Multidisciplinary design optimization for sustainable design using building information modeling

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Abstract. This paper illustrates the application of computational design using Rhinoceros software and Grasshopper plugin to investigate a real accommodation with respect to the solar radiation reduction. The paper also introduces the basic concepts of Building Information Modelling (BIM) utilization in construction. The multidisciplinary BIM model show that the Computable BIM Model can be used for Architecture, Structure, Mechanical – Electrical – Plumbing (MEP) to help architects, designers do sustainable design such as acoustic comfort, lighting design on effective cost manner with many rapid design options from the conceptual design phase, to facilitate wind load simulation, predict structural behaviour under fierce conditions, to estimate heat load, HVAC systems performance for energy saving and sustainable design.

1. Introduction
The climate change and the reduction of natural resources drive the world governments, local authorities and designers to act as quickly as possible. To respond to foreseen calamities and bad consequences due to climate change, many countries and organizations are taking their responsibilities. For example, the European Union committed to resolve this issue through the 2020 in 2020 initiative [1]. The "2020 in 2020" plans to reduce overall emissions to at least 20% below 1990 in 2020 as well as increase the rate of renewable energy in energy use to 20% by 2020.

Admittedly, Construction industry (Architecture Construction Engineering – AEC), the main body plays a major contribution to climate change. According to some recent studies, buildings consume 40% of global primary energy and contribute more than 30% of CO₂ emissions [2]. While Heating, Ventilation and Air Conditioning (HVAC) systems account for nearly 50% of energy consumption in buildings and account for 10% - 20% of total energy consumption [2]. For all these reasons, the new approach should be executed and implemented as soon as possible. Today, thanks to the recent developments in information technology, the construction industry is benefited with visual databases. The multidisciplinary BIM Model, fully equipped with almost needed data for various disciplines from architecture to structure and building mechanical – electrical systems (MEP).

2. Building Information Modelling background

2.1. Building Information Model (BIM)
Building Information Model (BIM) is a sharing model that reproduces building information, from project concepts to completing tasks and destroying phases of the entire project life cycle [2]. All project stakeholders can insert, update, extract, and modify information through the BIM information integration platform at different stages.

BIM, the latest technology trends in the construction industry, the progress in Information – Telecommunication Technology (ICT) recently leads to the advance in numerous applications in construction and Building Information Modeling (BIM) would be the remarkable result of ICT progress. In construction also, the demands for new cutting edge technologies like BIM are crucial for modern companies in order to keep the company remaining and staying competent.

Through the whole life cycle, BIM model is not only being used in building structure design, but also can be used for bidding and tendering management, construction management, cost calculation, equipment management, property management, etc., to realize dynamic sharing and reuse of building information data. In the continuous improvement of the construction of the entire life cycle of information at the same time the construction of the latter part of the management and maintenance. There are plenty of tools for energy simulation and analysis according to Tian et al. [20].

![BIM Model for Multi disciplines](image)

**Figure 1.** BIM Model for Multi disciplines (Adapted from Autodesk documents)

### 2.2. Sustainable design definition:
Sustainable Design is the intersection of sustainability and design innovation. Sustainable design is design that integrates, analyzes and optimizes environmental, social, and economic factors for the life of the product. Sustainable design is design that contributes to making the world a better place for future generations [2].

![Sustainable Design](image)

**Figure 2.** Sustainable Design Definition

Sustainable Design can deliver triple bottom benefits:

- **Economic Benefits:** Reduces the overall operating cost to the owner/occupant of the site or building, helps to improve productivity in employees.
- **Environmental Benefits:** Improve conditions of surrounding community and ecosystems, reduces overall cost to the owner/occupant.
- **Social Benefits:** Environmentally conscious construction practices will improve public health, safety and well-being.

Therefore, sustainable design is a desired goal and requirement for most construction projects.

### 3. Engineering design and computational models
Most of key BIM software providers such as Autodesk, Graphisoft, Nemetschek …and a number of addins, plugins, software extensions developers provide all sphere solutions for sustainable design. There are many early works have been done to build the mathematical models [9] or using tools for building envelope optimization [3-5,7], cost or energy consumption minimization [5,8,10,14,15].

