A BIM-BASED FRAMEWORK FOR SELECTION OF COST-EFFECTIVE GREEN BUILDING DESIGN

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ABSTRACT

The global climate has changed dramatically in recent years. In order to reduce the emission of carbon dioxide, green building has become a popular research topic worldwide. From the perspective of building lifecycle, the energy consumption in the operation phase accounts for the largest proportion of the entire lifecycle cost. Although the initial construction cost of a green building is generally higher than that of an ordinary building, the benefit generated through energy saving in the operation phase might be able to offset the additional cost required for the green building.

To help the owner get an appropriate green building design that can meet the owner's budget and achieve low energy consumption, a BIM-based (Building-Information-Modeling-based) framework is proposed in this paper. The BIM-based framework can automatically extract data of various green building designs from BIM software to estimate the construction cost of each design and to import them to energy simulation software to compute the cost of energy consumption. Based on the available cost information, an appropriate and cost-effective green building design can be selected.

Keywords: BIM-based (Building-Information-Modeling-based), Lifecycle Cost, Energy Consumption Cost, Initial Construction Cost.

1. INTRODUCTION

1.1. Background

Nowadays constructive energy consumption simulators such as eQUEST, EnergyPlus, and Ecotect can be used for quantifying the energy consumption cost. Taking eQUEST for an example, it needs particulars such as 8760 hours sunshine intensity, temperature, shape of buildings, interior space and nature of materials. In recent years, some companies like TSMC have already advocated for

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using eQUEST for calculation of energy consumption, and 8760 hours TMY2 climate information has been collected in Taipei, Taichung, Kaohsiung, etc. so it can be input into eQUEST directly. However, eQUEST is not commonly used due to the fact that process of using eQUEST is time-consuming and laborious.

1.2. Problem statements

Building's life cycle cost refers to a money cost composed of possession, operation, maintenance, and demolition of a building or a building system during a period of time. Not only is the lifecycle cost analysis of buildings a tool for evaluating construction cost, it also takes all the related financial factors into consideration, including initial investment cost and operation cost in the future. Thus information needed for such a calculation was variable and complex; large labor and consumption are a must when the calculation is worked out manually.

The green building features power conservation, waste reduction, environment-friendliness, and living standard rise; it will be a rage in the future and usher our construction industry into a new era. In past decades, few researches of green building were carried out from the angle of economy or especially from that of a building lifecycle, instead, the focus of most researches were always bringing into the concept definition of green building. In addition, the economic value of green building is contained inside its lifecycle which can reduce power consumption. In order to make the best option, all the cost that may be contained in a building lifecycle have to be thoroughly analyzed. However, the design and the materials involved in the green building are far too many to be analyzed each by each. The construction team proceeds to the design out of their experience. In other words, there is no telling that whether the project which has already been chosen is the best or not in terms of power consumption efficiency.

1.3. Research objectives

There are three objectives in this research:

(1) Application of BIM for partial Building Life Cycle Cost (BLCC) Estimation

Originally, the concept of BIM was designed to contain information management of the whole life cycle, and the information required by Building Life Cycle Cost Analysis (BLCCA) is exactly the information included in the whole life cycle of a building. As a result of that, in this research, focus will be on the evaluation of partial BLCC, for example, construction cost and electricity consumption, by regarding BIM as a data base of BLCC and utilizing the statistical way of BLCC.

(2) Effectively using BIM information input into building energy consumption analysis software

Firstly, owning to the failure of software of BIM for normal energy consumption analysis plus the fact that the models of BIM cannot be fully used if they are directly applied to the analysis, and also building models by using energy consumption software will need extra time and labor, both of them

are not fit an efficient analysis. However, the aforesaid two methods can be integrated to help count energy consumption cost and construction cost can the information from BIM models be filtered and the only information left in it is favorable to energy consumption analysis software. Thus, this research will use the integrated process of BIM to filter until the only information left is helpful for energy consumption analysis software, assessing reasonably and quickly the energy consumption of BIM models so that the efficiency for working out BLCCA can be heightened.

(3) Application of BIM for assessment of green building cost and benefits

The green building's true value is the energy consumption reduction, but relatively it has an expensive construction cost, and when it comes to judgment, unfortunately what usually can be depended on are only the experience of the design teams and the buyers' request. And the analysis of building energy consumption is too time-consuming that may probably lead to a result that is not the best among all projects. Thus, this research will write the BIM integrated program to evaluate the life cycle cost benefit of each project so that buyers can be helped to choose their most favorable option

1.4. Limitations

Due to the fact that the integrated system set up in the research is only for display of concept, there are some limitations to the research and they are as follows:

1. In this research only the initial construction cost and the electricity consumption of buildings' life cycle will be considered.
2. This research only concentrates on the square buildings with identical design for each floor.
3. This research will only discuss the cost for buildings' façade and what influences the cost of buildings' façade will have, this research will set the design of the central air conditioning and most of the parameters as constant values for convenience of the study.
4. The schedule system of the building usage in this research will be set as the schedule of a university, namely two holidays a week, the time for the operation of air conditioners and electric equipment will be set from 9:00 a.m. to 9:00 p.m. and the electric consumption in summer vacation will be about 20 % of school day.
5. This research will only focus on Asian district and will only gather the weather information of Taipei district for energy consumption simulation analysis.
6. The result produced by this research is based on the information of the aforementioned data base and that of the fictional buildings simulated by the system analyzed with the building life cycle cost analysis and the mathematical compromise theory, so the result can't be applied to all buildings and it will be affected if any new information of building components is added or curtailed.

