Optimizing Construction and Demolition Waste Management Strategies For Sustainable Environment

By

Nehal Ahmed Tarek Mohammed Abdelkader

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
STRUCTURAL ENGINEERING

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Title of Thesis:

Optimizing Construction and Demolition Waste Management Strategies For Sustainable Environment

Key Words:

Construction & Demolition Wastes – Recycling – Economic Viability – Genetic Algorithm – Multi-Criteria Decision Making – Sensitivity Analysis

Summary:

There have been numerous efforts to tackle the problem of construction and demolition waste accumulation worldwide unlike the situation in the developing countries and Egypt as well. This study develops a framework for identifying the optimum fleet required for wastes transportation and the most sustainable disposal strategy. Various fleet combinations are assessed against the time needed to transport the wastes, the total cost of transportation, energy consumed along with carbon emissions emitted from this fleet. Multi-objective optimization using non-dominated sorting genetic algorithm (NSGA-II) is performed in order to select the most feasible solutions. Ten types of multi-criteria decision-making techniques are performed in order to rank alternatives obtained from Pareto frontier points. In this regard, two group decision-making techniques are performed in order to aggregate the results obtained from the ten multi-criteria decision-making techniques. Sensitivity analysis is carried out to determine the most sensitive attribute and the most sensitive measure of performance. The research proposed a model for the economic assessment of two construction and demolition waste disposal strategies; landfilling and recycling. It examines the sensitivity of specific economic and environmental parameters and their effect on the selected disposal strategy. The proposed model is validated by examining a case study from the construction sector in New Cairo, Egypt.

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Acknowledgment

Firstly, I give thanks to God for protection, ability to do work and the wealth of knowledge I have at the moment.

My deepest gratitude is to my advisor, Prof. Mohamed Mahdy. I have been amazingly fortunate to have an advisor who has been always there to listen and give advice. His remarks and helpful constructive criticisms at various stages of my research were thought-provoking. I am grateful to him for his ceaseless encouragement and guidance. I hope that one day I would become as good an advisor to my students as Prof. Mohamed has been to me.

In addition, I would like to show huge appreciation to my advisor Prof. Manal Abdelhamid. I have certainly made a wise decision asking her to be my advisor and I am thankful for her acceptance to do so. She is really a decent advisor on the personal and professional level. Moreover, her technical capabilities in research supervision raised this research to its final stages.

In particular, without the love and patience of my family, none of this could have been possible. My family has been backbone to me and a source of inspiration in my research journey. Their support, care, prayers and motivation helped me overcome setbacks and cling to my graduate study. I greatly value their exceptional efforts for believing in me throughout my thesis preparation and beyond.

Finally, I would like to dedicate my thesis to my grandfather who passed away fourteen years ago.

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Abstract

Environmental performance is now considered a critical indicator of modern construction projects, in addition to the cost, time, quality, and safety. There have been numerous efforts to tackle the problem of construction and demolition waste accumulation worldwide unlike the current situation in most of the developing countries and Egypt as well. In Egypt, C&D wastes are often deposited without any consideration, inviting illegal dumping of other kinds of waste and garbage, which provoke a considerable burden on the environment and raise growing public concern in the local community. Moreover, investigations on the current situation of C&D waste management in New Cairo showed that there was an enormous demand for recycled materials due to the current evolving construction activities. C&D waste management that has not yet seen the light in New Cairo forms the prime focus of this research. The study develops a framework for identifying the optimum fleet required for wastes transportation and the most sustainable disposal strategy, in terms of economic and environmental aspects. Various fleet combinations are assessed against the time needed to transport the wastes, the total cost of transportation, energy consumed along with carbon emissions emitted from this fleet. Multi-objective optimization using non-dominated sorting genetic algorithm (NSGA-II) is performed in order to select the most feasible solutions. Ten types of multi-criteria decision-making techniques are performed in order to rank alternatives obtained from Pareto frontier points. Each decision-making technique follows a certain methodology and thus yields different rankings. In this regard, two group decision-making techniques are performed in order to aggregate the results obtained from the ten multi-criteria decision-making techniques. Sensitivity analysis is carried out to determine the most sensitive attribute and the most sensitive measure of performance. The research proposed a model for the economic assessment of two C&D waste disposal strategies; landfilling and recycling. It examines the sensitivity of specific economic and environmental parameters and their effect on the selected disposal strategy. The proposed model is validated by examining a case study from the construction sector in New Cairo, Egypt. A few recommendations for future studies are additionally introduced.

Chapter 1 : Introduction

1.1 General

The building industry ought to be organized with a specific end goal to achieve a sustainable society since buildings are in charge of more than 40% of global energy usage, 30% of raw material use, 25% of solid waste, 25% of water use, 12% of land use, and 33% of global greenhouse gas (GHG) emissions (United Nations Environment Programme, 2008 [180]; United Nations Environment Programme, 2009 [181]). The building industry consumes about 47.6% of the energy and 75 % of the electricity produced in the United States. The building sector emitted nearly half (44.6%) of all the CO2 emissions produced in the U.S. in 2010 (U.S. Energy Information Administration, 2012) [177]. The building sector represented 40% of total energy consumption in the European Union and half of CO2 emissions in the UK (Dowden, 2008) [45]. The building sector is expected to be responsible for 31% and 52% of total CO2 emissions in the world by 2020 and 2050, respectively (Pacheco-Torres et al., 2014) [138]. The four major energy end-use sectors are the industrial, transportation, residential and commercial sectors. The residential sector took the third place in the energy consuming sectors in the world by accounting for about 18% of the total energy use (U.S. Energy Information Administration, 2011) [176]. The residential sector is in charge of 21% of the total CO2 emissions in the U.S. (EIA, 2011) [178]. The rate of growth of carbon dioxide is 2.5% and 1.7% for commercial and residential buildings, respectively between 1971 and 2004 (United Nations environmental program, 2009). All the above-mentioned factors have exerted the pressure on all industries, including the construction industry, to implement well-established methods to protect the environment.

