A BIM-based tool for Evaluating the Impact of Change Order on Project Schedule, Cost, and Construction and Demolition (C&D) Waste

By

MOHAMMAD ADIL KHAN

(NUST201600000171408)

Masters of Science

In

Construction Engineering and Management

Department of Construction Engineering and Management

National Institute of Transportation (NIT)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST)

Islamabad, Pakistan

(2020)

This is to certify that the

Thesis titled

A BIM-based tool for Evaluating the Impact of Change Order on Project Schedule, Cost, and Construction and Demolition (C&D) Waste

Submitted by

Mohammad Adil Khan

(NUST201600000171408)

has been accepted towards the partial fulfillment
of the requirements for the degree of
Masters of Science in Construction Engineering and Management

Dr.-Ing. Abdur Rehman Nasir
Supervisor / Assistant Professor
Department of Construction Engineering and Management
School of Civil and Environmental Engineering (SCEE)
National University of Sciences and Technology (NUST)

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by Mohammad Adil Khan (Registration No. NUST201600000171408), of National Institute of Transportation (NIT) – SCEE has been vetted by undersigned, found complete in all respects as per NUST Statutes / Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ___________________________________

Name of Supervisor: Dr-Ing. Abdur Rehman Nasir

Date: _______________________________________

Signature (HOD):_____________________________

Date: _______________________________________

Signature (Dean/Principal):_____________________

Date: _______________________________________

ACKNOWLEDGEMENTS

I would first and foremost be thankful to Allah Almighty (SWT), who gave me the motivation and grit to complete my research. I am also highly in debt to my advisor Dr.-Ing. Abdur Rehman Nasir, for his valuable guidance, time and encouragement, during my research work. Last but not the lease, I am also thankful to my parents and siblings for their patience, prayers, and support.

ABSTRACT

A change order can be initiated by several different stakeholders including owner, owner's agent or design engineer. This can be caused due to several different reasons such as financial problems, changes in project scope or noncompliance with owners' requirements etc. Changes on one component of the project may cause a 'ripple effect' that can have an impact on other elements of the building. Project stakeholders face difficulties identifying which elements of the building will affected and evaluating the different impacts on project schedule, cost and C&D (Construction and Demolition) waste. Reducing C&D waste will not only lead to better financial performance of a project but will also improve on the construction industry in terms of economy and environment. A BIM-based framework in evaluating impact of change orders in a construction project was developed that enable to automatically detect the changes in building elements and evaluate the impacts of the proposed change on project schedule, cost and C&D waste. This framework was then integrated into a BIM based tool to track, report and visualize these impacts more effectively, helping stakeholders in comprehend the impacts of change orders and make better decisions for a project. This BIM based tool can help reduce C&D waste leading to better financial performance of a project and improve the economic and environmental impacts of the construction industry. The BIM-based tool was also tested with a case study to demonstrate its ability and usefulness.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

LIST OF ABBREVIATION

Engineered, Procurement & Construction	EPC
Architectural Engineering Construction	AEC
Building Information Modelling	BIM
Heating, Ventilation and Air Conditioning	HVAC
Change Order	CO
Variation Order	VO
Construction & Demolition	C&D
American Institute of Architects	AIA
Reinforced Concrete Cement	RCC

Chapter - 1

INTRODUCTION

1.1. Study Background

A change order can be initiated by several different stakeholders including owner, owner's agent or design engineer. Changes on one component of the project may cause a 'ripple effect' that can have an impact on other elements of the building. Project stakeholders face difficulties identifying which elements of the building will affected and evaluating the different impacts on project schedule, cost and C&D (Construction and Demolition) waste. Previous studies have evaluated the impacts on project schedule and cost, however there is a lack of research on evaluating the impact of waste produced during the construction process. Reducing C&D waste will not only lead to better financial performance of a project but will also improve on the construction industry in terms of economy and environment.

According to FIDIC, a contractor is obligated to carry out the variation order as per owner's request. Before executing the work, the contractor must submit a proposal containing his rough analysis regarding the planned changes, his methodology, amendment to project schedule, and cost required. A contractor must evaluate the impact of the changes on the work, the required resources and methods, and the cost and schedule. Change orders also impact the C&D waste of the project, but it is rarely considered before making any decisions.

This study calls for the development of a framework in evaluating impact of change orders in a construction project. This framework will be integrated into a building information modelling (BIM)-based tool that will enable to automatically detect the changes in building elements and evaluate the impacts of the proposed change on project schedule, cost and C&D waste. The proposed tool will integrate several different platforms, namely, Autodesk Revit, Application Programming Interface (API) and Microsoft Excel. A plugin will be developed that can extract the relevant parameters from both the models and identify the building elements affected due to the change order. The BIM-based tool will highlight the changes in term of schedule, cost and C&D waste. This BIM-based tool will allow project stakeholders in better evaluating the impact of the change order and its impact. Stakeholders will also have the option to try several different what-if scenarios and improve their decision-making.

1.2. Problem Statement

Change orders frequently arise during a construction project. There can be various reasons for a change order to be sanctioned including financial problems, changes in project scope or noncompliance with owners' requirements etc. The current practice of change order relies primarily on paper-based documentation which are in descriptive and tedious form. This can overwhelm any person who tries to study it, especially those who are not trained or are part of the profession. Also, a drawback of this paper-based system is that it is not well-organized and difficult to keep record. Project stakeholders often face difficulties in understanding the information on the change order. A poor understanding of the change order can lead to them assess its impacts inaccurately and as a result, make a poor decision.

Unfortunately, when change orders are sanctioned, there are no tool or guide in evaluating the impact of a change order with respect to all three parameters: schedule, cost and C&D waste. Stakeholders do not have access to such tool that can aid in making decisions regarding the design and execution of the change orders. Instead, they must rely upon paper-based documentation to assess the impacts using their judgment and experience. This can overwhelm them with too much information and lead to failure in comprehending all impacts. Some stakeholders might even fail to evaluate the impacts of change of one component to the rest of the building.

1.3. Research Objectives

The main objectives of this research are:

a) To investigate strategies for enabling in the evaluation of time, cost and C&D waste during a construction project
b) To develop a BIM-based framework for evaluation the impacts of a change order at a construction project in terms of time, cost and C&D waste.
c) Integrate the framework as a BIM-aided tool that can track and visualize the impacts of a change order on subject parameters.

1.4. Research Significance

Increasing cost of construction projects have made it vital for project stakeholders to take serious decisions to save significant amount in total profit of the project. Project stakeholders must commonly deal with deciding on change orders during the construction phase. This change order can affect project time and cost (Bower, 2000). Concurrently, change orders are a source of C&D waste which causes a loss to economy of the project (Ekanayake, 2000; Adewuyi & Otali, 2013). This waste can contribute to the project expenditure in form of storing and sorting. Project stakeholders are required to manage cost, schedule and C&D waste to increase profit.

This research will try to develop a tool that can help in comprehending and visualizing the change order more easily. This tool needs to quantify the magnitude of change in one component of the building to the rest of the project with respect to the subject parameters. Stakeholders need to be better equipped in making decision regarding change orders. A BIM-based tool will help in project stakeholders in retrieving the records more quickly and comprehending it more easily.

1.5. Advantages

This study can:

1. Help in project stakeholders in comprehending change orders more easily and quickly
2. Help in visualizing the impact of change order on a BIM model
3. Allow stakeholders to identify any improvements to the change order based on their judgement
4. Help in analyzing different what-if scenarios and improve decision-making
5. Save in project expenditure by reducing the need to store excess of construction material
6. Reduce the negative consequences on the environment from excessive C&D waste.
7. Reduce the depletion of resources

1.6. Areas of Application

This research will mainly focus on semi high-rise buildings used for office commercial and residential purposes. Since facility use does not influence the tendency of waste generation, as many buildings use as available will be considered.

1.7. Thesis Organization

This research has been organized into five chapters. An overview of those chapters is given below.

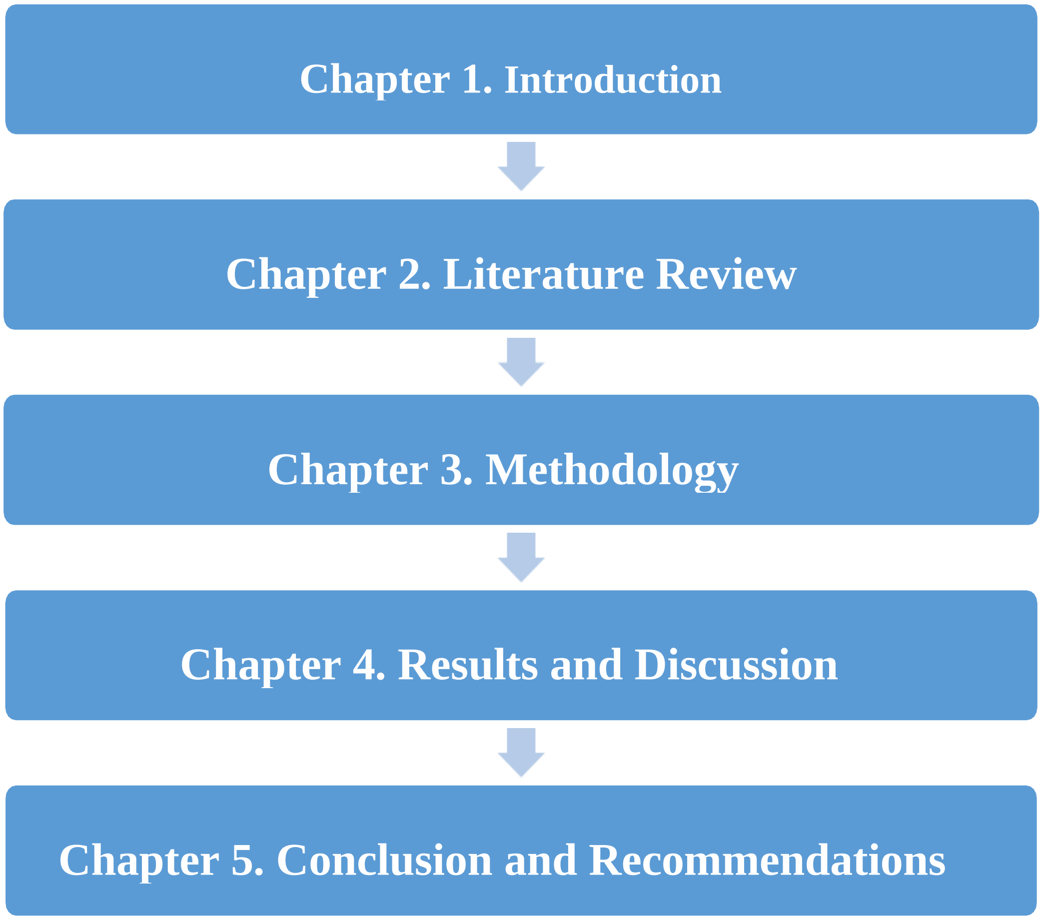


Figure 1.1 Thesis Organization

Chapter 1 is "Introduction" includes Background Study, Research Significance, Problem Statement, Research Objectives, Advantages and Scope of Research.