2. MATHEMATICAL ANALYSIS

2.1. Building life cycle cost analysis

The life cycle cost to a building's facilities includes all the cost for different stages, including proposal, design, construction, operation and maintenance. And the estimation for the life cycle cost thereof is an important reference for accessing to the economic lifespan of a building. In 2010, Chun Ta Tzeng, Che Ming Chiang, Kuang Sheng Liu, Yen Chun Chen pointed out the purpose of life cycle cost analysis, and they are as follows:

1. Definite methods and proposals should be well laid out, so the assessment between every proposal will be reasonable and fair.
2. The most economical proposal is chosen.
3. A great analysis tool is provided for having an absolutely clear insight into the costs needed in every stage and the relation thereof between them.

The problems that can be addressed by the life cycle cost analysis are as follows:

1. The definite reclamation date can be estimated.
2. The best proposal can be found out.
3. Reasonable and valid analyses can be performed on all the costs needed in every stage of every proposal.
4. The scope and the progress of each proposal can be assessed.

2.2. Compromise Programming

In 1974, Yu and Leitmann conceived Compromise Decision, and it was later developed to Compromise Programming for multi-criteria decision-making. Multi-criteria decision-making problem, in fact, is an expansion of mono-criteria decision-making problem, and the distinction between them is that the multi-criteria decision-making copes with at least two objective parameters at the same time, but the mono-criteria decision-making merely focuses on one objective parameter, and both of them aims to work out the maximum or the minimum optimal solution of their objective parameter in feasible solution region. The geometrical meaning thereof is shown in Figure 1. And the formula below is the mathematical representation of the multi-criteria decision-making problem:

$$\min z = \left\{ \sum_{i=1}^{n} w_i^p (f_i^* - f_i)^p \right\}^{\frac{1}{p}} \tag{1}$$

where

i represents n criteria or objectives

w_i corresponds to a weight of a particular criteria or objective

p represent the importance of the maximal deviation from the ideal point (p=1,2,∞)

f_i^* the best value for criteria, respectively(also referred to as positive ideals)

f_i the feasible solution

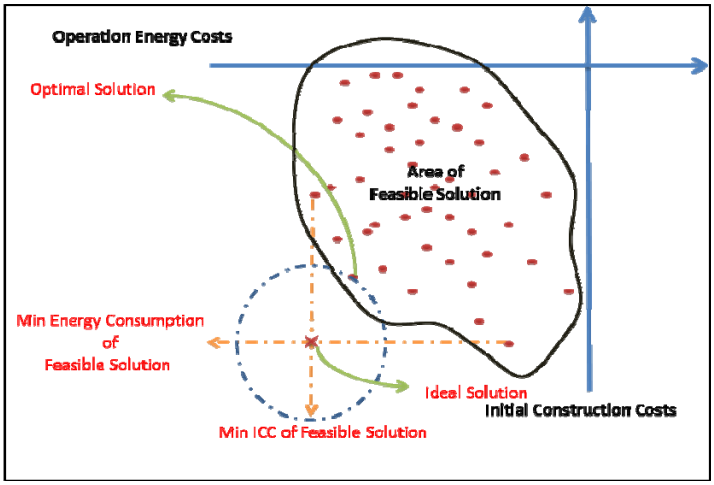

Figure 1: The geometrical meaning diagram of Compromise Decision.

