Cairo University

Assessment of Steel Structure Deconstructability using BIM-based Approach

By

Andrew Magdy Samy Basta

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
Integrated Engineering Design In Construction Projects

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Assessment of Steel Structure Deconstructability using BIM-based Approach

By

Andrew Magdy Samy Basta

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
Integrated Engineering Design In Construction Projects

Under the Supervision of

Prof. Mohamed Mahdy Marzouk

Professor of Construction Engineering
and Management
Structural Engineering Department
Faculty of Engineering, Cairo University

Prof. Mohammed Hassanien Serror

Professor of Steel Structures
Structural Engineering Department
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Assessment of Steel Structure Deconstructability using BIM-based Approach

By

Andrew Magdy Samy Basta

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
Integrated Engineering Design In Construction Projects

Approved by the Examining Committee

Prof. Mohamed Mahdy Marzouk ………………… Thesis Main Advisor
Professor of Construction Engineering and Management - Structural Engineering Department, Cairo University

Prof. Mohammed Hassanien Serror ……………..... Advisor
Professor of Steel Structures - Structural Engineering Department, Cairo University

Prof. Sherif Ahmed Mourad ……………….……… Internal Examiner
Professor of Steel Structures - Structural Engineering Department, Cairo University

Prof. Ayman Ezzat Othman ………………………...External Examiner
Professor of Construction Engineering and Management - British University in Egypt

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Name: Andrew Magdy Samy Basta

Date of Birth: 06/06/1992
Nationality: Egyptian
Registration Date: 01/10/2016

Awarding Date: …./…./2018
Degree: Master of Science
Department: Integrated Engineering Design In Construction Projects

Supervisors:

Prof. Mohamed Mahdy Marzouk
Prof. Mohammed Hassanien Serror

Examiners:

Prof. Mohamed Mahdy Marzouk – Cairo University (Thesis main advisor)
Prof. Mohammed Hassanien Serror – Cairo University (advisor)
Prof. Sherif Ahmed Mourad – Cairo University (Internal examiner)
Prof. Ayman Ezzat Othman – British University in Egypt (External examiner)
- Professor of Construction Engineering and Management - BUE

Title of Thesis:

Assessment of Steel Structure Deconstructability using BIM-based Approach

Key Words:

Building Information Modeling; Steel structure; Design for Deconstruction (DfD); Deconstructability Assessment Score (DAS); Dynamo; Revit.

Summary:

Recently, attention is being focused on Design for Deconstruction (DfD) as one of the most effective structure end-of-life design scenarios. Although several research efforts have dealt with the DfD and reversible buildings design theories for the past few years, the lack of technological support for developing tools to improve DfD to be BIM compliant has been clearly noticed. This research presents a Deconstructability Assessment Scoring (DAS) methodology for quantitative assessment of Steel Structures deconstructability. The proposed methodology takes into consideration a number of steel parameters and their deconstructability Seven innovative solutions contributing to steel connections deconstructability are considered in the proposed research. Furthermore, steel elements reusable fire-proofing systems are introduced to provide the required fire resistance and deconstructability. The detailed analyses for the selected parameters are adopted and implemented to form the Steel Structure Deconstructability Assessment Scoring (SS-DAS). The proposed methodology is implemented in Autodesk Revit using Dynamo. The proposed innovative solutions are modeled as families to automate the scoring process.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the reference section.

Name: Andrew Magdy Samy Basta Date:

Signature:

Acknowledgments

First of all, I would like to express my full gratitude to my advisors **Prof. Mohamed Mahdy Marzouk** and **Prof. Mohammed Hassanien Serror** for their continuous support, patience, motivation through all steps of this research.

Secondly, I would like to express my full appreciation to COSMOS-E Engineers and Consultants company in addition to the visited steel fabrication workshop crew for the precious information obtained regarding steel structure components.

Last but not the least, I should say to my family:
"Many thanks for supporting and loving me through writing this thesis and through my whole life. **Father**, **mother** and **brother**, **I appreciate your existence in my life**!"