Chapter 2 is “Literature Review” includes Definition of Change order, its importance in construction projects, sources of change orders and its impact, C&D waste and use of BIM in building construction industry.

Chapter 3 is “Research Methodology” includes the Overview and Requirements of the Framework Design. Input, Data Extraction, Change Impact Analysis and Output is deliberated in detail.

Chapter 4 is “Results and Discussion” includes discussing developed BIM tool and its User Interface. Its features and Buttons are elaborated

Chapter 5 discusses the conclusions of this study and future recommendation are also suggested in the end.

Chapter - 2

LITERATURE REVIEW

2.1 Introduction

In this chapter we will presents a detailed review of the research studies already carried out on change order, its importance in construction projects, sources of change orders and its impact, C&D waste and use of Building Information Modelling in construction.

2.2 Definition of Change and Change Orders

Change is defined as "to give a different position, course or direction" and order is defined as "to command" (Anon., 2018). Change can be defined as many ways according to the construction industry norms. CII (2000) defined change as any order or decision sanctioned by stakeholders that result in a project's alteration. Ibbs et al (2001) defined change as "any additions or deletions to project goals or scope". Later, Ibbs (2005) classified change as "both physical and unphysical".

Changes are authorized by a legal document known as a change order (CO) or variation order (VO). A CO "is the formal document that is used to modify the original contractual agreement and becomes part of project's documents" (Fisk, 1997; O'Brien, 1998). For this research, the definition for CO will be followed according to the AIA (2017) i.e. a CO "is a written order to the contractor, signed by the architect and the owner, issued after the contract has been executed, authorizing a change in the scope of work or an adjustment in the contract sum, contract time, or both"

Changes are inevitable at all construction projects and cannot ignored in decision making. Usually the client initiate changes during the design stage and execution phase of the project. Some variations are made to the project design and specifications. AEC teams must accordingly revise project plans and try to apply those change. It is important that the impact of those changes is analysed so that the project does not fail to meet its cost, schedule, and target waste. Changes can have significant impact on project's original schedule and cost (Hallock, 2006). It can also lead to increased probability of delays and conflicts between project stakeholders (Vandenbergh, 1996).

2.3 Construction Industry

The construction industry is significant sectors of the economy. It provides 5-10% jobs and contributing 5-15% towards a country's GDP (DTIE, 2009). Therefore, it is vital that construction sector sustain successful deliveries of projects.

Construction projects vary in size, duration and complexity; however, they share many common features. In the US, it is estimated that "more than $60 billion dollars is spent annually on changes" (DART 1995). CO caused delays in the "70% of the construction projects in Saudi Arabia" (Assaf, 2006). The construction industry is one of the sectors in Pakistan's economy, contributing up to 2.3 percent the country's GDP. It also provides significant amount of employment opportunities. Khan (2008) stated that it offers jobs to about "5.5% of the total employed labour" or 24 lakh persons. The construction sector in Pakistan is flourishing as it has grown by 17.2% in 2006-07 against the previous years and the wages have got almost doubled. The construction industry of Pakistan is labour intensive. In comparison to other industries, it is considered backward due to the lack of good management practices and modern technologies (Ali, 2006).

Azhar et al. (2008) identified that changes such as additional work were significant factors causing cost overrun in Pakistan's construction sector. Ensuring successful completion of projects, ultimately generating more revenues for the economy

2.4 Sources of Change Orders

COs are very common during a construction project and can originate from several sources. Clients use CO as a tool to input changes towards building design according to desire and taste, whereas contractors and consultant use it to mainly correct any error in their design, specifications, and construction methods.

Ming et. al. (2004) opined that the sources for CO can be both external and internal. Internal factors include complication in project, erroneous cost estimation, lack of available resources, or a change funding in the project. External causes such as changes in mechanical design, changes in regulations, changes in the economy, and public opinion also cause CO.

According to Arian et al. (2006), changes can occur due to several foreseen or unforeseen reasons. Sources of CO in a construction project can be classified as four main sources; client, consultant, contractor and other changes. This is shown in Table 2.1.

1. Client-related changes: changed initiated by the client of the project for any changes to the scope or objective of project

2. Consultant-related changes: changes initiated by consultants for requests that are not part of the original contract's scope

3. Contractor-related changes: changes suggested by contractors for any alteration to the original drawing

4. Other changes that may come indirectly from other non-stakeholders

2.5 Impact of Change Orders

A change "can have impacts on any part of the projects". It can have an influence on the project‘s final predicted budget, final end date of the project, the performance of work, productivity level and the possibilities of legal problems arising.

Hanif et al (2016) studied sources of variation orders in hydropower projects in Pakistan were and found the following

- Error in design
- Change of scope
- Change in design,
- Unavailability of equipment
- Changes in contract.

There are many researches that have concentrated on the effect of CO on construction projects. 50% of construction projects in Hong Kong suffered delays that originated from changes (Kumaraswamy, 1998). It was determined that CO were frequent source of delays.

CO that impacts schedule can also affect the project budget. The impact of CO on project budget can be incremental or decremental effect. In some cases, depending on the nature of contract and its clauses, one party may get all the benefits while other must face all the losses. In other cases, none of the parties may face any effect from the CO. As it can be seen from the literature review, there is a need to focus on the schedule, cost and most importantly waste of a project when looking into the impacts of change orders.

2.6 Construction & Demolition Waste

Waste can be defined in number of ways. Recent research consider waste as any deficiency that results in excessive use of tools, material, labour, equipment and capital in larger amount than those required for the construction. Formoso et al. (1999) defined waste "due to construction activities that causes both direct and indirect costs but do not add any value to the product from the owner's perspective".

The construction process consumes not only a large amount of raw material and natural resources but also produces a significant amount of waste. This waste has a negative impact on the economy and the environment including depletion of natural resources, air pollution, surface and ground water pollution, risks to public health, and losing considerable land resources. Unsurprisingly, there is an increasing pressure to improve C&D waste management to reduce its associated adverse impacts.

According to Haseeb et al. (2011) construction industry in Pakistan provides widespread employment, foreign investment, housing, growth to other industries and helped money flow within the economy of the country. Likewise, the construction industry also generates a lot material waste of different type and amount.

Bekr (2014) has concluded that one of the sources of waste was when contractor procured materials based on an original plan and specification and then the design was changed to suit the CO. Most materials cannot be returned to supplier and the work that has already been executed need to be demolished or reworked. (Love & Li, 2000).

Other studies have also found that that design changes and correction are major causes of waste generation(Al-Hajj & Hamani, 2011)(Bossink & Brouwers, 1996).

In the construction industry in Pakistan, there is lack of study on C&D waste. Arshad et al. (2017) dealt with quantifying the material waste and its source in different projects. The result of the survey found that bricks, tiles, and plaster from mortar were the source of most waste. However, no research has been conducted to investigate the evaluate the C&D waste generated in the country. It is hoped that this BIM-based tool will allow professionals in the country to evaluate C&D waste on the construction projects more easily and help reduce the negative consequences of the project on the resources and environment.

C&D waste can estimate through many different techniques and methods. This can be categorized as follows in Table 2.1:

Table 2.1 C&D Waste Method

Technique	Research	Waste type	Scope
Site Visit Method o Direct measurement o Indirect measurement	 Kartam et al. (2004) Poon et al (2004)	 C C&D	Project Level
Generation Rate Calculation Method o Per-capita multiplier o Financial value extrapolation o Area-based calculation	Zezhou Wu et al (2014)	C&D	Regional Level
GIS	Wu et al 2016	D	Regional Level
Classification System accumulation method	Solis-Guzman et al. (2009)	C&D	Both
Material flow analysis approach	Hu et al 2010	C&D	Both
BIM	Jack C. P. Cheng et al (2013)	D	Project Level

As it can noted from the above table, methods such as direct measurements require a lot of time, cost and energy including coordination with other stakeholders. Indirect methods and generation rate calculation methods have a lot of assumption in them and provide data for specific region and the information provided are for governmental or regulatory purpose. GIS is an accurate method, however, its equipment and set up is highly expensive. BIM provides a more suitable environment for more accurate prediction of waste. Also there is need for waste information in project level as every project is unique and has separate pros and cons.

2.7 Change Management Process using BIM

Building Information Modelling (BIM) is the most modern technological platform available on computers that provide accurate building data and information Architecture, Engineering, and Construction (AEC) industries worldwide. BIM allows "multi-disciplinary information to be superimposed within one digital building model".

BIM can be used to accurately extract material and volume information through the BIM model and integrate the information for detailed planning. This was demonstrated by Anqi Shi (2020) used Revit and Dynamo for a detailed quantity take-off. The data was then exported into Excel, allowing the user to inserted the price per unit to the file and to generate a more accurate Bill of Quantity (BOQ).

BIM has also been used to estimate C&D waste. Cheng et al. (2013) created a BIM plugin for quantification Demolition waste. Data from Hong Kong municipality was collected and input into the system to generate estimation of demolition waste for construction projects at Hong Kong area only. More recently, Guerra et al. (2019) used BIM to automate CW quantification. CW is estimated as the materials purchased. Algorithms developed to quantify concrete and drywall waste streams

Moayeri et al. (2017) was the first to evaluate the impact of design changes on time. The first objective of their study was to assist stakeholders in making well-thought design-change decisions by visualizing the impact of a schedule change on the different project components. This was achieved by developing a plugin that was integrated into a BIM software. The plugin helped in identifying the physical changes (size, location, and material) on a 3d model. It also analysed by comparing the original BIM model with a BIM model with the proposed changes. The second objective was to evaluate the impact of the changes on a schedule where both scenarios (before-changes and after-changes) were compared. This plugin helped stakeholders in evaluating the impacts of change order on project schedule but ignored other important parameters like cost or C&D waste.

Likhitruangsilp et al. (2018) proposed a similar change detection model wherein in addition to providing information on the changed physical conditions, it also provided evaluation on project schedule and cost. This was done by identifying the changed elements in BIM models through an element-by-element comparison and then generating a detailed report. The platform for this model was provided in Autodesk Revit and Dynamo, and the report was generated on Microsoft Excel. A report generated in the end quantified the impact of changes in terms of time and cost. User could get an overview of any delay analyses and cost evaluations. This research, however, lacked in helping stakeholders evaluate the impact of C&D waste from the change order on the construction project.

