus, eQuest, TRACE, DOE2 and ECOTECT. However, there are all working individually and does not have the capability to synchronize themselves with the BIM models. As the result, users need to input data directly into them to get the result. Also these tools are complex and needs too much effort to learn how to work with [10].

The current efforts in the areas relate to green building concept, are mainly focus on minimizing the energy consuming of the building [11, 12, 13]. Although those methods can improve the sustainability of the building by optimizing the energy consumption and save the money for the stake holders and owners through the time of occupancy, the problem that arise through that perspective is they do not covers all aspect of sustainability. Also because those methods do not have universal benchmarks, the result can only be compared with the previous result from the same project.

Sustainability should cover a broader range of items to be evaluated. Also it is vital to have a benchmark and measurement scale so that we can measure the level of sustainability of the building based on it. LEED rating system, as the choice of this paper, will give us the necessary tools for measuring the sustainability. The result is a comparable score. Also as the LEED rating system considers a variety of specifications of a project into countable scores, the result contains more aspects of sustainability.

There have been other researches in the field of automating the LEED calculation or in some specific part relates to the LEED/sustainability. Some research emphasize on a method for optimizing the material selection for green buildings with the focus on LEED rating system [14, 15]. Another effort puts it's emphasize on sustainable highway design and uses two systems to evaluate the sustainability, LEED and GRI, and proposes a framework to link the design to the sustainable rating system [16]. However, it does not consider the BIM model products in its framework.

In the field of automation of the LEED scoring, Wei Wu and Raja Issa (2011) proposed a framework to make the LEED automation though the web service with emphasize on documentation in the process of acquiring the LEED certification.

No research has looked into computerizing the evaluating of the sustainability rate of a building except one. By introducing the buffer software (Virtual Environment) and using it to get the information from BIM mode and evaluate the LEED rate, S. Azhur (2011) evaluate proposed method for evaluating the LEED score, but the result has been described as "not accurate". The reasons of inaccuracy of the results are: 1- the current BIM-Based sustainability analyses and LEED certification process do not have one-to-one relationship and LEED feature does not integrated in the current available software, 2-some of the finishes that are needed to be evaluated in by LEED criteria, cannot be accurately modeled in the BIM product. 3- The BIM models only can provide information for 17 credits and 2 pre-requirements directly. The rest of the criteria either have semi-direct or indirect relationship with data that can be obtained from BIM models.

Based on the current BIM products and popularity of them (such as Revit 2013), they are a proper choice for integrating the LEED evaluation capability. Also it is possible to customize and add extra features into the BIM products. These extra features can provide the information that are crucial for evaluate the LEED score, but cannot be found and extracted from the original BIM products.

2.5 Challenges

The LEED certification is awarded based on the scoring system and an automated system that can calculate the LEED scores based on its criteria, will help the stakeholders to achieve an optimum level of design that maximize the LEED score and minimize the cost without sacrificing the design requirements. However, there are some challenges in regard to establish and implementation a proposed framework. The first challenge is the lack of existence of adequate information in the BIM model in order to be used for evaluating process of LEED score. Based on the LEED rating system, some credit can be award to the building if the building has certain specification that the original BIM model does not provide information about them. As the result we need to obtain that extra information through another source rather than the BIM model. The second challenge is the lack of sufficient information regards some of the instances in the BIM mode that LEED rating system needs to evaluate the LEED score. As an example, a BIM model can give us the full quantitative information about the interior and exterior walls of the building but for a renovation project it does not specify whether a specific wall is an existing wall or it is a new wall. The rate of the existing wall to the new wall in renovation project is one of the criteria that is needed for rating a building based on the LEED rating system. As the result, the BIM model products are needed to be modified in a way that the extra data can be provided for evaluating

sustainability ratio of a project. The third challenge arise from the nature of the LEED rating system which requires the process of evaluation to last till the occupation phase and does not finish at the design phase. As the result, in order to gain the proper documentation process from pre-design to occupancy a proper report that shows what are the assumptions that LEED score is based on them, is vital for gain the desirable result from an automated rating system. It can be done by adding some notes to the plans or providing a comprehensive report that shows what stakeholders need to follow during the construction phase to gain the predefined sustainable score based on the LEED rating system.

2-6 Scope of work

This paper limits itself to cover one section of LEED evaluation system. This concept can be extracted to cover the rest of the LEED sections. Also this paper focuses on the residential project. However, due to the similarity of the procedure for evaluating the LEED score of the commercial buildings, by adding the extra criteria to the proposed framework, we can use it for both commercial as well as buildings.

