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# APPLICATION OF BIM IN SUSTAINABILITY ANALYSIS

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A project report submitted in partial fulfillment of the requirements for the award of  
the degree of Master of Science (Construction Management)

Faculty of Civil Engineering  
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JULY, 2010

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To my beloved mother and father

## **ACKNOWLEDGEMENT**

In the name of God, the most Gracious, the most Merciful

I wish to express my sincere appreciation to my supervisor, Assoc. Prof. Dr. Abdul Kadir Bin Marsono, for his invaluable advice, assistance and guidance. Without his continued support, this thesis would not have been the same as presented here.

My heartfelt gratitude also goes to my beloved family, thank you for the encouragements, supports and prayers, for being my inspiration, for your understanding and most importantly, for your endless love.

## **ABSTRACT**

Building Information Modeling (BIM) is the process of generating and managing building data during its life cycle. Typically it uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction. The process produces the Building Information Model, which encompasses building geometry, spatial relationships, geographic information, quantities and properties of building components. On the other hand, Green Building Index (GBI) as the localized sustainability building rating system in Malaysia assesses the impact of building on environment based on energy efficiency, indoor environment quality, sustainable site & management, materials & resources, water efficiency and innovation.

By integrating GBI assessment criteria with BIM technology, this research proposes a comparative case study analysis of Residential New Construction (RNC) and Non-Residential New Construction (NRNC) based on the Autodesk Ecotect Analysis software (a comprehensive, concept-to-detail sustainable design analysis tool that provides a wide range of simulation and analysis functionality through desktop and web-service platforms) and Autodesk Green Building Studio (A web-based energy analysis service which performs whole building analysis, optimizes energy efficiency, and works toward carbon neutrality earlier in the design process) to investigate the influence of construction material on energy consumption, lifecycle energy cost and carbon emission.

## ABSTRAK

Building Information Modeling (BIM) adalah proses menghasilkan dan menguruskan data bangunan semasa kitaran hidupnya. Biasanya, ia menggunakan tiga-dimensi, masa-nyata, perisian pemodelan bangunan yang dinamik untuk meningkatkan produktiviti dalam pembinaan dan mereka bangunan. Proses ini menghasilkan Building Information Model, yang meliputi geometri bangunan, hubungan kejuruteraan, maklumat geografi, jumlah dan sifat bagi komponen bangunan. Di samping itu, Green Building Index (GBI) sebagai sistem penilaian bangunan keberlanjutan terlokalisasi di Malaysia mendapatkan kesan bangunan terhadap persekitaran berdasarkan kecekapan tenaga, kualiti dalaman persekitaran, pengurusan tapak, sumber dan bahan-bahan serta inovasi dan kecekapan pengairan.

Dengan menghubungkan kriteria penilaian GBI dengan teknologi BIM, kajian ini mencadangkan satu perbandingan kes analisis bagi Residential New Construction (RNC) dan Non-Residential New Construction (NRNC) berdasarkan perisian Autodesk ECOTECH Analysis (Sebuah alat rekaan analisis konsep ke huraian penuh yang menyediakan pelbagai simulasi dan fungsi analisis melalui desktop dan pangkalan web-servis) dan Autodesk Green Building Studio (Sebuah perkhidmatan analisis tenaga berasaskan web yang melakukan analisis keseluruhan bangunan, mengoptimumkan kecekapan tenaga, dan bekerja ke arah peneutralan karbon dalam peringkat awal proses rekaan) untuk mengetahui pengaruh bahan pembinaan pada konsumsi tenaga, kos kitaran tenaga dan pembebasan karbon.



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## LIST OF ABBREVIATIONS

ABBREVIATIONS	FULL NAME
ACEM	Association of Consulting Engineers Malaysia
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AWWA	American Water Works Association
BES	Building Energy Simulation
BIM	Building Information Modeling
BREEAM	BRE Environmental Assessment Method
CAD	Computer Aided Design
CARMA	Carbon Monitoring for Action
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CFD	Computer Fluid Dynamics
CHPS	Collaborative for High Performance Schools
DOE	Department of Energy
EA	Energy and Atmosphere
EUI	Energy Use Intensity
GBI	Green Building Index
GBXML	Green Building Extensible Markup Language
HVAC	Heating, Ventilating, and Air Conditioning
ICF	Insulated Concrete Form
LEED	Leadership in Energy and Environmental Design
MEP	Mechanical, Electrical and Plumbing
NRNC	Non-Residential New Construction
OSB	Oriented Strand Board
PAM	Pertubuhan Akitek Malaysia
RNC	Residential New Construction
SIP	Structural Insulated Panel
SCM	Supplementary Cementitious Materials

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 An Introduction to Building Information Modeling**

Building Information Modeling is the process of generating and managing building data during its life cycle. Typically it uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction [Holness, 2008]. The process produces the Building Information Model, which encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components [Lee, et al, 2006].