Chapter - 3

RESEARCH METHODOLOGY

3.1 Introduction

In this chapter is to describe the detailed method adapted for this study in order to complete research purpose and aims that were introduced in Chapter 1. This includes the literature review and study of change order strategies conducted as presented in Chapter 2. It will be followed by selection of the best strategies for evaluation of change order impacts for development of a BIM based framework to do achieve the research objectives. This BIM based framework then will be integrated as BIM based tool for use of engineers to help in track and visualize the impacts of change order. The BIM based tool will then be validated using a simple case study or exposing it to field experts. Conclusion will be drawn from the feedback of the validation techniques and used to improve or give recommendations for future study. This is shown in figure 3.1

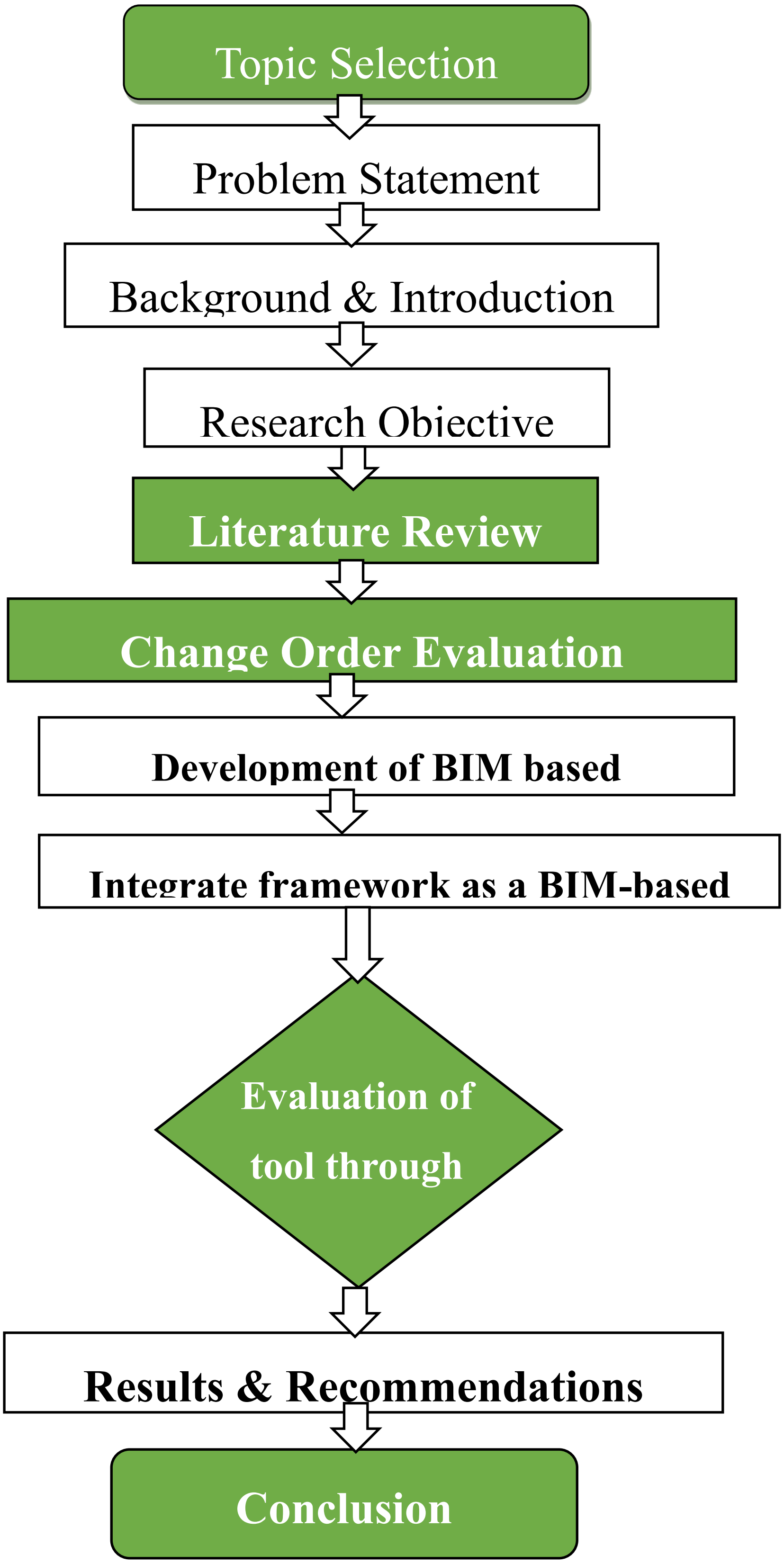


Figure 3.1 Research Methodology

3.2 Overview/Requirement in Framework

The framework should be developed while keeping in mind that the BIM based tool is required to have some features such as;

- The tool should be easy to use with no need of training;
- The tool should automatically identify change impacts;
- The tool ought to be able to evaluate cost, schedule and waste data after change order is applied;
- The tool should extract data BIM model and present it in different mediums such as Revit and MS Office
- The tool should allow multiple users to access and change the project. Also allow them to report and extract data.
- The tool should have room for expansion and extension

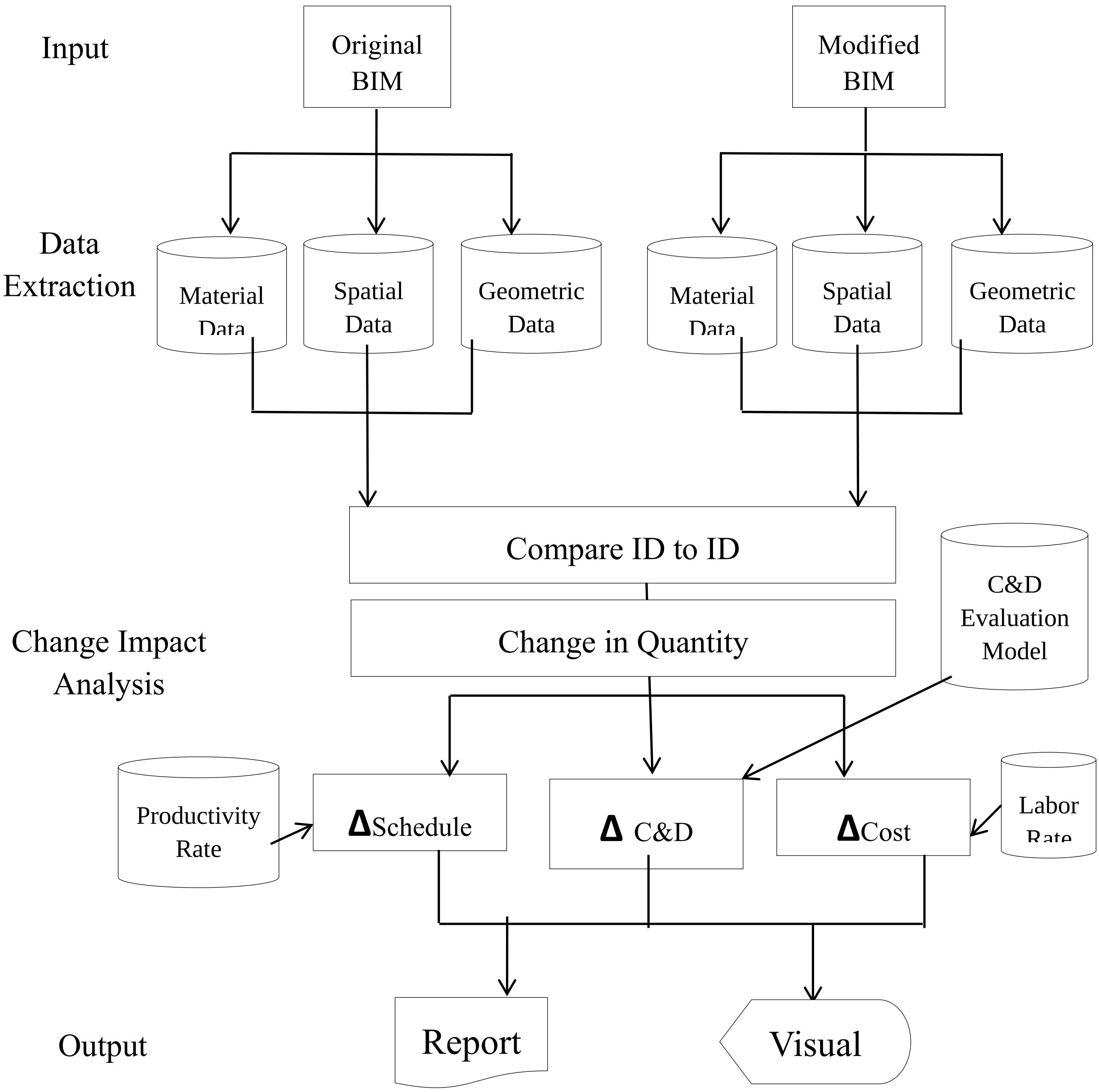


Figure 3.2 Proposed BIM Framework

3.3 Proposed Framework

The BIM framework will provide stakeholders the tool to track and highlight the impact of changes leading to less delays and cost overruns; and reduce possible legal conflicts among stakeholders. A BIM framework that can support change management, visualize the impacts and analyze the project schedule, cost and C&D impact of each changes.

The framework has four main steps. The first is input; the second is data extraction; the third is change impact analysis and finally, output in form of either report or visualization. The modified model is illustrated in Figure 3.2.

First for an input, a developed 3D BIM model of the project. This is be in original form and later in the modified (with changes in respect to change order). Data extraction will extract mainly 3 categories of data. Material data consists the types of material used, including the different layers, their individual makeup and type. Spatial data provides it location information in the form coordinates (x, y and z) and height level (ground level, level 1, level 2 etc). Geometric data provides mainly the volumetric data such as quantity. This quantity is not only of the element but also of the individual layers. Once all the input and data extraction are complete, the BIM framework will conduct the necessary analysis. This change impact analysis will compare the individual elements in both the original and modified model to evaluate impact of variation order on three main parameters; schedule, cost and C&D waste. These parameters are evaluated using the adopted strategies. Finally, output is provided in either report form (PDF or tabular information) or by visualizing it

3.3.1 Input

The process of project change order management begins when a stakeholder (usually a client) requests variation. The types of change can have unique impact on the project. BIM model development is the initial phase and consists of all the building details. A simulated model is created using a BIM software that using all the system details of the project. This can be referred to as 'Original' model. Simultaneously, another model consisting of planned changes is also created using the software. This can be on top of the previous model and saved as separate model. This can be referred to 'Modified' model. Using these two BIM models, original and modified model, the framework will receive data input.

3.3.2 Data Extraction

In the BIM framework, work breakdown structure (WBS) is broken down to a elemental-level. Every element has its data information as shown in Figure 3. Information about the BIM models is collected and categorized in three main forms: Material, Spatial and Geometric data.

i. Material Data

Material data consists the types of material used, including the different layers, their individual makeup and type. These materials types include Concrete, Glass, Wood, Bricks, Paint and Metals etc. Elements are categorized according to their material types.