Buildings are constituted from multiple materials which require large amounts of energy to extract and manufacture, known as the embodied energy (Stephan and Crawford, 2012) [162]. Approximately 78% of the total embodied energy originated from the concrete and steel building materials (Kofoworola and Gheewala, 2009) [99]. Current building energy assessments concentrate exclusively on the operational energy that results in neglecting an expansive part of the of the total energy demand. One of the major problems when formulating a comprehensive life cycle energy assessment is ignoring the transportation energy. Incomplete energy assessment won't bring about net energy savings and could even infer higher overall energy consumption. A comprehensive technique to assess the energy use of a building over its life cycle is subsequently required (Stephan and Crawford, 2012) [162].

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) has declared that GHG emissions, on account of human exercises, have increased by 70% between 1970 and 2004. The average worldwide temperature has increased by 0.74°C between 1906 and 2005, while in the late 50 years, it increased by 0.13°C every 10 years, double the temperature increment of the previous 100 years. Tests have demonstrated that it will keep on increasing at a rate of 0.2°C at regular intervals in the following 20 years. That's why the global warming caused by greenhouse gas emissions has attracted the international society's attention (Pachauri and Reisinger, 2008) [137]. In response to this threatening problem, a life cycle carbon emissions assessment is needed (Chau et al., 2015) [30]. Kyoto protocol is a worldwide agreement that was developed in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005 (United Nations Framework Convention on Climate Change, 2014) [182]. Signing the Kyoto Protocol is considered an evolution in climate change research as it was the first agreement between nations to reduce greenhouse-gas emissions (Climate Change Secretariat, 2002) [35]. Since then, a number of studies discussing the climate change topic have been conducted (Houghton et al., 2001) [87]. The 20th century witnessed the industrial revolution and the modern technologies that use excessive amounts of energy without paying attention to its effects on the climate (Esmaeilifar et al., 2014 [58]; Samari, 2012 [150]). This, in turn, has resulted in a scarcity of natural resources, global warming, air pollution, drought and overall critical climate changes (Christy and Spencer, 2003) [34]. The industrial revolution and modernization have expanded the building development all around the world that requires an enormous amount of energy and produces a lot of CO2 (Fong et al., 2009) [65]. Under the Kyoto protocol, the European Union consented to target a decrease in greenhouse gasses by 8% for the period 2008-2012 (Viguier et al., 2003) [186]. The European Union overachieved its target by accomplishing a reduction of 12.2% from the base year (Institute for Global Environmental Strategies, 2014) [89]. The European Union is now targeting to achieve a reduction of 20% from the base year by 2020 (European environmental agency, 2010) [60]. Improvement is thus a necessity to increase the efficiency of dealing with the issues of energy consumptions and CO2 emissions in buildings.

The construction industry is considered a great exploiter of primary materials and a huge emitter of wastes and thus is required to comply with the sustainability targets (Al-Ansary, 2001) [11]. The major hindrance in achieving a sustainable construction industry lies in handling the wastes resulted from construction and demolition activities. The sustainable development is defined as “a process, which enables all people to realize their potential and improve their quality of life in ways that simultaneously protect and enhance the Earth’s life-support systems” (Parkin, 2000) [139]. Yesterday’s actions are no longer valid and the construction industry, therefore, is obliged to adopt economic efficient and environmentally friendly strategies for managing C&D wastes. The utilization of recycled concrete aggregates is increasingly encouraged as an alternative to virgin aggregates. The responsibility lies on project managers to make sure that contractors are knowledgeable of the full dimensions of recycling and can use the recycled material in the intended applications (Roos and Zilch, 1998) [149].

1.2 Construction & Demolition Wastes Management

In addition to the global warming problem, the global industrialization and urbanization have resulted in significant amount of construction and demolition (C&D) waste. C&D wastes have no absolute definition, their composition varies according to the location, type, age of the project as well as the construction and demolition techniques (El Haggar, 2007) [50]. The EPA defines C&D waste as “waste that is generated from the construction, renovation, repair, and demolition of structures such as residential and commercial buildings, roads, and bridges”. According to its generation phase, C&D waste can be divided into three categories: construction waste (CW), renovation waste (RW) and demolition waste (DW). Another definition of C&D waste, “Wastes from razed buildings and other structures are classified as demolition wastes. Wastes from the construction, remodeling, and repairing of individual residences, commercial buildings, and other structures are classified as construction wastes” (Tchobanoglous et al., 1977) [169]. A Chinese guideline defined C&D wastes as: “The soil, material and others are discarded and generated by any kinds of construction activities, including the development, rehabilitation, refurbishment of construction projects” (Ministry of Communications of the P.R. China, 2005) [123]. C&D waste comprises mainly concrete, asphalt, masonry, wood, glass, plastics, insulation material, metals, paper, cardboard, ceramic tiles, gypsum board, marble, granite, and filling material (Meyer and Walsh, 1996) [121]. This