3. Proposed framework for evaluate the sustainability based on LEED rating system

Revit (Autodesk Revit) is a parameter driven modeling product. In order to propose a framework to show how we implement the evaluation process into the BIM modeling product, first we need to identify how much the BIM model product is compatible with LEED system. Despite the 17 credits and 2 pre-requirement criteria, the rest of the credits and pre-requirements either have semi direct or no relationship with the available in BIM model. As the result we need to provide a procedure that not only uses the available data in BIM model, but also can provide a proper and user-friendly interface to get the extra needed data for calculating the LEED score from users. This interface is a part of the propose framework and we called it LEED Evaluator (LE). (Figure 1)

The framework of LE should be formal, flexible and general. It should be formal because the LEED rating system uses solid, pre-defined and standard measurements that need to be followed exactly in the analyzing engine. Also the flexible framework gives the designer the power to uses different preference and options for describing the different approaches that affect the rate of sustainability of the building. The general framework makes it possible for the framework to evaluate the sustainable rate of building independent of a specific type of project or building model.

The proposed building sustainability rating framework (LEED EVALUATOR) is developed by using the concept of ontology and IDEF0. A simple IDEF0 consists of 5 components: Input, Output, Control, Evaluator and Core (Figure 1).

1-inputs

The input provides the data that are needed to evaluate and calculate the LEED score and can be divided into two separate categories: 1-the data that are extracted from original BIM Model and 2- the feature data that the user needs to insert into the proposed LE interface.

2-Output

The output is the result of evaluation of the sustainability ratio and includes the LEED score and a brief description of each section of LEED rating system that project obtain scores from. Due to the procedure that USGBC defines, getting the LEED certification does not summarize in design phase. The LEED certification can be gained through continues process of evaluating and documentation throughout the several phases of project from pre-design stage till the occupation critical. An output that not only shows the possible LEED score of the building based on the data user enters at the design phase, but also gives a list of criteria that provide credits toward the total LEED score can be helpful for the documentation process. As the result, the output consists of both the score and the list of LEED criteria that the LEED score is based on them.

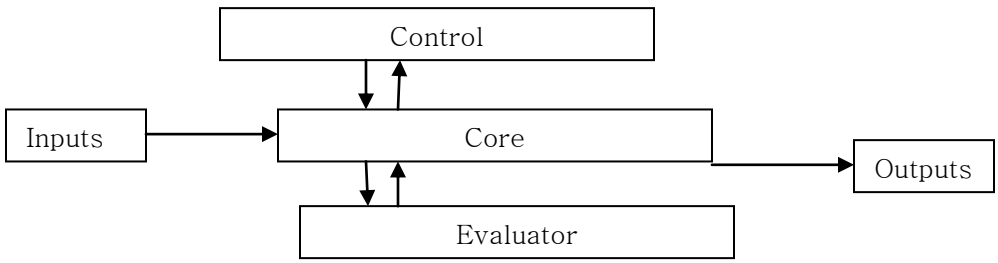
3-Control

Each section of the LEED rating system has some pre-requirement sub-section/s and if a project wants to gain credits in each part of that section, it first needs to satisfy the pre-requirement sub-section/s of that section. Controls are the pre-requirement of each section of LEED that will be checked prior to evaluate the sub-sections of each LEED's sections.

4-Evaluator

Each sub-section of LEED rating system is evaluated at the Evaluator part of LE based on the extracted data and data user enter directly through the LE interface

Figure 1: LEED Evaluator



5-Core

The core is the heart of the LEED EVALUATOR. It gets all the data from input and decides which one of those information are needed for the Control or Evaluator and the result of scoring will be sent to the output.

Figure 2 shows the abstract view of the framework used for evaluating the LEED score of the building. At the next step, we show how this framework, define the algorithm to calculate the LEED score of the Sustainable Site section of LEED rating system for a project.