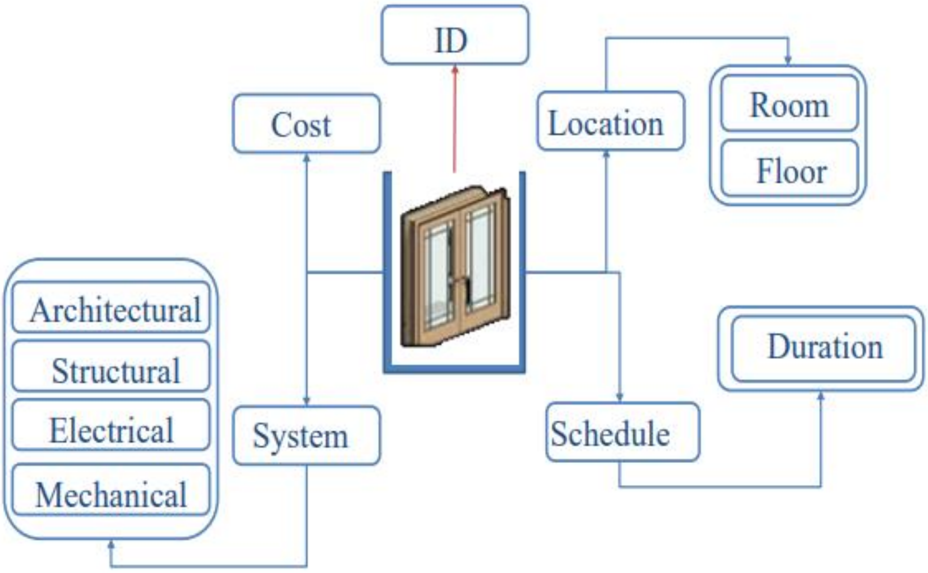


Figure 3.3 Model Component Information

ii. Spatial Data

Spatial data is also known as "geospatial data or geographic information" that represents the size, shape and location of a feature on the surface. Spatial data provides it location information in the form coordinates (x, y and z) and height level (ground level, level 1, level 2 etc). Knowing your data is important. The geographic reference to the data comes from the coordinate system it is assigned. A coordinate system is a three-dimensional reference scale which places points and other features on the surface of the site. Knowing the correct coordinate system is important. Data that is not geographically referenced to the correct coordinate system will yield inaccurate results. Most data will be in a local coordinate system. These systems are much more accurate in their limited geospatial extend as compared to global coordinate systems.

iii. Geometric Data

Geometry deals with mathematical properties (topology, metric, order). Data can be analyzed using these properties. Simply, it will refer to geometrical shapes in the application. Geometric data provides mainly the volumetric data such as quantity. This quantity is not only of the element but also of the individual layers. This can be used for further calculating and evaluating project cost, schedule and waste.

3.3.3 Change Impact Analysis

This study focuses on change impact analysis on the subject parameters of cost, schedule and waste. As a result, this step of the framework is categorized into 3 parts: -

i. Change Schedule Impact Analysis

The impact of project schedule by change order needs to be analyzed by the develop BIM based tool capable of calculating days duration of project's total schedule. The framework can estimate the impact of change order on the final end date of the project after estimating the extension of duration (days) required for work on each of project's component and element. The framework allows any user to try out different scenarios of change orders to examine its impact on the project schedule.

The BIM based tool will provide analysis of the change on schedule. This is achieved by compiling 2 lists of all the elements impacted by the variation order of the project. One list is extracted from the old original model of the project while the second list is compiled from the new modified model. Changes, either direct or indirect, are compared to each other and the elements affected are compiled.

Using information from BIM model, the framework can use man-hours and component elemental quantity to estimate the time taken for construction of each project component impacted by the CO. This is done by Equation 3-1 in which D stands for the duration of the element, P represents the productivity. Productivity (P) is calculated by dividing Man hour (MH) by unit of work. Q is the volumetric quantity of the element. Equation 3-1 is also used to estimate the impact due to indirect changes in the project.

$D = P \times Q$ where, $P =$ Man hour (MH) / Unit of work 3-1

The framework uses Equation 3-2 to estimate element's duration, where ΔQ represents the component's quantity differences between the original and modified projects, as given in Equation 3-3

$$D = P \times \Delta Q \quad \text{3-2}$$

$$\Delta Q = Q\text{original} - Q\text{modified} \quad \text{3-3}$$

The resultant effect of the change order can increase or decrease the duration of the project; adding or subtracting days to the final-end date. Volumetric quantity of each component extracted from the BIM model is multiplied with its relevant productivity value from productivity table. This will give us the duration of each element that will sum toward the end date of the whole project. Stakeholders can use this BIM framework to view the changes and quantify the impacts of their desired CO on the project.

ii. Change Cost Impact Analysis

The main aim of framework is to provide stakeholders control over the project's budget. Stakeholders supervise the budget constraints and improve decisions about project finance by adjusting the S-curve. Project cost can be categorized in many different branches. As categorized by Moselhi's (1998) change orders can be divided as direct costs and indirect costs. The impacts of these changes are either related to productivity and time. This is illustrated in figure 3.4

The framework uses Equation 3-4 in order to calculate the element's cost. Q is the element

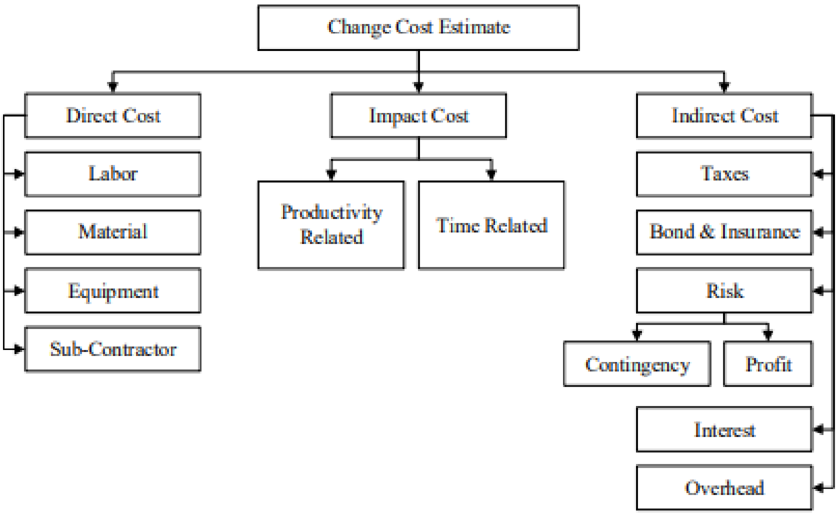


Figure 3.4 Costs in Project (Moselhi, 1998)

quantity, and C is the element unit cost:

$$\text{Element's cost} = Q \times C \qquad \text{3-4}$$

Once there is an addition or reduction in the quantity of the element, project component cost needs to be . The framework uses Equation 3-5 (Moselhi, 1998) to estimate the element's cost, where ΔQ represents the quantity differences between the original and modified project's element, as given in Equation 3-6.

$$\text{Changed element's cost} = \Delta Q \times C \qquad \text{3-5}$$

$$\Delta Q = Q\text{original} - Q\text{modified} \qquad \text{3-6}$$

The cost of the component work can either increase or decrease. Impact cost consists of Productivity cost and Time cost as shown in Equation 3-7:

Impact cost = Productivity + Time 3-7

Equation 3-8 is used to estimate the productivity costs (LP), representing the loss of productivity on a percentage change, and Equation 3-9 is used to estimate time-related costs:

Productivity = LP × Cost of Labour 3-8

Time Cost= Extension from original duration of the project day× Cost (per day) 3-9

iii. Change C&D Waste Impact Analysis

The BIM framework needs to extract and produce C&D waste for the selected BIM model affected by change order. Both Construction waste and Demolition waste need to be dealt separately as both nature and sources of waste are different and unique in every project. The methodology adopted by (Cheng & Ma, 2013) was used to calculate C&D waste using BIM individually.

Construction Waste

The BIM framework needs to extract and produce C&D waste for the selected BIM model affected by change order. Both Construction waste and Demolition waste need to be dealt separately as both nature and sources of waste are different and unique in every project. The methodology adopted by (Cheng & Ma, 2013) was used to calculate C&D waste using BIM individually.

To calculate construction waste, three factors need to be considered while calculating final demolition waste. The first one is the construction waste change factor (Cw), as shown in Table 3.1 The values of the waste volume change factor were determined with reference to the construction change factors that were concluded in Qasim (2018) This Dw factor varies in different countries and different types of projects. Therefore, the framework must allow user to customize the Cw for their project as required.

Construction waste volume is calculated using the equation (3-10). The second one is the material reuse and recycling amounts in the construction project. This allows engineer to enter customized recycling and reuse data for calculation adjustment. The final factor is unit conversion. Finally, density information is needed to calculate material weight. Density are fixed universal values that can be pre-fixed or (if necessary) changed depending on the nature of project and material. Examples of the density values are shown in Table 3.2

Table 3.1 CW Factor Table (Qasim et al, 2018)

Material Type	**Construction Waste Change Factor (Cw)**
Concrete	2.7
Steel	6.5
Plaster from mortar	1.1
Wood	0.7
Glass	2.5
Polythene sheets	0.9
Bricks	1.7
Aluminum	8
Marble	4.3
Ceiling boards	4.2
Bitumen	4.2
Natural Rocks	1.8
Door and Plywood	0.7

Table 3.2 Density Table

Material Type	**Density (tons/m3)**
Concrete	2.5
Wood	0.78
Glass	2.5
Drywall	2.2
Bricks/Masonry	1.8
Metallic	7.1

Based on the data extraction from BIM model and inputs from the user volume and weight of the waste to be disposed will be calculated in the framework.

The amount of construction waste is the total amount of construction waste generated subtracted by those reused on the same project site, also those recycled and reused in other projects or sites. The formula is:

$$Vcw = (Vcwow \times C) - Vcwros - Vcwra - Vcwrot \quad 3\text{-}10$$

$$Wcw = Vcw \times \rho \quad 3\text{-}11$$

where C is the construction waste change factor (dimensionless); Vcw is construction waste volume (m3); Vcwow is original construction waste volume (m3); Vcwros is construction waste volume reused on the same project (m3); Vcwra is construction waste volume recycled (m3); Vcwrot is construction waste volume reused in other project (m3); ρ is density of waste material (kg/m3).

Demolition Waste

Construction Waste can be calculated for every BIM model that is selected; however, Demolition waste can only be calculated of the BIM model that has the applied changes due to change order. Only the Modified BIM model can produce the potential demolition waste resultant of the demolition or renovation work on the project. It is not necessary that there will be demolition waste in every change order sanctioned by the stakeholders.

To calculate demolition waste, similarly three factors need to be considered before calculating final demolition waste. The first one is the demolition waste change factor (Dw), as shown in Table 3.3. The values for demolition waste change factor (Dw) were derived from a previous study by Llatas (2011). This Dw factor varies in different countries and different types of projects. Therefore, the framework must allow user to customize the Dw for their project as required. Demolition waste volume is calculated using the following equation 3-12. The second one is the material reuse and recycling amounts in the construction project. This allows engineer to enter customized recycling and reuse data. Again, the final factor is unit conversion. Using the density of the material, waste material is found in terms of its weight (tons or kg).

Table 3.3 DW Factor Table (Llatas 2011)

Material Type	**Demolition Waste Change Factor (Dw)**
Concrete	1.11
Steel	1.01
Wood	1.04
Glass	1.06
Cement	1.09
Masonry/Bricks	1.1

The amount of demolition waste is the total amount of demolition waste generated subtracted by those reused on the same project site, also those recycled and reused in other projects or sites. The formula is:

$$Vdw = (Vow \times D) - Vros - Vra - Vrot \qquad 3\text{-}12$$

$$Wdw = Vdw \times \rho \qquad 3\text{-}13$$

where D is the demolition waste change factor; Vdw is demolition waste volume (m3); Vow is original demolition waste volume (m3); Vros is demolition waste volume reused on the same project (m3); Vra is demolition waste volume recycled (m3); Vrot is demolition waste volume reused in other project (m3); ρ is density of demolition waste material.