3.1. Analysis Tools for Sustainable Design

- **Conceptual Design Phase:** Autodesk Green Building Studio, Ecotect, IES VE Pro…

![Figure 3. IES VE for conceptual analysis](image)

- **Building Performance:** DesignBuilder, CFD Simulation, Simergy, Trace700…

![Figure 4. Simergy for MVAC operation analysis](image)

- **Whole Building Energy Analysis:**
  - Solar Analysis: Light Analysis Extension for Revit, Ecotect…
  - Daylight Analysis: Light Analysis Extension for Revit, Ecotect
  - Thermal Analysis: Heat load calculation, Simergy, Trace700

- **Cost analysis:**
  - **OneClick LCA:** One Click LCA™ is an easy-to-use plugin that delivers an automated Life-Cycle Assessment and Life-Cycle Costing from Revit models.
  - **Tally:** Tally® is an Autodesk® Revit® application that allows architects and engineers to quantify the environmental impact of building materials for whole building analysis as well as comparative analyses of design options.

4. BIM Model for Multidisciplinary Design Optimization (MDO)

This session presents the method of finding the optimized form of the building facade to achieve optimal conditions for the visibility and the amount of Annual Sun Exposure (ASE) transmitted into the building.
NSGA-II algorithm (Non dominated Sorting Genetic Algorithm II) is used to solve the objective function. The algorithm is integrated into the Wallacei toolkit, a plugin for Rhinoceros software. The results are retrieved from the Ladybug toolkit on Grasshopper BIM platform. The Rhinoceros (Rhino) software was used instead of other design software such as AutoCAD, SolidWorks, ANSYS, Catia, etc…because Rhino software has Grasshopper plugin with many powerful features which are suitable for computational BIM for architecture while almost other software are for mechanical design. The old Ngô Tấ Tố Flat, located at 10°47'30.5"N 106°42'44.9"E, is investigated for effective façade design.

Table 1. Simulation data

| Name          | Data    |
|---------------|---------|
| Length        | 5m      |
| Width         | 2.5m    |
| Height        | 3m      |
| Area          | 12.5m²  |
| Operation hours | 6AM - 10PM |
| Function      | Guest room + balcony |

4.1. Weather data

Weather data plays a critical role in simulation. These simulations use the weather data from EnergyPlus, Department of Energy (DoE), USA for Ladybug toolkit.

Table 2. Design variable constraints

| Design Variables                        | Range          | Value |
|-----------------------------------------|----------------|-------|
| Number of Hexagon horizontal cells      | 4 … 10         | 6     |
| Number of Hexagon vertical cells        | 4 … 10         | 6     |
| Cell to Wall Ratio                      | 0.40 … 0.80 (%)| 40    |
| Grid rotation angle in horizontal axis  | -30 ... 30 (°) | 60    |
| Grid rotation angle in vertical axis    | -30 ... 30 (°) | 60    |
4.2. Simulation results and discussions

The objective function converges by 20 iterations with 10 options per iteration, finally 200 results analyzed to finalize the optimum solutions.
Figure 7. View analysis and Annual Sun Exposure results

Façade components simulated results with NSGA II are shown in figure 7 and table 3 in relevant scale respectively. All optimized analyses meet LEED v.4 with ASE <10% and View analysis in range 2% to 4%.

Table 3. Simulated data for objective function result comparison

| Option  | ASE (%) | View analysis >2% |
|---------|---------|--------------------|
| a       | 3.3125  | 78.4%              |
| b       | 2.9375  | 76.2%              |
| c       | 3.75    | 79.2%              |
| d       | 3.3125  | 78.7%              |
| e       | 5.1875  | 79.9%              |
| f       | 5.625   | 85.6%              |
| g       | 3.25    | 77.5%              |
| h       | 5.1875  | 84.9%              |
| i       | 2.6875  | 75.5%              |
| j       | 3.3125  | 78.7%              |
5. Findings and Conclusions

Building Information Modelling received great concerns from largest firms, consultants and designers in the world. The multidisciplinary model can benefit all stakeholders from architectural, structural, mechanical designers, consultants and owners by all predictable outcomes on virtual models before the real buildings are built. The project stakeholders can estimate energy consumption, cost analysis, lifecycle cost with simulations done via virtual models. This paper started the steps which show the solved optimization façade to reduce the solar radiation then energy consumption in general. The computable BIM models can help to perform energy analysis, cost analysis, wind load analysis…Those calculations were not able to be facilitated formerly.

This paper with all above mentioned software and tools shows sustainable design can be done easily for the overall optimization. The further works are carried on for Building Envelope Optimization and MVAC system optimization individually and finally the total solution reached using numerical methods like FEM and FVM.

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