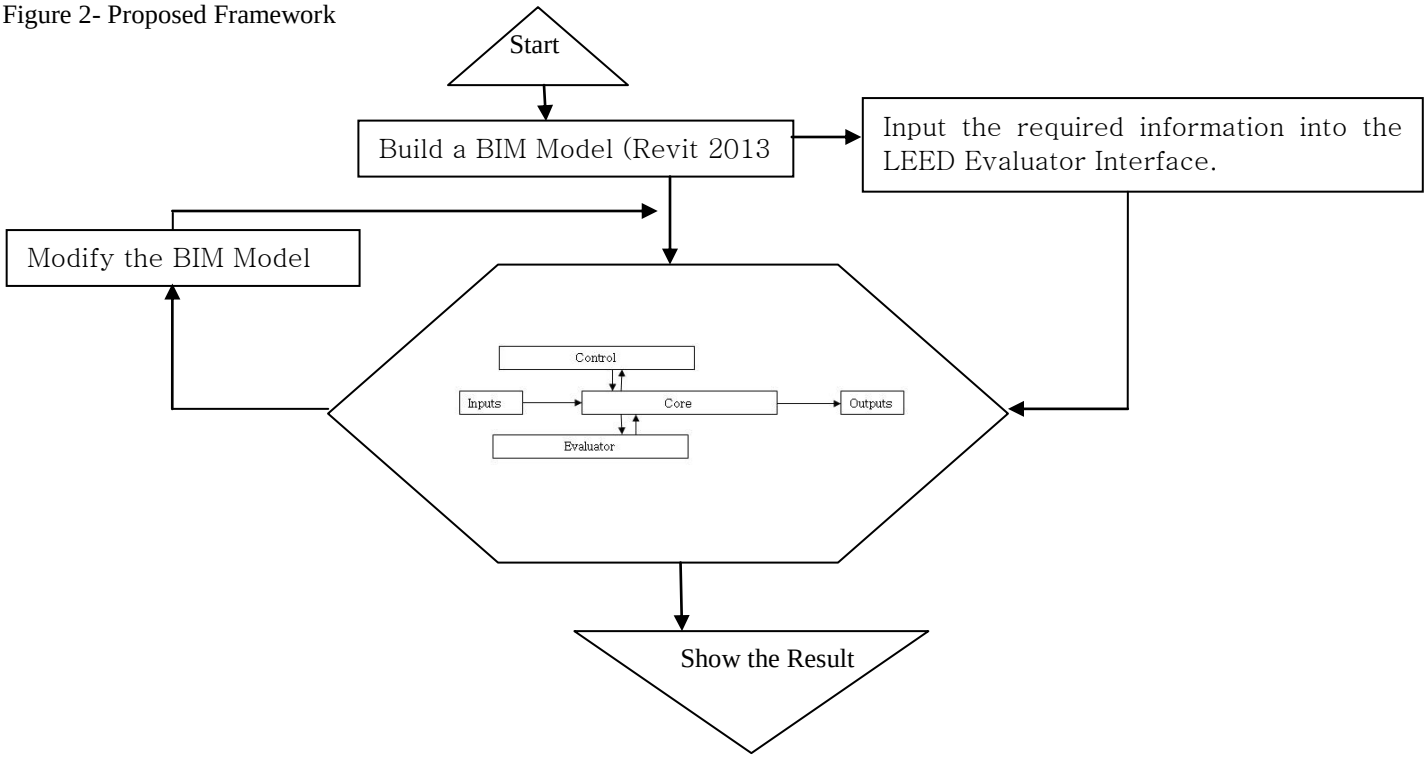
4. Algorithm

The algorithm for evaluating the LEED score is developed and implemented into seven separate sections based on the seven sections of LEED rating system. Development of the first section of the LEED (the Sustainable Site section) is represented in this paper.

The Sustainable Site section (SS) (LEED 2009 updated 2011) includes one pre-requirement and 13 sub-sections that can award the maximum of 26 points. Among these 14 different sections two sections (Heat Island Effect – Roof and Alternative Transportation) have semi-direct relation with the BIM model. For the rest of 12 sections, user needs to insert the data that are needed to evaluate the LEED score. The information for evaluating the LEED score will be asked from user to insert into the user friendly interface of LEED Evaluator program

Although it was possible to verify the existence of a bus or train station in the model by adding a new shared parameter to Revit, in order to follow the generality rule of the framework in the algorithm, we use a simple check box and filling box to get the information from user. As the result, BIM model that does not cover the area that bus and/or rail station are at, can still use the LEED Evaluator program. However, the program will search the model for bus stop and if it can find one, it will calculate its distance to the project and use the result to evaluate the LEED score. For the Credit 7.2 (Heat Island Effect – Roof) LEED Evaluator uses the BIM model data to calculate the roof area of the project. For credit 4.3 Alternative Transportation, total number of the parking spots is extracted from BIM model.