3.3.4 Output

The final stage of the BIM framework would be giving output to the user. This could be in either two forms: Report or Visualization.

i. Report

By quantifying the cost, schedule and C&D impact of requested variation order, the framework can provide a report for stakeholder to support in change management process and any decision-making. The report elaborates all the affected elements with respect to their changed impacts. The report also includes information about original planned model, providing user the ability to compare the differences between the original model and modified model. The table below shows heading of the report generated from the framework results.

Table 3.1 Result Table

Category	**Element ID**	**Element Name**	**Type of Change**	**Old Quantity**	**New Quantity**	**Change in Quantity m^3**	**Old Duration**	**New Duration**	**Change (Hours)**	**Change (Days)**	**Old Total Material Cost**	**Old Total Labor Cost**	**Old Material + Labor**	**New Total Labor Cost**	**New Total Material Cost**	**New Material + Labor**
Name	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values
Name	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values
Name	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values	Values

ii. Visualization

The framework finally also visualizes the impact of CO by marking the alteration in the two models in the report by using different colour codes for the different results of the comparison. Elements that have their quantity changed are showed by either yellow (increase) or orange (decrease) in both original and modified model report. Elements that have been moved in the new model but not in the old model are highlighted as red. No colour is applied on elements that do not face any impact or ripple effect. Project model view give better visualization ability to the user. Also, user can view the changes also in section and elevation views aswell Therefore, stakeholders can better comprehend their desired changes and make better decision about executing change order. Changes in different system levels such as HVAC, piping etc are also shown through this feature.

Chapter 4

RESULTS AND ANALYSIS

4.1 Introduction

The aim of this chapter is to describe to BIM tool created as a result of the framework developed in Chapter 3. The BIM tool was integrated using Autodesk Revit 2020 and supplementary software such as Dynamo and MS Office. Later it was used to evaluate the impact of change orders. This was then used on a case study of simple housing project.

4.2 BIM-based tool

A BIM tool was developed by Autodesk Revit 2020 and supplementary software such as Dynamo and MS Office. Dynamo was used for Visual programming purposes that provided the back-end Python programming. Nodes available in the open sites were used to achieve the desired outcomes.

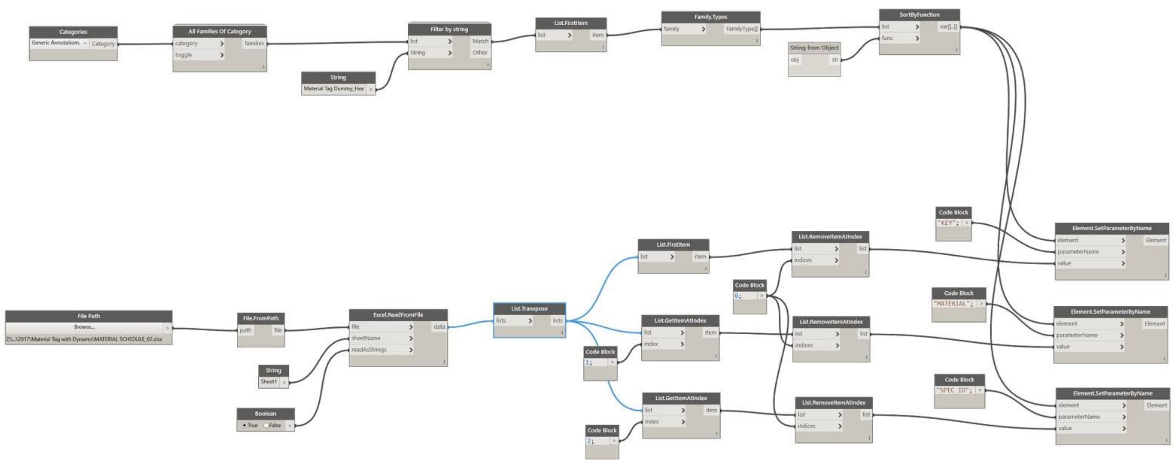


Figure 4.1 Dynamo Visual Programming

4.3 User Interface

User Interface is the platform through which user could access the BIM software tool to input and initiate the process of evaluating change impact. Model screen will provide user view the project and its changes. Buttons have been incorporated into tool for executing algorithm and macro for user's ease.

4.3.1 Model Screen

The BIM tool was developed as such to allow dual models to show and process at the same time. User can rely on a dual screen environment that shows the original and modified model and corresponding differences to it.

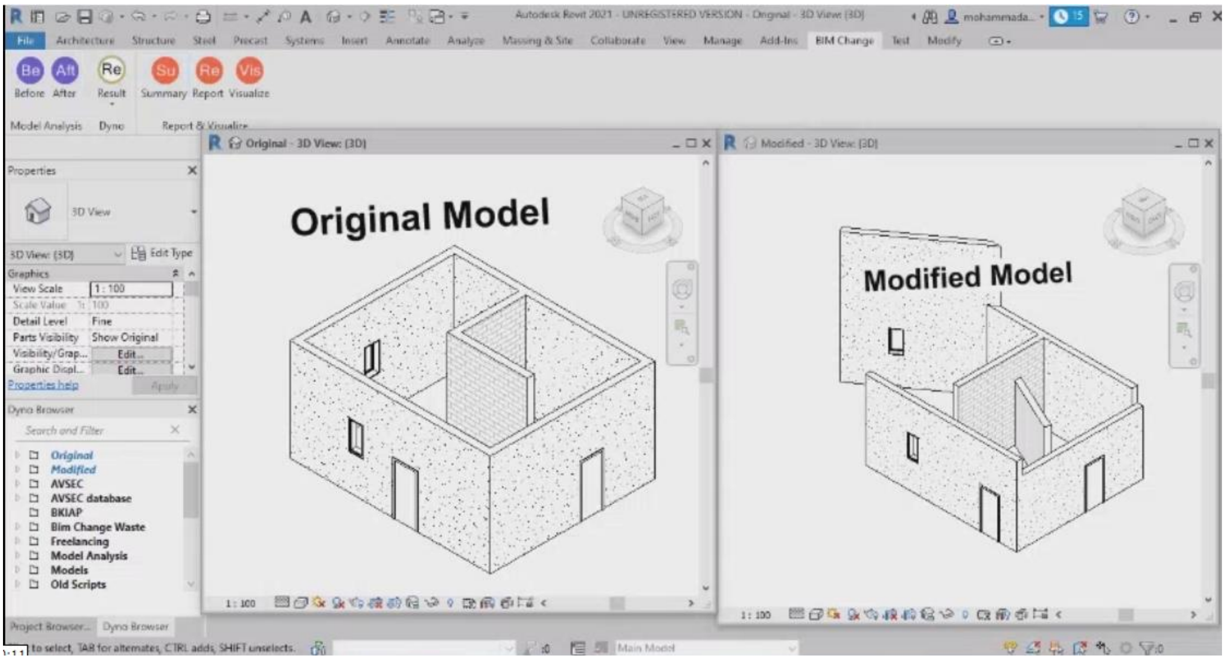


Figure 4.2 Model Screen

4.3.2 Buttons

Six buttons were developed in according to the input, data analysis and output required in the BIM framework. An additional setting button was also created as detailed in the following:

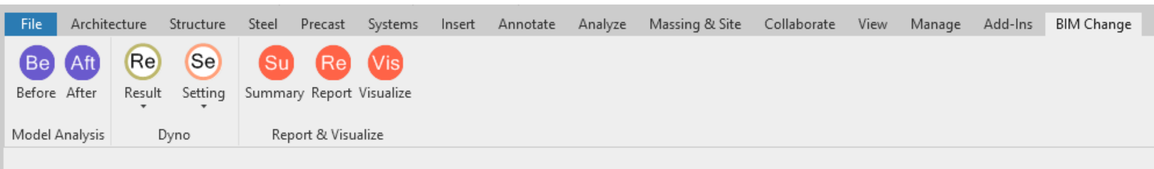


Figure 4.3 Toolbar

i. Before

This button will capture all the elements present on the screen from the model and assign it as 'Original' model with the actual and as-planned conditions of the project. These include its Material, spatial and geometric information. This data can be exported if required. This is provided as shown below

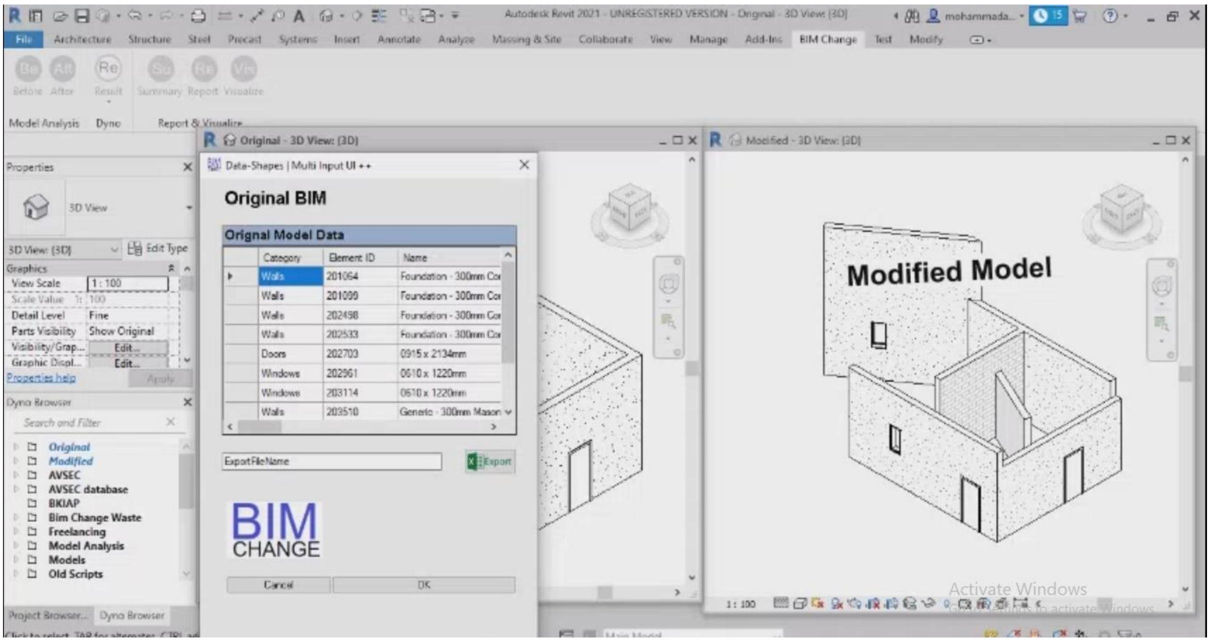


Figure 4.4 Change Report

ii. After

This button will capture all the elements present on the screen from the model and assign it as 'Modified' model with the variation and as-changed conditions of the project. These include its Material, spatial and geometric information. This can be exported in excel if required. This is provided as shown below-. After using this button, the BIM tool starts change impact analysis to provide output in the next buttons.