Georgia Institute of Technology coined the term. This theory is based on a view that the term Building Information Model is basically the same as Building Product Model, which Professor Eastman has used extensively in his book and papers since the late 1970s (“Product model” means “data model” or “information model” in engineering). Architect and Autodesk building industry strategist Phil Bernstein first used the actual term “building information modeling” and nicknamed it “BIM”. Jerry Laiserin then helped popularize and standardize it as a common name for a digital representation of the building process to facilitate exchange and interoperability of information in digital format. According to him and others, the first implementation of BIM was under the Virtual Building concept by Graphisoft’s ArchiCAD, in its debut in 1987 [Yessios, 2004].

Building information modeling covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example manufacturers' details). BIM can be used to demonstrate the entire building life cycle, including the processes of construction and facility operation. Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility or group of facilities. BIM can be seen as a companion to PLM as in the Product Development domain, since it goes beyond geometry and addresses issues such as Cost Management, Project Management and provides a way to work concurrent on most aspects of building life cycle processes. BIM goes far beyond switching to a new software. It requires changes to the definition of traditional architectural phases and more data sharing than most architects and engineers are used to.

The American Institute of Architects has further defined BIM as “a model-based technology linked with a database of project information”, and this reflects the general reliance on database technology as the foundation. In the future, structured text documents such as specifications may be able to be searched and linked to regional, national, and international standards [Lee, et al, 2006].

An instance of BIM software is Autodesk Ecotect which is a comprehensive environmental design tool that covers a wide range of simulation and analysis functions required to truly understand how a building design will operate and perform. Environmental design principles, such as solar, thermal, shading, lighting, and airflow, are most effectively addressed in the early phases of the design process. With Ecotect tools, architects and engineers can measure how fundamental criteria will affect building performance in the conceptual and detailed phases of design. Architects and designers work easily in 3D and apply a rich palate of tools that are important for our customers to drive and support an energy efficient and sustainable future [Holness, et al, 2006].

## 1.2 Sustainable Design

Sustainable design (also called environmental design, environmentally sustainable design, environmentally-conscious design, etc) is the philosophy of designing physical objects, the built environment and services to comply with the principles of economic, social, and ecological sustainability. The intention of sustainable design is to “eliminate negative environmental impact completely through skillful, sensitive design”. Manifestations of sustainable designs require no non-renewable resources, impact on the environment minimally, and relate people with the natural environment. Applications of this philosophy range from the microcosm — small objects for everyday use, through to the macrocosm — buildings, cities, and the earth’s physical surface. It is a philosophy that can be applied in the fields of architecture, landscape architecture, urban design, urban planning, engineering, graphic design, industrial design, interior design, and fashion design. Sustainable design is mostly a general reaction to global environmental crises, the rapid growth of economic activity and human population, depletion of natural resources, damage to ecosystems and loss of biodiversity.

The limits of sustainable design are reducing. Whole earth impacts are beginning to be considered because growth in goods and services is consistently outpacing gains in efficiency. As a result, the net effect of sustainable design to date has been to simply improve the efficiency of rapidly increasing impacts. The present approach, which focuses on the efficiency of delivering individual goods and services, does not solve this problem. The basic dilemmas include: the increasing complexity of efficiency improvements, the difficulty of implementing new technologies in societies built around old ones, that physical impacts of delivering goods and services are not localized but distributed throughout the economies, and that the scale of resource uses is growing and not stabilizing. The motivation for sustainable design was articulated in E. F. Schumacher’s 1973 book “Small Is Beautiful“. In architecture, sustainable design is not the attachment or supplement of architectural design, but an integrated design process. This requires close cooperation of the design team, the architects, the engineers and the client at all project stages, from the site selection, scheme formation, material selection and procurement and project implementation [Lee, et al, 2006].