Figure 2- Proposed Framework

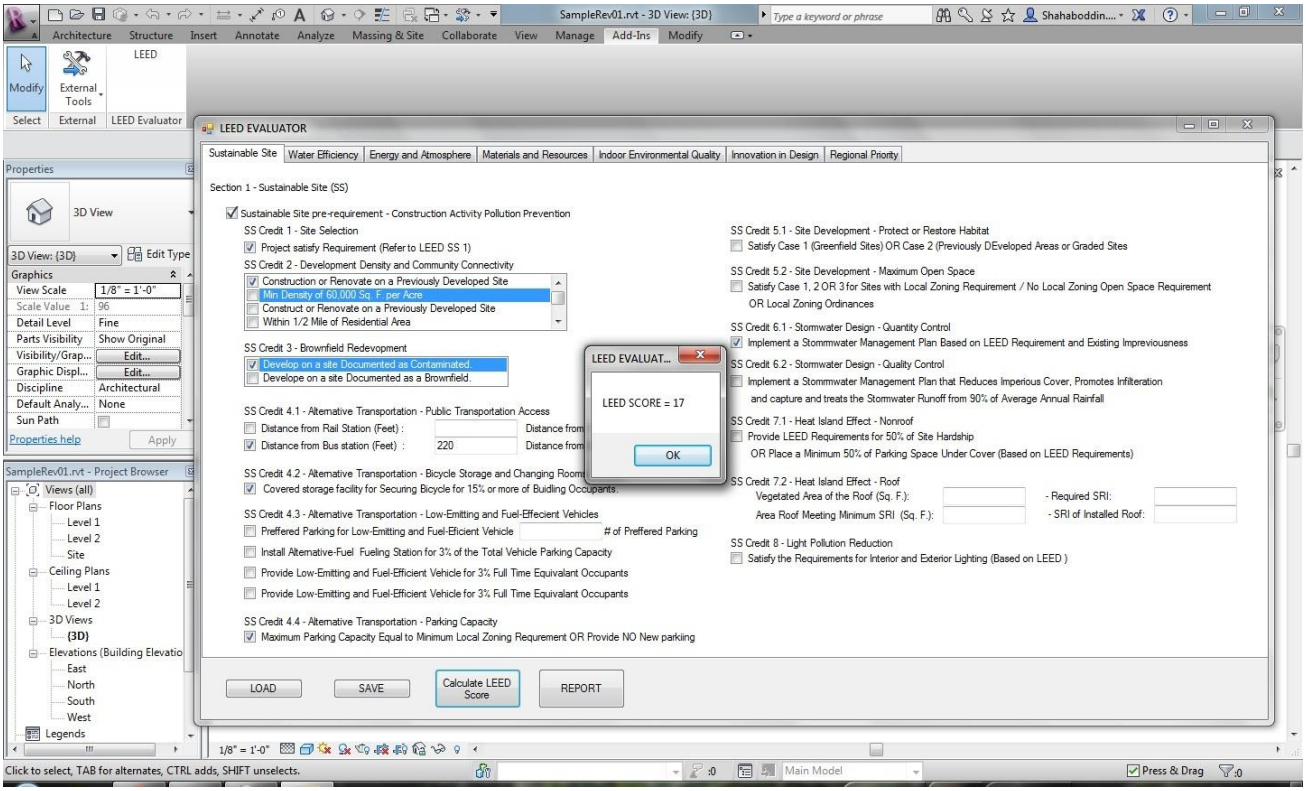


5. Implementation

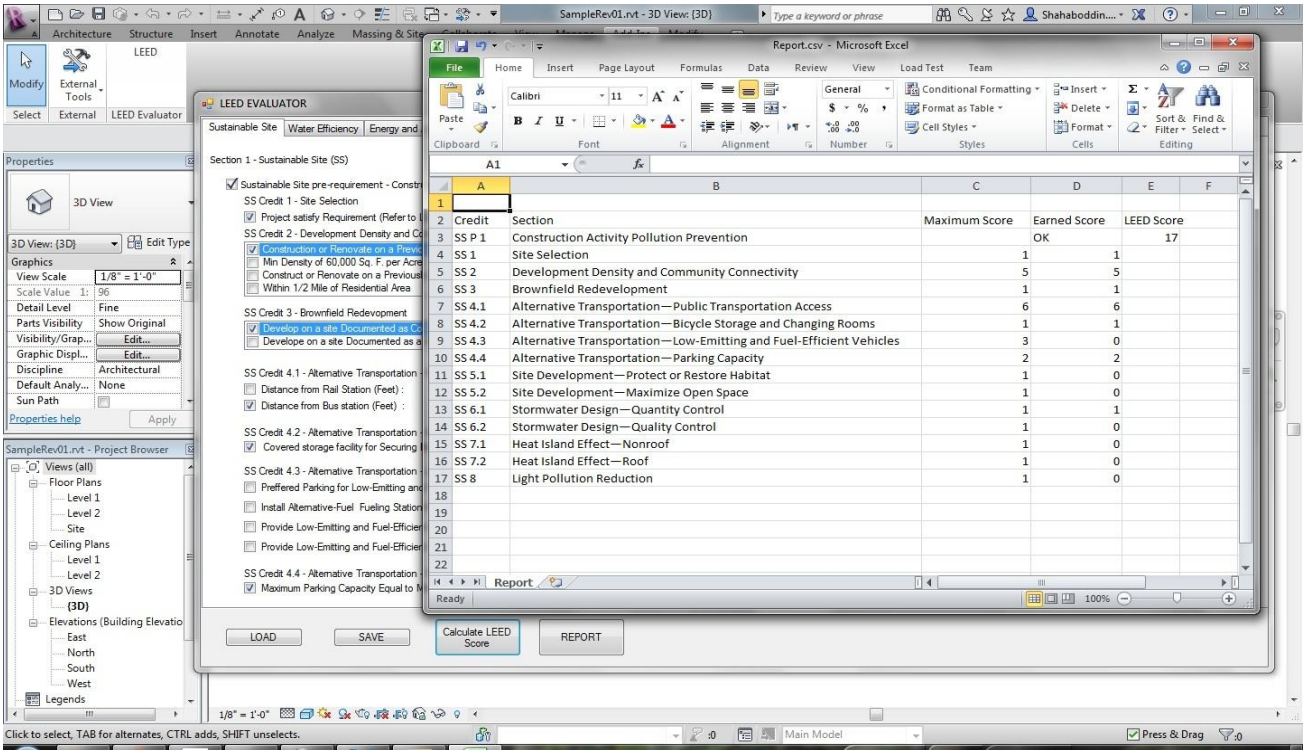
The proposed framework for evaluating the building sustainability rate based on the LEED rating system is implemented into the Autodesk Revit Architecture 2013. Revit products have the proper capability to .provide the required information through using the three BIMs' model products: Revit Architectures 2013, Revit MEP 2013 and the Revit Structure 2013. The information required for evaluating the LEED score are provided for LEED EVALUATOR from the data extracted from BIM model and the data that user input into the program directly through its user-friendly interface (Picture 1). The roof area and total number of parking spots are extracted from Revit model and the rest of the

information are needed to be inserted by user into the LEED EVALUATOR program. Due to the high level of indirect relationship between the data required for evaluating the LEED score and the information that can be extracted from BIM model, using an interface to obtain the necessary information form user is vital. LEED score can be calculated by the LEED EVALUATOR program.

Picture 1 – LEED EVALUATOR Interface



Picture 2-



The LEED evaluation is carried out through following steps: The required data extracted from BIM model and they are saved into program data base. The user can enter the remaining required data through the program interface. In order to gain the maximum LEED score, user can retrieve the data he/she enters into the program by using the save and load feature of the program. By pressing the Calculate button, program calculate the LEED score based on the existing data. User can also get a report with the detail scoring of each sub-section by pressing the Report button (Picture 2).

Revit API (Application Programming Interface) provides the possibility to run the LE program and its interface. By using the Revit SDK (Software Development Kit) the necessary classes for programming the Revit API using C# language has been created and the necessary codes are added to extract the data from BIM model.

8. CONCLUSIONS

BIM software becomes a powerful tool for evaluating different aspect in the AEC industry to gain variety of objectives from constructability to energy efficiency level of the building. Because there are a few categories in the LEED system that have one-to-one relationship with the BIM model data, it is impossible to use only the extracted data from BIM model to calculate the LEED score of the building. However, by using the programming capability of the BIM model product (Revit), it is possible to calculate LEED score with merging the BIM product with external feature program (such as LEED EVALUATOR). The proposed approach is aim to demonstrate the feasibility of using the BIM model product to develop a computerize method for evaluating the LEED score of the building. The further steps can be adding the rest of the LEED categories to the LEED EVALUATOR program and ultimately combine it with other added features such as cost estimating to make a nD BIM model product.

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