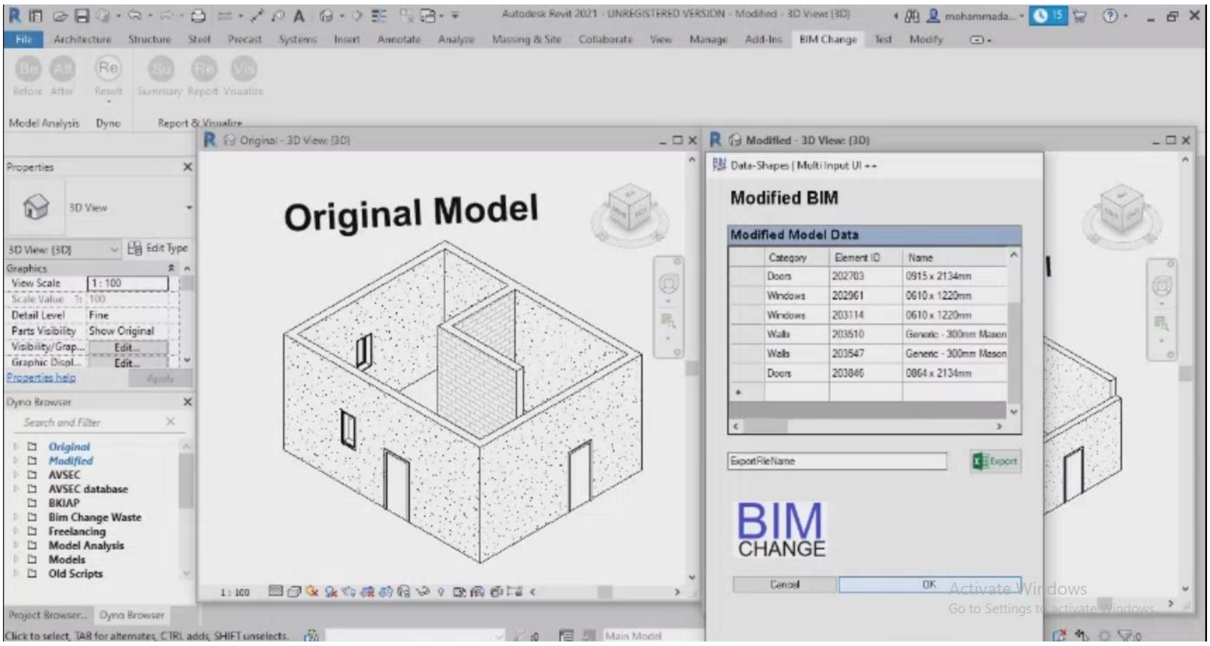


Figure 4.5 Change Report after Process

iii. Result

This button will provide user the result in detail format. This can be 4 main windows.

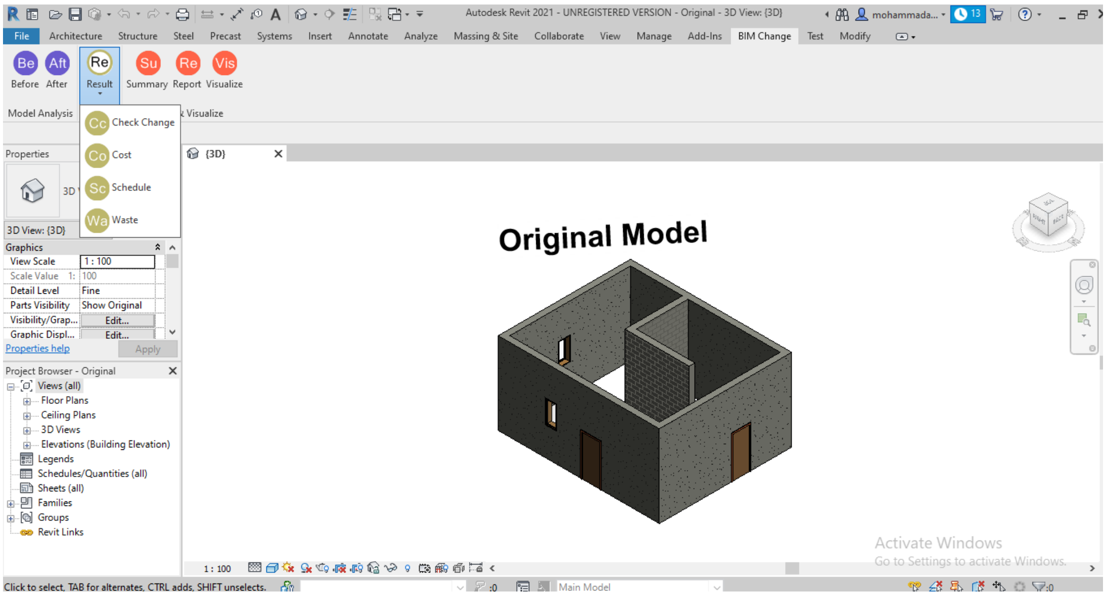


Figure 4.6 Result Options

iv. Check Change

This provides the detail changes in elemental level of the BIM model with respect to alteration its material, quantity and coordinates.

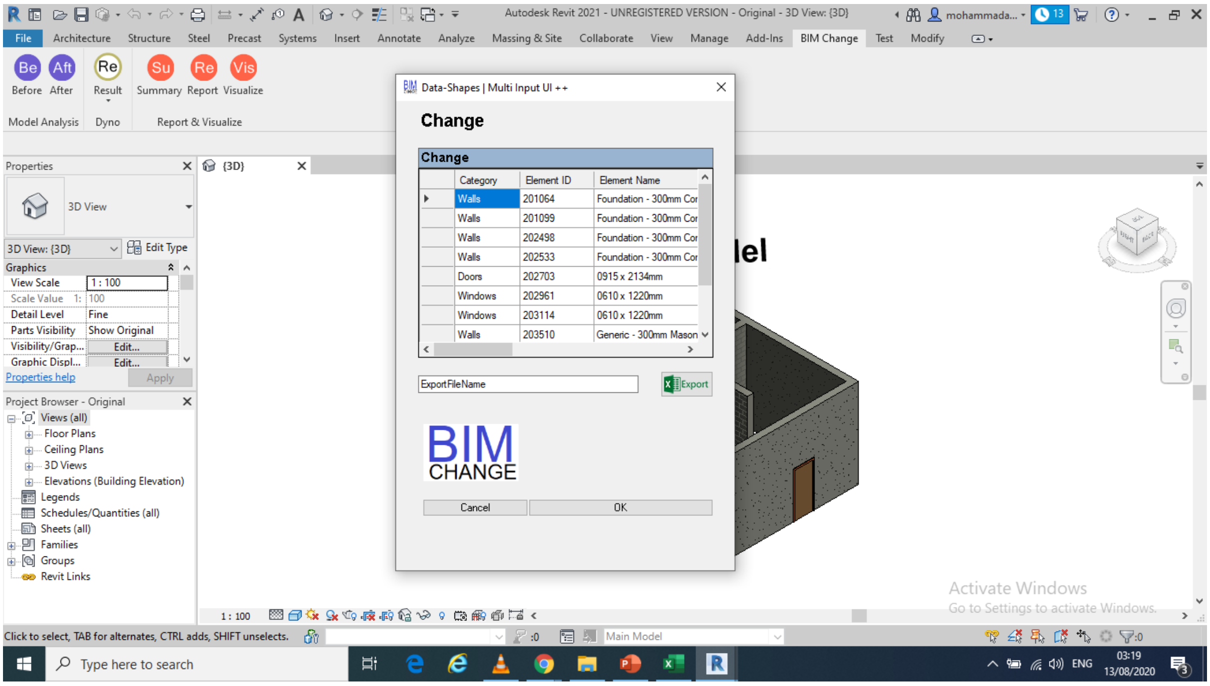


Figure 4.7 Change Result

v. Cost

Cost window shows the detail changes in construction cost due to change order. This variation is due to the change in quantity that effects the material required and the cost to procure that material. Similarly, labour cost also changes due to quantity change and the man-hours to complete the work.

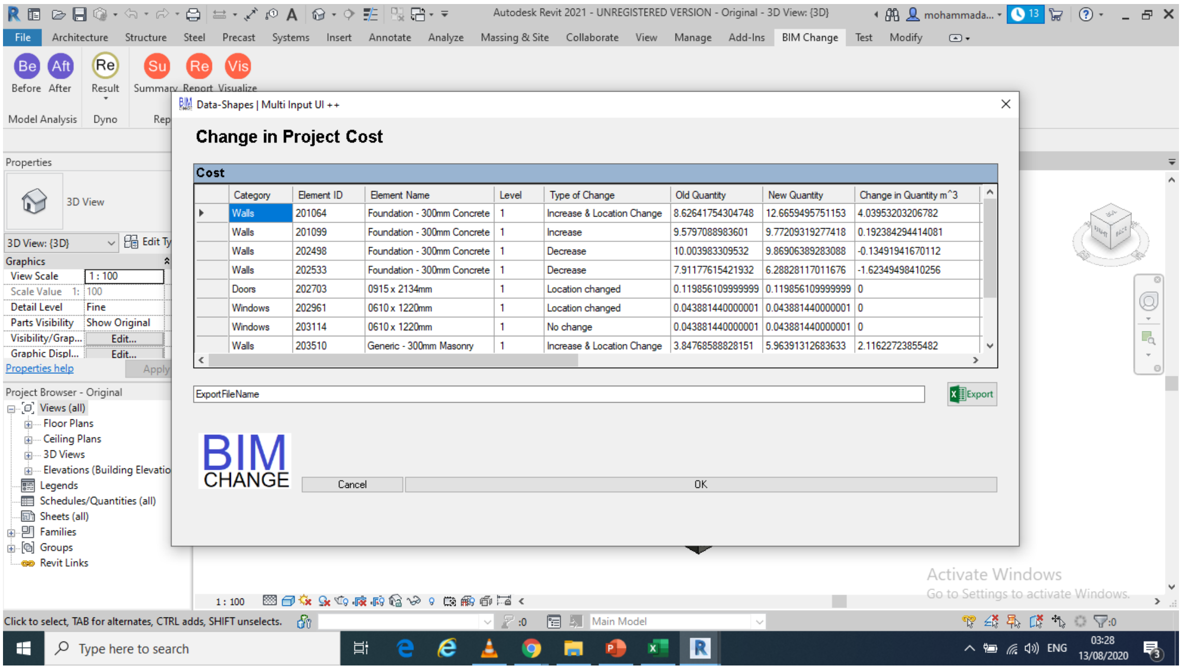


Figure 4.8 Cost Result

vi. Schedule

Schedule window shows the detail changes in construction schedule due to change order. This variation is due to the change in quantity that effects the material required and the duration to complete every component.