### 1.3 Principles of Sustainable Design

While the practical application varies among disciplines, some common principles are as follows:

- i. Low-impact materials: choose non-toxic, sustainably-produced or recycled materials which require little energy to process.
- ii. Energy efficiency: use manufacturing processes and produce products which require less energy.
- iii. Quality and durability: longer-lasting and better-functioning products will have to be replaced less frequently, reducing the impacts of producing replacements.
- iv. Design for reuse and recycling: “Products, processes, and systems should be designed for performance in a commercial afterlife”.
- v. Design Impact Measures for total carbon footprint and life-cycle assessment for any resource use are increasingly required and available. Many are complex, but some give a quick and accurate whole earth estimate of impacts.
- vi. Sustainable Design Standards and project design guides are also increasingly available and are vigorously being developed by a wide array of private organizations and individuals. There is also a large body of new methods emerging from the rapid development of what has become known as “sustainability science” promoted by a wide variety of educational and governmental institutions.
- vii. Biomimicry: “redesigning industrial systems on biological lines ... enabling the constant reuse of materials in continuous closed cycles...”
- viii. Service substitution: shifting the mode of consumption from personal ownership of products to provision of services which provide similar functions, e.g. from a private automobile to a car sharing service. Such a system promotes minimal resource use per unit of consumption (e.g., per trip driven).

- ix. Renewability: materials should come from nearby, sustainably-managed renewable sources that can be composted when their usefulness has been exhausted.
- x. Healthy Buildings: sustainable building design aims to create buildings that are not harmful to their occupants nor to the larger environment. An important emphasis is on indoor environmental quality, especially indoor air quality.

#### **1.4 Sustainable Design Analysis and Building Information Modeling**

Sustainable design is more important than ever. Building information modeling solutions make sustainable design practices easier by enabling architects and engineers to more accurately visualize, simulate, and analyze building performance earlier in the design process. The intelligent objects in the building information model enable the advanced functionality of the desktop tools that are included with Autodesk Ecotect Analysis software. Using Autodesk Ecotect Analysis, architects and designers can gain better insight into building performance earlier in the design process, helping to achieve more sustainable designs, faster time to market, and lower project cost.

Designing energy-and resource-efficient buildings, in many locations, is no longer optional, but mandatory. While owners have always sought designs that are cost-effective to operate and that will command premium lease values, research shows that green buildings (for example, LEED-certified) are more likely to deliver on these criteria. A 2008 report from McGraw Hill Construction finds a 13.6 percent decrease in operating costs from green building and a 10.9 percent increase in building values as reported by architects, engineering firms, contractors, and owners over the past three years (McGraw Hill Construction September 19, 2008). More pressing is the growing number of local and national regulations that mandate targets for energy and resource efficiency as well as carbon emission reductions in new and renovated buildings. These government initiatives—such as the 2007 U.S. Energy Independence and Security Act or the European Union’s Energy Performance Buildings Directive—are certainly put in place to help reduce greenhouse gas

emissions and slow our impact on climate change, but they are also instituted to reduce dependence on unpredictable markets for oil as an energy source and, most recently, to help stimulate the global economy.

According to the U.S. Department of Energy (DOE), buildings contribute roughly one-third of greenhouse gas emissions worldwide, primarily from electricity consumption; in the United States, 76 percent of all power generated is consumed by buildings. As voluntary goals—such as the AIA 2030 Challenge to achieve carbon neutral buildings by 2030—become the basis for regulation, improving building energy performance presents an enormous opportunity for innovative architecture, engineering, and construction practices. Building professionals can help dramatically reduce the negative environmental impact of new and renovated buildings by employing sustainable design principles.

Design decisions made early in the process can deliver significant results when it comes to the efficient use of the vital resources. Employing sustainable analysis tools helps architects and engineers to make better informed decisions earlier in the design process and enable them to have a greater impact on the efficiency and performance of a building design.

Historically, analysis software could be complex and require special training—making it unsuitable for infrequent users such as architects or designers. Sustainable analysis tools, such as Autodesk Ecotect Analysis helps users to become proficient faster by providing access to immense stores of data and the ability to more quickly iterate for optimal sustainable designs. Designing and delivering more sustainable projects can be complex. It requires close coordination across different project stages, from design through construction and operation. Many firms are looking for the best way to integrate building information modeling technology with sustainable design and analysis tools. BIM is core to Autodesk's sustainable design approach for building performance analysis and simulation. BIM enables architects and engineers to use digital design information to analyze and understand how their projects perform before they are built. Developing and evaluating multiple alternatives at the same time enables easy comparison and informs better sustainable design decisions [Autodesk, 2009].

## **1.5 Problem Statement**

It is quite clear that design alternatives and more specifically material selection process has a significant influence on energy consumption, lifecycle cost and carbon emission. As a result, identifying and measuring effects of a proper material selection process makes professionals to move towards reduction of energy consumption, carbon emission and lifecycle cost.

As a consequence, despite having much theoretical effort on energy efficiency and carbon neutrality, coming to practice, the problem emerges from having most residential and non-residential buildings not energy efficient (bellow certified as the minimum requirement of building rating systems), not carbon neutral (due to reluctance of construction industry to move towards up-to-date construction technology rather than following traditional construction systems) and also not cost effective (partly due to not practically distinguishing lifecycle costs of alternative construction materials).