Andrew Magdy

September 9th, 2018

Table of Contents

List of Tables

List of Figures

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Abstract

Recently, attention is being focused on Design for Deconstruction (DfD) as one of the most effective structure end-of-life design scenarios. Although several research efforts have dealt with the DfD and reversible buildings design theories for the past few years, the lack of technological support for developing tools to improve DfD to be BIM compliant has been clearly noticed. This research presents a Deconstructability Assessment Scoring (DAS) methodology for quantitative assessment of Steel Structures deconstructability. The proposed methodology takes into consideration a number of steel parameters such as connection type, member type, and steel-concrete composite action solutions. Deconstructability of the steel member types (including built-up and hot-rolled) as well as steel connection types (including bolted and welded) are investigated. Seven innovative solutions contributing to steel connections deconstructability are considered in the proposed research including; Quicon, Lindapter, ConXtech, post-tensioned moment connection, post-installed friction-grip bolted shear connection and clamped steel-concrete connection. Furthermore, steel elements reusable fire-proofing systems such as endothermic wraps and flexible fire blankets are introduced to provide the required fire resistance and deconstructability. The detailed analyses for the selected parameters are adopted and implemented to form the Steel Structure Deconstructability Assessment Scoring (SS-DAS). Accordingly, the SS-DAS provides a vastly index that expresses the steel structure deconstructability. The proposed methodology is implemented in Autodesk Revit using Dynamo. The proposed innovative solutions are modeled as families to automate the scoring process by extracting the model bill of quantity, calculating the structure parameters ratios and incorporating these ratios providing each design alternative model with its unique SS-DAS index. It should be noted that SS-DAS index is used to reflect its sustainability aspect with respect to different design alternatives for the steel structure with a high Level of Detailing (LOD). A case study of steel structure utility building is worked out to illustrate the use of the developed methodology. The framework is expected to assist project owners in making efficient decisions with respect to selecting the most deconstructable steel structure design alternative.

Chapter 1 : Introduction

1.1. General

For many years, the conventional construction industry encountered a technological revolution due to the need for non-conventional processes with mitigated errors, less construction time, more effective design quality, and high conflict resolution. Accordingly, Building Information Modeling (BIM) showed up to provide this needed features. BIM has been used widely in the construction industry as a result of the awareness of its implementation importance.

In addition to BIM main benefits for conceptual design, feasibility studies, clash detection, etc., it contributed strongly to various construction sectors; safety, facility management, rehabilitation of heritage buildings, etc. [1]. In spite of the beneficial contribution of BIM in Architecture, Engineering Construction (AEC) industry, the main contribution has been often in phases of design, bidding, construction, and facility management, only few works have been considering the end-of-life phase issues [2].

Due to the rapidly increased population, a huge number of building and construction demand is created. As a resource-intensive industry, the AEC industry considered as a main contributor to the main environmental impacts such as: global warming, natural resources depletion, waste generation, and pollution, which in return have a bad influence on natural health and human survival [2].

1.2. Problem Statement

The construction industry has been facing difficulties due to the call for facilities design for end-of-life activities such as: relocation, renovation, disassembly, and disposal. From the ecosystem and sustainability perspectives, these activities have many side effects:

- Large volume of demolition and land-filling wastes, since most of construction materials are unrecoverable, unrecyclable, or undeconstructable.
- High amount of energy consumption, increasing the Carbon gas emissions with environmental impact.
- High amount of facility's capital investment loss.

Landfills are no more capable to receive that massive demolition and end-of-life waste, environment can no longer suffer from toxic gases and CO2 emissions and Earth has no additional material and energy sources for the upcoming life-time. Sequentially, waste produced, energy consumed, and CO2 gas emissions released by reason of AEC industry practices began to be observed significantly. Since the current AEC industry is highly directed towards building renovation and demolition therefore, ensuring adequate Construction, Demolition, and Excavation Waste (CDEW) management at the end-of-life of building is crucial. The need to adequately manage and reduce CDEW at the end-of-life therefore requires replacing the traditional demolition scenario with a more sustainable scenario such as: deconstruction [2]. Although many researches considered CDEW management, only few studies handled the mitigation of end of life waste right from early design stages [3]. Through the last decade, the deconstruction theory showed up to upgrade and improve the design for end-of-life activities of facilities. Subsequently, Design for Deconstruction (DfD) took place to enhance the engineering design process to avoid the end-of-life activities problems.