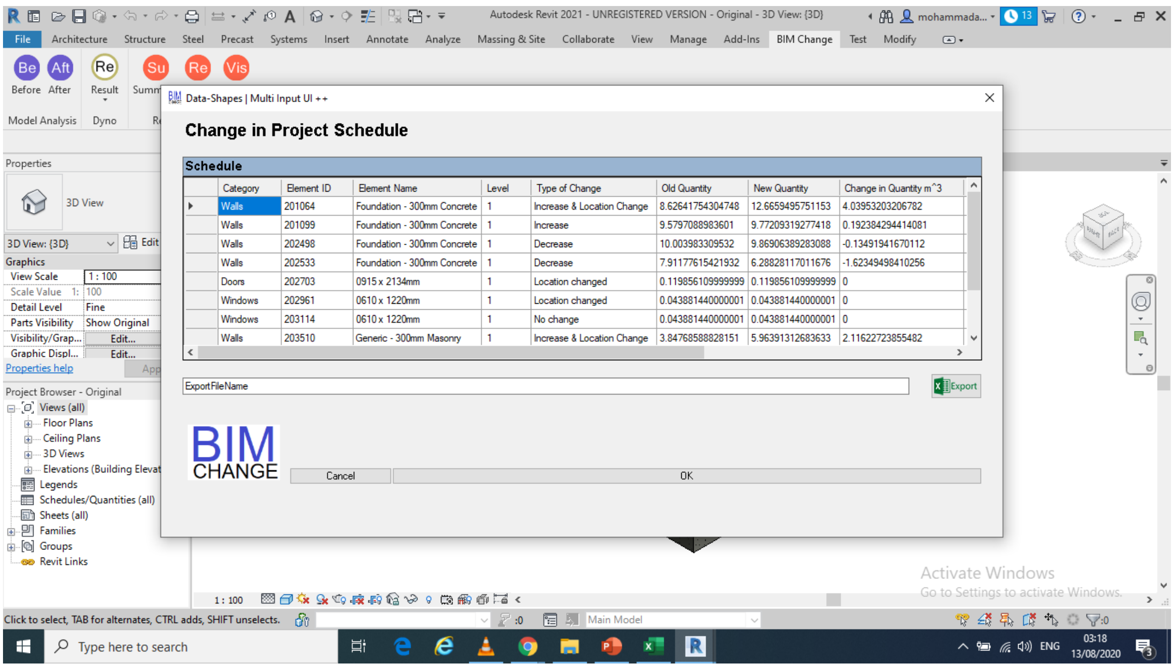
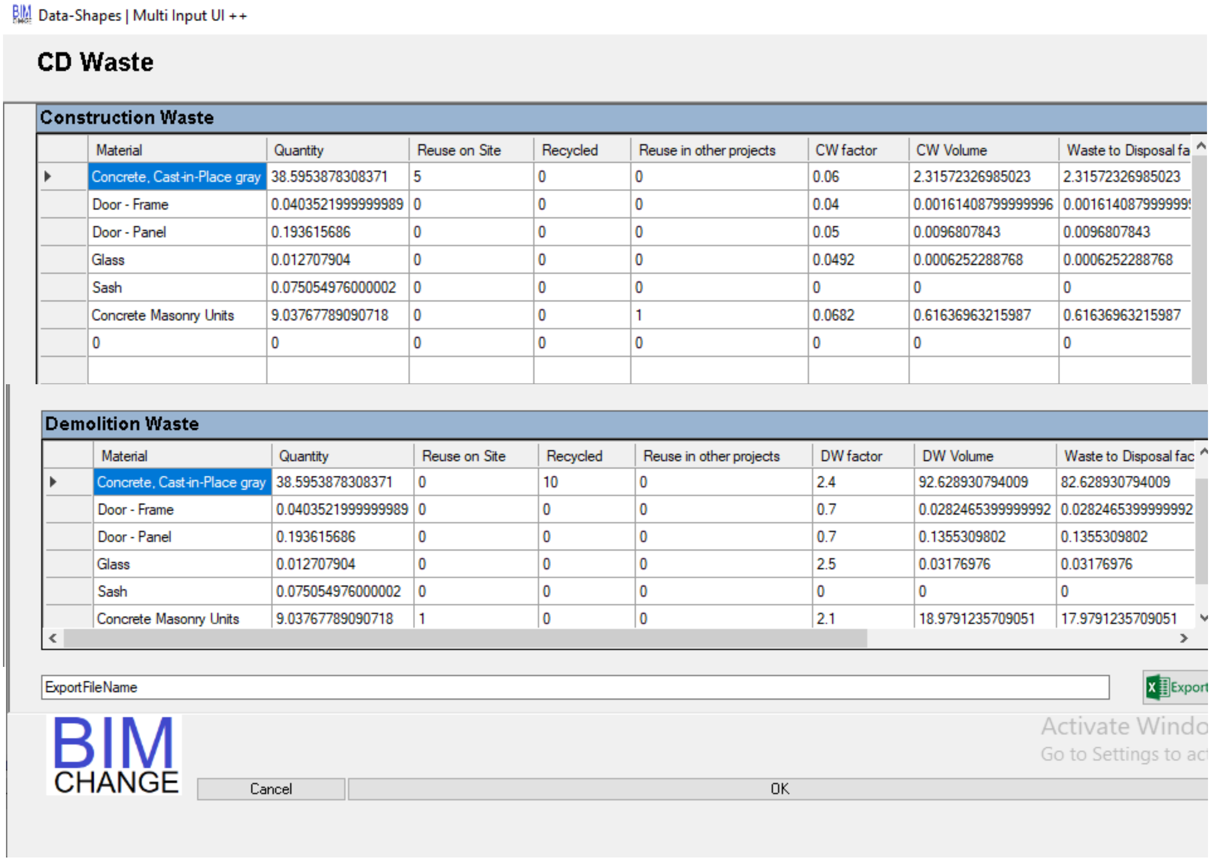


Figure 4.9 Schedule Result

vii. Waste

The Waste window show the construction waste and demolition waste separately of the BIM models. Every material used in the models are scrutinized and categorized for users comprehension. The most important thing to note here is that BIM Change tool's ability to break down all material data of all elements on the view screen and combined them into one



Construction Waste

Material	Quantity	Reuse on Site	Recycled	Reuse in other projects	CW factor	CW Volume	Waste to Disposal fa
Concrete, Cast-in-Place gray	38.5953878308371	5	0	0	0.06	2.31572326985023	2.31572326985023
Door - Frame	0.0403521999999989	0	0	0	0.04	0.00161408799999996	0.001614087999999
Door - Panel	0.193615686	0	0	0	0.05	0.0096807843	0.0096807843
Glass	0.012707904	0	0	0	0.0492	0.0006252288768	0.0006252288768
Sash	0.075054976000002	0	0	0	0	0	0
Concrete Masonry Units	9.03767789090718	0	0	1	0.0682	0.61636963215987	0.61636963215987
0	0	0	0	0	0	0	0

Demolition Waste

Material	Quantity	Reuse on Site	Recycled	Reuse in other projects	DW factor	DW Volume	Waste to Disposal fac
Concrete, Cast-in-Place gray	38.5953878308371	0	10	0	2.4	92.628930794009	82.628930794009
Door - Frame	0.0403521999999989	0	0	0	0.7	0.0282465399999992	0.0282465399999992
Door - Panel	0.193615686	0	0	0	0.7	0.1355309802	0.1355309802
Glass	0.012707904	0	0	0	2.5	0.03176976	0.03176976
Sash	0.075054976000002	0	0	0	0	0	0
Concrete Masonry Units	9.03767789090718	1	0	0	2.1	18.9791235709051	17.9791235709051

Figure 4.10 C&D Waste Result

list of all the material being used in the project. Complex structures with different layers of different materials are also broken down and data is extracted for the BIM framework.

viii. Setting

This button is for customizing the factors or density values used in the BIM tool. Some values in CW factor, DW factor, density table, Material Cost Table and Productivity table may vary due to different location or different nature of the project. Some values may also not be available and need to be added. This button provides the table for user for adjustment in the table values.

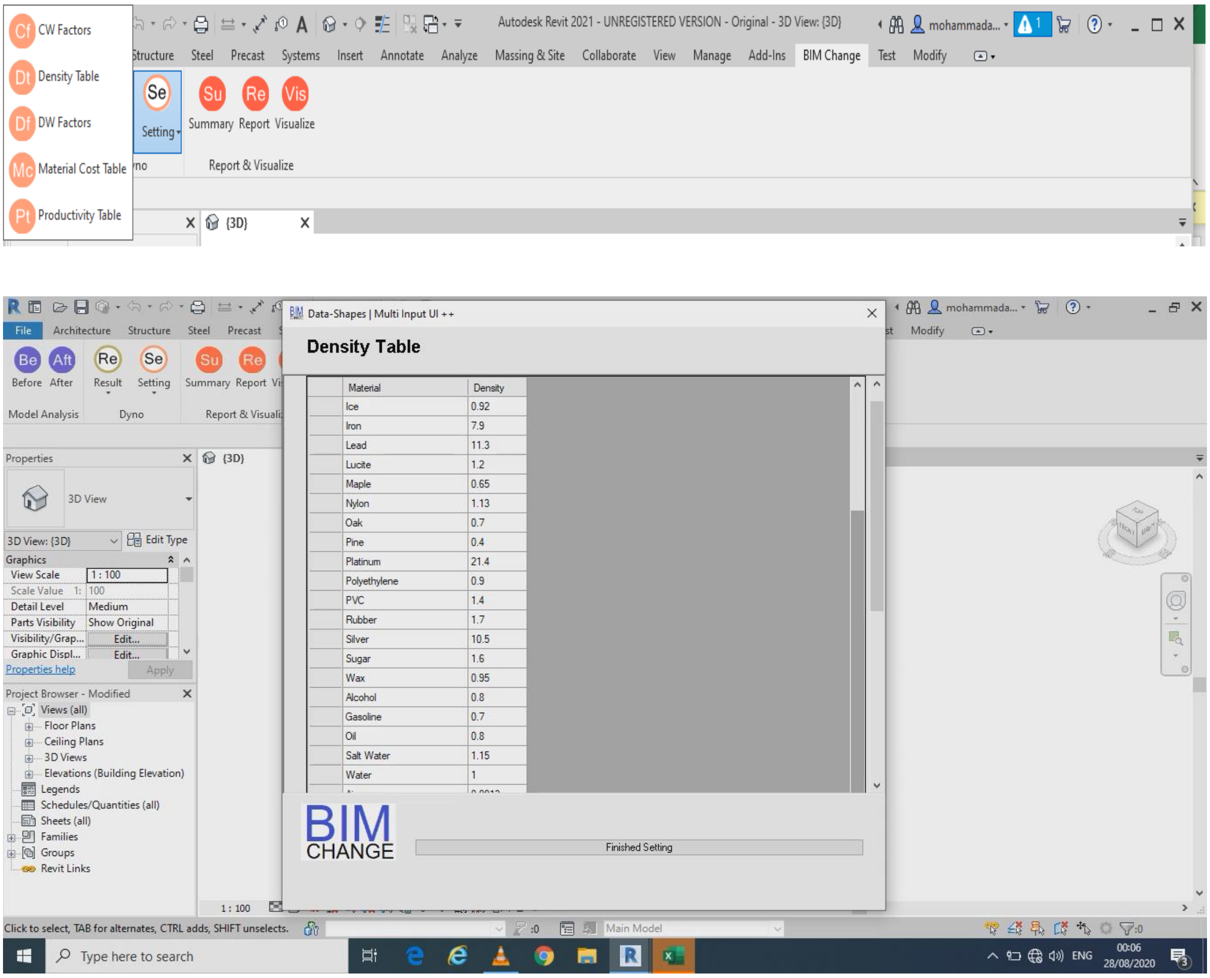


Figure 4.11 Setting: Density

ix. Summary

Summary button is used to provide a quick summary of the result and output from the BIM tool. It is for users ease and can be exported to excel if required. It shows the difference in Time (Days), Cost (Rs) and Construction waste (tons) in the different BIM model. It also shows any Demolition waste (tons) in case of any demolition or renovation work.

