Minimizing Construction Emissions Using Building Information Modeling and Decision-Making Techniques

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ABSTRACT

The construction industry is regarded as a major contributor to environmental emissions, due to extensive usage of resources and the waste products produced. This article presents a building information modeling (BIM)-based model that is capable of measuring six types of emissions for different activities of construction projects. The paper investigates eight multi-criteria decision-making (MCDM) techniques for ranking alternatives based on project time; project life cycle cost; project environmental impact; and primary energy consumed by different activities. Three group decision-making techniques are performed to provide consensus and final ranking of alternatives. The Monte Carlo simulation is implemented in order to account for the discrepancy in the calculation of greenhouse gases produced from buildings. Also, a case study of academic buildings is introduced in order to demonstrate the practical features of the proposed model.

KEYWORDS

Environmental Emissions, Building Information Modeling, Multi-Criteria Decision Making, Group Decision Making, Monte Carlo Simulation

1. INTRODUCTION

Greenhouse gases have become a major scientific and political issue during the last decade. Most scientists agree that greenhouse gases play a major role in global warming. It is expected that the amount of greenhouse gases will be doubled in the next 20 years due to rapid growth in urbanization and inefficiencies of existing building stock (United Nations Environmental Program (UNEP), 2009). Greenhouse gases have a great influence on global temperature and weather patterns. Seven of the top ten warmest years on record have occurred since 1998 in the United States (EPA, 2014). Average global temperature has increased by 0.85 °C from 1880 to 2012 (Intergovernmental Panel on Climate Change (IPCC), 2014). Carbon dioxide emissions should be decreased by 50% to 85% in order to keep the global increase in a mean temperature within 2°C-2.4°C (Intergovernmental Panel on Climate Change, 2007).

Temperature has increased in a very significant manner in the north, west of the United States and in Alaska (EPA, 2014). The average of North America covered by snow has decreased by a rate of 3100 square miles per year (EPA, 2015a). The increase in the heat waves occurred due to the climate change causes heat stroke and dehydration (EPA, 2015b). Greenhouse gases produced were 569.9 MtCO₂-Eq in the United Kingdom in 2013 (Department of Energy and Climate change, 2014). Carbon dioxide emissions produced were 5190 MtCO₂ in the United States and 1320 MtCO₂ in Japan in 2012 (PBL Netherlands environmental assessment agency, 2013).
Many countries have perceived the importance of reducing greenhouse gases which led to Kyoto protocol. Kyoto protocol is an international agreement that was set up in December 1997 and it was linked to the United Nations Framework Convention on Climate Change to outline reduction targets in greenhouse gases (Seo & Hwang, 2001). The European Union agreed to set a target of reducing greenhouse gases by 8% for the period 2008-2012 below 1990 levels (Viguier et al., 2003). The world average PM10 density is 71µg/m³. The density of particular matter in China is 98 µg/m³ in 2009 (Wu et al., 2015). Construction industry consumes considerable amount of greenhouse gases where it is responsible for 20.1% of the consumed energy worldwide (US Energy Information Administration, 2016). The consumed energy grows by an average of 2.1%/year from 2012 to 2040 (US Energy Information Administration, 2016).

Internet of Things (“IoT”) refers to a global network that is used to interconnect a group of smart objects or devices using the internet technologies or it may be used to refer to a group of technologies to maintain a certain task such as radio-frequency identification (RFID), Wireless sensor network (WSN), smart phones, machine to machine communication devices, etc. (Miorandi et al., 2012). There are many advantages associated with the implementation of advanced IoT technologies which are: 1) reduction of electricity and water as well as enhancing the inhabitants’ satisfaction in smart buildings, 2) real time environmental monitoring of data such as temperature, rainfall, and river height, and 3) providing advanced traffic control systems in smart cities.

Based on the aforementioned statistics, dealing with the environmental emissions became undoubtedly one of the greatest challenges in the recent century. The proposed methodology is a building information modeling (BIM)-based methodology that is capable of assessing and selecting the best alternatives for construction projects. Each project component is divided into group of alternatives. Each alternative is assessed against the time needed to execute this alternative, alternative life cycle cost, emissions associated with this alternative and primary energy consumed by this alternative. The assessment methodology incorporates an application that utilizes C#.net programming language. The proposed methodology considered all different phases of construction projects such as manufacturing phase, transportation on-site and off-site phases, construction phase, operation and maintenance phase, recycling/reuse phase, and deconstruction/demolition. Multi-objective optimization is performed using non-dominated sorting genetic algorithm (NSGA-II) in order to select the most feasible alternatives taking into consideration: project duration, project life cycle cost, project overall emissions, and total project primary energy as objective functions. Eight types of multi-criteria decision-making techniques are performed in order to rank alternatives obtained from Pareto frontier points. Consequently, group decision making provides a consensus and final ranking for alternatives. Finally, Monte Carlo simulation is performed to consider uncertainties and variations in calculation of greenhouse gases.

2. LITERATURE REVIEW

Several efforts were done in the field of construction emissions evaluation and estimation. Zhang et al. (2015) introduced a scheme for energy and material flow during different project life cycle phases dividing the project into three main stages which are: materialization, operation and disposal stage. They concluded that the reinforced concrete block masonry structures (RM structures) reduce carbon dioxide emissions by 38-112 Kg CO₂/m² when compared to reinforced concrete structures or brick concrete structures. Sim et al. (2016) analyzed the life cycle assessment of 25-story apartment building in terms of air emissions. They concluded that the apartment building produces 10,642, 215.14 kg CO₂, 326,393.29 kg CO, 9401.8 kg CH₄, 8444.57 kg NOₓ, 2877.47 kg SO₂, 603.95 kg NMVOC (non-methane volatile organic compound), and 27.05 kg N₂O during its entire life cycle of the project.
Spatial Cluster Analysis for Etiological Research and Identification of Socio-environmental Risk Factors
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On the Intersection Between Speaker Installations and Urban Environments: A Soundscape Design Perspective
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