The main research gap is the lack of technological support for developing tools to improve DfD to be BIM compliant, in addition to infancy of the assessment of structures deconstructability. Accordingly, there is a necessity to develop a BIM compliant framework to assess structures deconstructability which in return would contribute to structures design satisfaction.

1.3. Research Objectives

The main objective of this research is developing a framework to enhance the assessment of the deconstructability of steel structures. Creating the framework, it will efficiently help the engineers to assess their designs' deconstructability through a BIM-based process that can be linked to the Engineering Design Process reducing time, effort, and human errors. As a result, the most deconstructable design of the steel structure would be evaluated using this framework.

1.4. Research Scope

The proposed framework has been established using BIM-based software tools. A steel structure 3D modeling software (Autodesk Revit) has been employed with high capability to model both the steel structure members and connections. Hence, a compliant tool has been developed (Dynamo tool) to capture a set of deconstructability parameters and give the structure its deconstructability score. The parameters in question are related to members' profile (built-up or hot-rolled), deconstructable connections (friction-grip bolted [4] and clamped connections [5]) ratio, connection bolting type, connection welding type, reusable-fireproofed members' ratio (e.g. flexible blanket systems [6]), members' repetition and structure similarity, and existence of qualified deconstruction manager and a deconstruction aware crew. Hence, Deconstructability Assessment Scoring System (DAS) criteria has been modified and applied to case- study of a steel structure to obtain the DAS score.

1.5. Research Methodology

To achieve the previously stated objectives, the following methodology is to be followed:

1) Analyze steel structure components by conducting workshop visits.
2) Introduce innovative solutions.
3) Modify the former DAS equation to adopt the chosen parameters.
4) Prepare the steel structure model with a high Level of Detailing (LOD).

5) Enrich all model elements with the needed deconstructability information.
6) Utilize Dynamo tool for Autodesk Revit to develop a prototype and link it to the steel structure Revit model.
7) Calculate the DAS score for the model and import it to Revit database.
8) Apply the BIM-based framework to a real steel structure.

The output of the above listed steps as DAS score is ready to be utilized by any further add-in tools for further functions.

1.6. Organization of the Thesis

Following the introductory chapter, the thesis is organized as follows:

- Chapter 2 presents a literature review of design for deconstruction and effective deconstructability principles. Moreover, an analysis for steel structure components is taking place. At last, it mentions the importance of DfD plan and experienced team existence in addition to the significance of adopting BIM for DfD and deconstruction processes.

- Chapter 3 shows the proposed framework. The proposed framework consists of seven main steps utilizing two main BIM tools; Autodesk Revit and Dynamo tool. A workshop visit takes place to analyze steel structure’s main parameters. Moreover, this chapter introduces a group of eight innovative solutions.

- Chapter 4 describes a BIM-based framework starting with a modification for the BIM-DAS model equation. Then, it introduces a steel structure deconstructability assessment score system (SS-DAS). The developed framework considers enriching the steel structure 3D model with shared parameters. The chapter also shows the creation of an SS-DAS Dynamo prototype to automate calculations of different design alternatives.

- Chapter 5 presents the application of the BIM-based framework on a real case study. It introduces a number of design alternatives for the case study. Afterwards, SS-DAS Dynamo graph is used to calculate SS-DAS index for each alternative. This chapter then illustrates a clear comparison of the different SS-DAS values showing the effect of utilizing each of the innovative solutions.

- Finally, conclusion, research contributions, future work and recommendations are presented in Chapter 6.