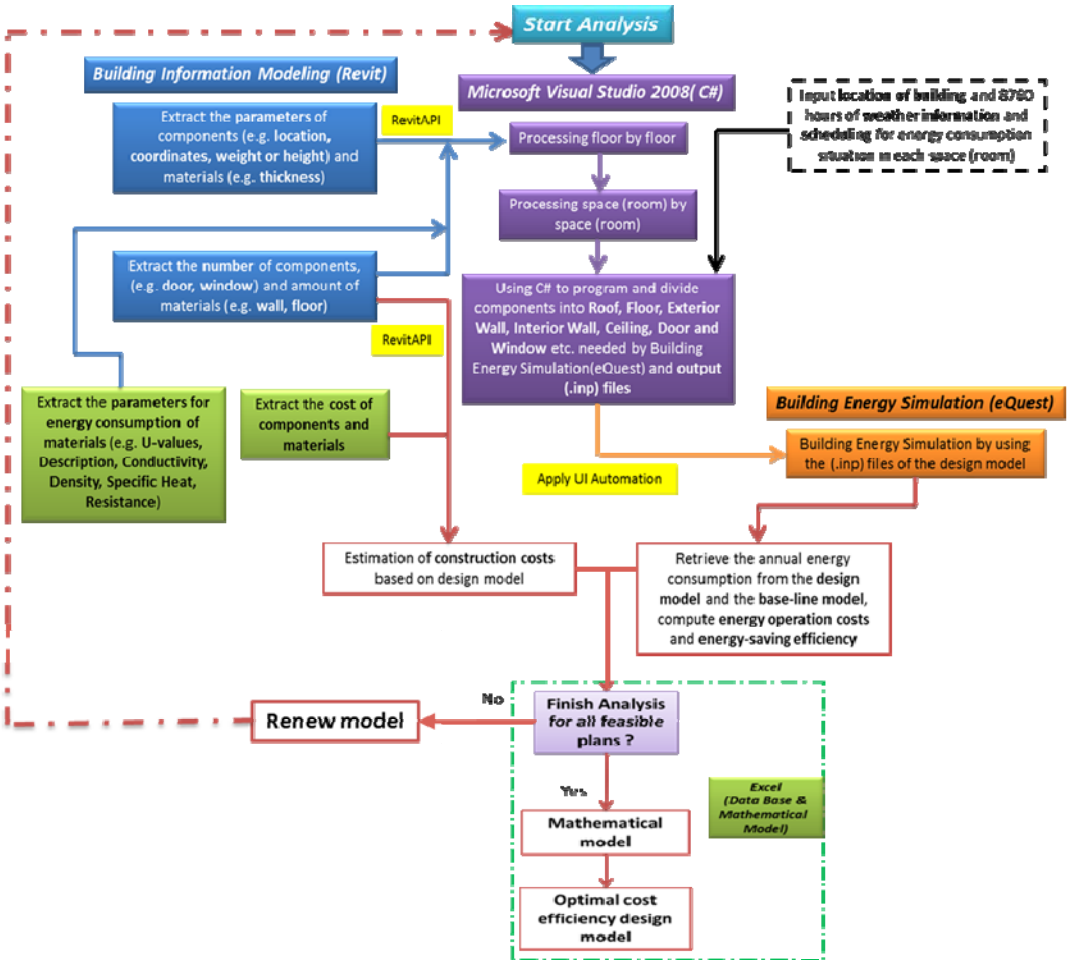

Figure 2: Data processing diagram.

3. SYSTEM DEVELOPMENT

As what it is shown in the Figure 2, the analysis system developed in this research integrates BIM software (Autodesk Revit), building energy consumption software (eQUEST) and database and mathematical calculation (Excel) by Visual Studio 2008 (C# language). Revit API, Microsoft.Office.Interop.Excel and UIA provided by Autodesk Revit and Visual Studio will also be used and UIA will be adopted as a tool to integrate Autodesk Revit, Excel and eQUEST. The system in this research is developed based on the embryonic system developed by Chi-Feng Hua in 2011 to calculate the initial construction cost and the operation electrical consumption cost.

3.1. Evaluation of electrical consumption cost

While modeling, we take advantage of the database function of BIM to input the material cost and the energy consumption parameters into every corresponding component. And we mark every wall with either exterior wall (building crust) or interior wall (inside room separation) and each zone with their name in Revit. When the model is finished, we transmit all the data from BIM to Visual Studio 2008 (VS 2008) through a specific Revit API developed in this research.

Based on those data, we use VS 2008 to create a file in accordance with the format of eQUEST (inp file). All components will be categorized into different groups needed by Building Energy Simulation. In eQUEST's inp file, the logicality of building program code starts from floor to space (room). According to the reading order, the analysis system developed in this research processes the accessed data relationally for inp file programming. When inp file programming is finished, we can use it to analyze the yearly consumption cost of a building.

3.2. Automatic conversion of construction design and database analysis

Constructive cost varies depending on difference materials used for buildings, so does energy consumption cost. In this research, we try every kind of combination to find the optimal solution. When design is modified manually, it's very time-consuming and laborious. Thus, we use the function of automatic construction material change that is built-in Revit API to change construction design. After each analyzing, we record the construction crust combination, the electricity consumption cost, and the construction cost into an automatically setup Excel file. Then, both Compromise Theory analysis and BLCCA will be conducted automatically in the system. After that, the system will compare the results to the plan with the lowest construction cost and the optimal cost benefit, so the breakeven time thereof can be found as a choice for owners.

4. CONCLUSIONS

The gist of this research is to roughly estimate BLCC by operating BIM information model plus energy consumption analysis software (eQUEST) and to delve into the feasibility of the use of BIM for green building design. In this research, we integrate and manage BIM data, conducting a series of assessment from building design to operation management by using BIM 3D to show the

practical use of BIM in the entire life cycle. The developed system can estimate construction cost and electricity consumption cost effectively and quickly, so buildings can be designed “greener” more quickly and cost-effectively. BLCCA can be conducted more easily and quickly by BIM. Taking advantage of mathematical calculation, the optimal design for building projects can be found. Through this research, we can help owners to find the most beneficial proposal.

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