## **1.6 Limitation of Research Scope**

A one story building in the area of Universiti Teknologi Malaysia was modeled as the case study for energy efficiency and carbon neutrality analyses in both residential and non-residential usages.

Consequently, Green Building Index as the localized sustainability building rating system in Malaysia is prioritized. It is worth mentioning that the results of energy efficiency and carbon neutrality analyses are based on Autodesk Ecotect Analysis software (a comprehensive, concept-to-detail sustainable design analysis tool that provides a wide range of simulation and analysis functionality) and Autodesk Green Building Studio (a web-based energy analysis service which performs whole building analysis, optimizes energy efficiency, and works toward carbon neutrality earlier in the design process).

## **1.7 Research Aim and Objectives**

This research aims to propose a comparative study of sustainability analyses between Residential New Construction (RNC) and Non-Residential New Construction (NRNC) and as a consequence investigates on material alternatives to reduce energy consumption, lifecycle energy cost and carbon emission based on integrating GBI assessment criteria with BIM technology.

Therefore, there are three objectives in concern due to research significance as follows:

- i. To propose a case study comparison of sustainability analyses between Residential New Construction and None-Residential New Construction
- ii. To investigate the influence of construction material on reducing energy consumption, lifecycle energy cost and carbon emission
- iii. To investigate the influence of material insulation on reducing energy consumption, lifecycle energy cost and carbon emission



## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Overview**

The industry standard LEED, assigns ratings of platinum, gold, silver or bronze in recognition of total credits earned by the project. The industry standard for energy efficiency, ASHRAE 90.1, is incorporated into LEED through Energy & Atmosphere (EA) Prerequisite 2 – Minimum Energy Performance; EA Credit 1 – Optimize Energy Performance; EA Credit 2 - On-Site Renewable Energy. The U.S. Army policy requires all new buildings to be certifiable at the LEED silver rating. Fort Bragg established the goal of LEED platinum by 2020 for all facilities. For the past 50 years, a wide variety of building energy simulation (BES) analysis tools have been developed, enhanced, and applied throughout the building energy community. Examples of these analyses tools are BLAST, EnergyPlus, eQUEST, TRACE, DOE2, and ECOTECT. Input data in these tools are complex, 2D drawing or text-based applications which require a great deal of time to learn (Crawley et al. 2005).

Building designers consider energy analysis a time-consuming process and leave it to mechanical or electrical engineers late in the design process. Several research papers describe energy analysis as a holistic evaluation (Abaza, 2002). Dahl et al. (2005) and Lam et al. (2004) showed that decisions made early in a project have a strong affect on the life cycle costs of a building. As Grobler (2005) presented, building designs (conceptual and detailed designs) affect most of the life cycle costs of the construction and operation of a building.

A recent innovation in building design and construction, Building Information Modeling has received tremendous interest for its impact on sustainable development and provides the opportunity to develop energy analysis software programs for the industry. It is also worth noting that several researchers proposed to combine Lean and BIM technologies to improve modeling process in sustainable development (Riley et al, 2005). While the converging approach would enable virtual simulation in collaborative environments, and thus is expected to change the A/E/C industry in terms of delivery and management of the built environment, it is found that the approach emphasizes the whole process in design and construction processes. Yezioro et al. (2008) conducted assessing building performance using 3D CAD model for energy analysis in the early design stages. Early design energy analysis provides an opportunity to make cost-effective decisions early in the building life cycle, and to meet federally mandated energy conservation targets. (The Energy Policy Act of 2005 mandates that all new federal facilities must be at least 30% more energy efficient than the base case of ASHRAE 90.1 2004). Healthy buildings can pay for themselves since building construction, operation and energy costs typically amount to small portion (about 10%) of a business's costs while 90% goes towards salaries (USGBS, 2008).

In addition, Pertubuhan Akitek Malaysia (PAM) and the Association of Consulting Engineers Malaysia (ACEM) also developed Green Building Index. It is a profession driven initiative to lead the Malaysian property industry towards becoming more environment-friendly. The Green Building Index rating system assesses the impact of a new building on its environment based on the six criteria of Energy Efficiency, Indoor Environment Quality, Sustainable Site & Management, Materials & Resources, Water Efficiency and Innovation [GreenBuildingIndex, 2009].

## **2.2 Sustainability and the Construction Industry**

“Sustainability” is becoming a central concern for us all. It is a concern that has grown out of wider recognition that rising populations and economic development are threatening a progressive degradation of the earth's resources. The