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Reducing the operational energy demand in buildings using building information modeling tools and sustainability approaches

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Abstract A sustainable building is constructed of materials that could decrease environmental impacts, such as energy usage, during the lifecycle of the building. Building Information Modeling (BIM) has been identified as an effective tool for building performance analysis virtually in the design stage. The main aims of this study were to assess various combinations of materials using BIM and identify alternative, sustainable solutions to reduce operational energy consumption. The amount of energy consumed by a double story bungalow house in Johor, Malaysia, and assessments of alternative material configurations to determine the best energy performance were evaluated by using Revit Architecture 2012 and Autodesk Ecotect Analysis software to show which of the materials helped in reducing the operational energy use of the building to the greatest extent throughout its annual life cycle. At the end, some alternative, sustainable designs in terms of energy savings have been suggested.

1. Introduction

Currently, concern about climate change and resource depletion issues is increasing around the world. The building and construction sectors have been identified as one of the major contributors to global environmental impact due to their high energy consumption [1,2].

Energy consumption and greenhouse gas emissions to the environment attributed to buildings are significant contributors to this environmental impact. The consumption of operational energy by buildings has the single largest impact on the environment [3]. The building sector accounts for about 40% of total energy consumption and 38% of the CO_2 emissions in the U.S. [4]. About 27% of the emissions in Great Britain are attributed to the building [5]. Thermal aspect of the building operational energy is one of the key points to be

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investigated since it has the main proportion of operational energy consumption of the buildings. Every building is made up of a series of component, which have a role in thermal dissipation. The rate of energy dissipation in each of these building components depends on design and environmental conditions. But due to their sensitivity, they follow a proportion. So, actions done in order to promote the quality of buildings in terms of heat exchanges can lead to significant energy saving. Using appropriate thermal insulation can reduce heating and cooling loads that not only leads to help to the family economy, but also causes a reduction in greenhouse gas emissions by reducing energy consumption. The thermal building insulation materials and solutions constitute one of the key fields [6].

Green buildings often include measures to reduce energy consumption – both the embodied energy required to extract, process, transport, and install building materials and the operational energy, i.e., the energy consumed during the in-use phase of a building's life to provide necessary services, such as heating, cooling, and providing power for equipment. To reduce the thermal aspects of energy consumption in the operational stage, high-efficiency windows and insulation in walls, ceilings, and floors increase the efficiency of the building. Reducing the use of operational energy should be the main concern of architects who wish to design and build "green" buildings.

One of the relevant issues is implementing the traditional planning environment in which energy and performance analyses of buildings typically are performed after architectural design has been completed and construction documents have been produced.

Analysis of the energy consumption of buildings is a difficult task, because it requires considering the detailed interactions between the building, the HVAC system, and the surroundings (weather), as well as obtaining mathematical/physical models that are effective in characterizing each of those items. The dynamic behavior of the weather conditions and building operation and the presence of multiple variables require the aid of computers in the design and operation of buildings that have improved performance from the standpoint of reduced energy consumption. The disadvantage of taking this approach is that the use of computer simulations requires considerable amounts of detailed, input data and time, even for experienced users [7].

The most effective decisions related to the sustainable design of a building are those that are made in the pre-construction and/or construction stages. Obviously, decisions made after these stages lead to the inefficient and expensive process of retroactively modifying the design of the building to achieve a set of performance criteria [8]. In order to realistically assess the performance of a building in the early design and pre-construction phases, access to a comprehensive set of knowledge of a building's form, materials, context, and technical systems is required.

Since Building Information Modeling (BIM) allows multidisciplinary information to be superimposed within one model, it creates an opportunity for sustainability measures and performance analysis to be performed throughout the design process [8,9].

The main purpose of the study was to identify several sustainable designs that can have positive effects on energy saving and to evaluate the annual lifecycle performance of a building in terms of its thermal aspect of energy consumption in the operational stage by using BIM, as well as by assessing the configurations of local, alternative materials to determine those that have the greatest impacts on building performance by reducing the annual usage of operational energy, thereby improving the energy efficiency of the building.

2. Literature review

Many researchers have focused on the promotion of energy efficiency in buildings. For example, Short et al. [10] reported that natural ventilation was an effective strategy for enhancing the energy efficiency of buildings. Jones-Lee and Loomes [11] showed that a prior strategy with a benefit–cost ratio measure can lead to energy savings. Many of the previous studies concentrated mainly on technical or design strategies [12]. Peippo et al. [13] used a numerical optimization procedure to determine the optimal, building-design variables that would result in the lowest lifecycle cost given certain project specifications and an energy consumption target. They showed the importance of considering the building as a complete system to optimize the design variables simultaneously, since design options are strongly coupled.

In daily practice, architects must meet the demands of their clients and future building occupants for energy efficiency. Moreover, most industrial countries now have building regulations that enforce at least a basic set of energy conservation measures. Sometimes, significant efforts are made to encourage building design teams to do better than just meeting the minimum requirements [14].

Several methodologies have been developed for estimating energy consumption. Some of them are based on statistics, while others are based on simulations [15]. In general, it is accepted that weather data must be given careful attention and consideration in forecasting the energy consumption of buildings [16]. Papa et al. [17] proposed a normalized energy use index (NEUI) based on a temperature function. They discussed the influence of weather variables, such as solar radiation and air velocity, and concluded that the ambient temperature has the greatest effect on energy consumption.

Computer-aided design (CAD) is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design [18]. BIM systems are the latest generation of object-oriented, CAD systems in which all of the intelligent building objects that combine to make a building design can coexist in a single 'project database' or 'virtual building' that captures everything that is known about the building. Although BIM was developed in the mid-1980s, only recently has its popularity increased within the architectural, engineering, and construction (AEC) industries.

In 1986, Graphisoft introduced its first "Virtual Building Solution" known as ArchiCAD [19]. This revolutionary new software allowed architects to create virtual, three-dimensional (3D) representations of their projects instead of the standard two-dimensional (2D) objects found in competing CAD programs of the time. This was important because architects and engineers then were able to store large amounts of datasets 'within' the building model. These datasets include the geometry of the building and spatial data, as well as the properties and quantities of the components used in the design.