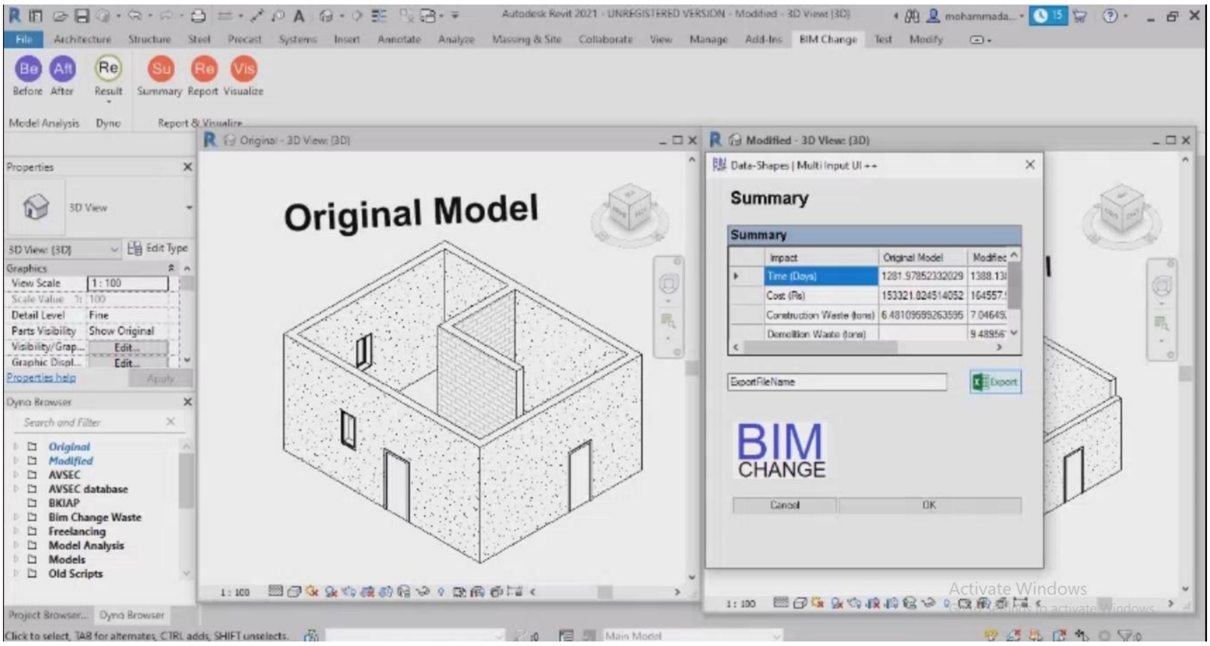


Figure 4.12 Summary

x. Report

This button provides a final report of the effect of change order with the subject parameters of cost, schedule and C&D waste. This report can be altered and printed in excel. It can be exported in pdf form. Graphical analysis is also provided for easier comprehension

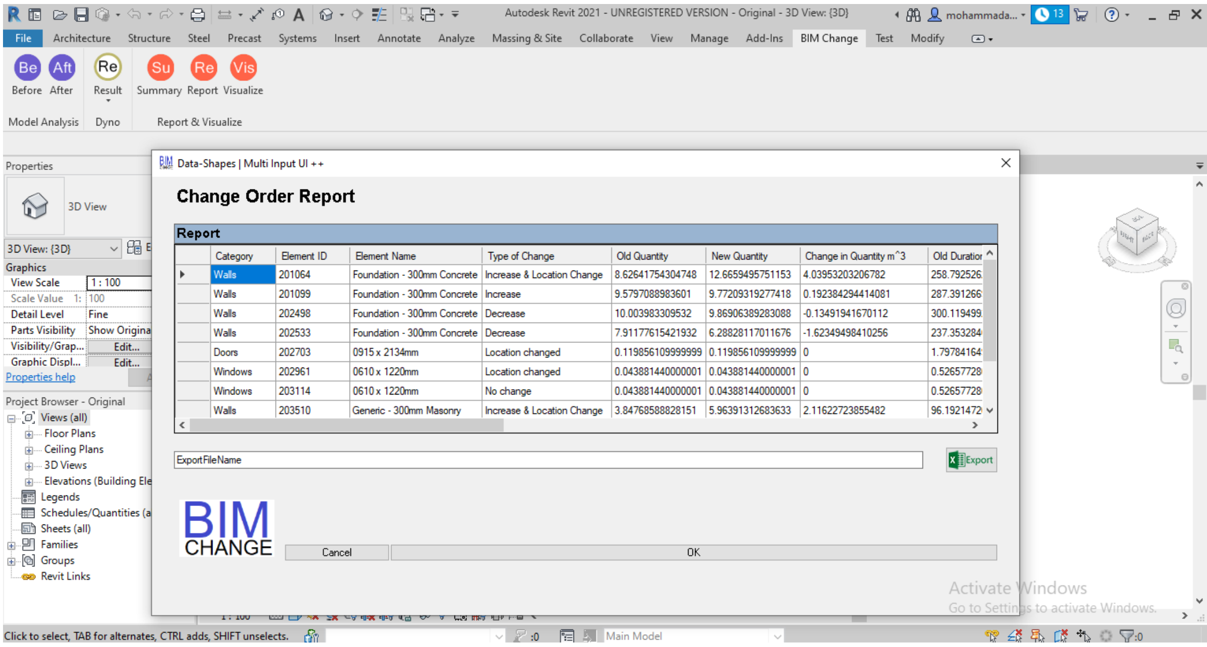
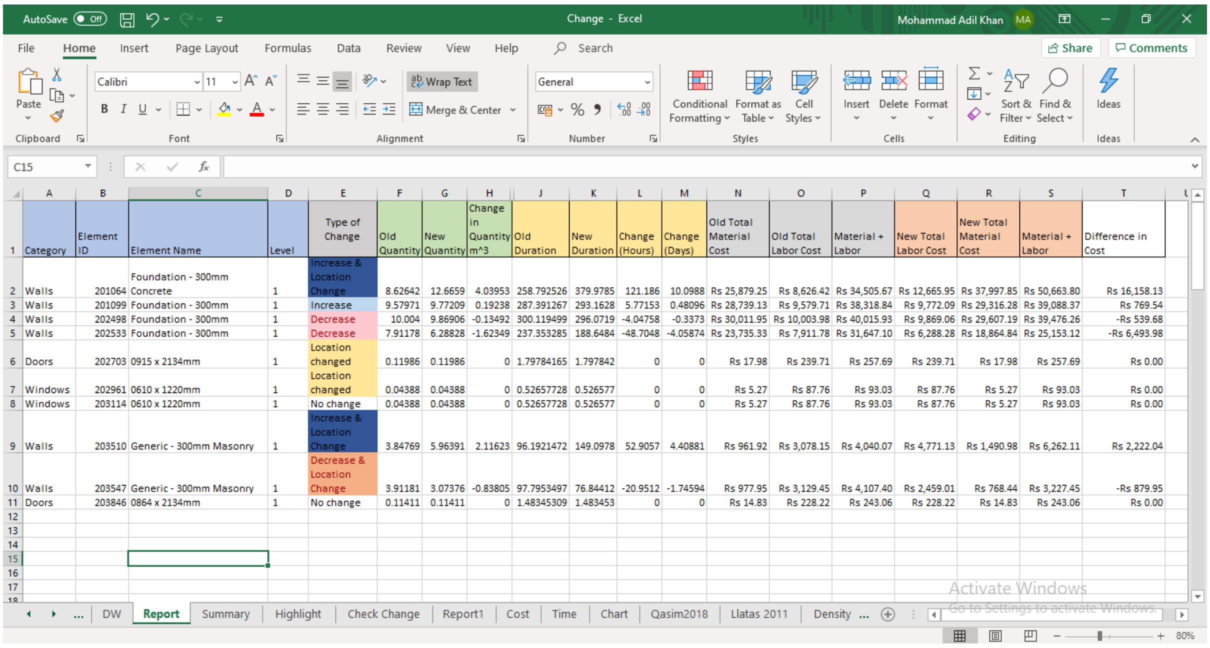


Figure 4.13 Report



Category	Element ID	Element Name	Level	Type of Change	Old Quantity	New Quantity	Change in Quantity m^3	Old Duration
Walls	201064	Foundation - 300mm Concrete	1	Increase & Location Change	8.62642	12.6659	4.03953	258.792526
Walls	201099	Foundation - 300mm	1	Increase	9.57971	9.77209	0.19238	287.391267
Walls	202498	Foundation - 300mm	1	Decrease	10.004	9.86906	-0.13492	300.119499
Walls	202533	Foundation - 300mm	1	Decrease	7.91178	6.28828	-1.62349	237.353285
Doors	202703	0915 x 2134mm	1	Location changed	0.11986	0.11986	0	1.79784165
Windows	202961	0610 x 1220mm	1	Location changed	0.04388	0.04388	0	0.52657728
Windows	203114	0610 x 1220mm	1	No change	0.04388	0.04388	0	0.52657728
Walls	203510	Generic - 300mm Masonry	1	Increase & Location Change	3.84769	5.96391	2.11623	96.1921472
Walls	203547	Generic - 300mm Masonry	1	Decrease & Location Change	3.91181	3.07376	-0.83805	97.7953497
Doors	203846	0864 x 2134mm	1	No change	0.11411	0.11411	0	1.48345309

Element ID	New Duration	Change (Hours)	Change (Days)	Old Total Material Cost	Old Total Labor Cost	Material + Labor	New Total Labor Cost	New Total Material Cost	Material + Labor	Difference in Cost
201064	379.9785	121.186	10.0988	Rs 25,879.25	Rs 8,626.42	Rs 34,505.67	Rs 12,665.95	Rs 37,997.85	Rs 50,663.80	Rs 16,158.13
201099	293.1628	5.77153	0.48096	Rs 28,739.13	Rs 9,579.71	Rs 38,318.84	Rs 9,772.09	Rs 29,316.28	Rs 39,088.37	Rs 769.54
202498	296.0719	-4.04758	-0.3373	Rs 30,011.95	Rs 10,003.98	Rs 40,015.93	Rs 9,869.06	Rs 29,607.19	Rs 39,476.26	-Rs 539.68
202533	188.6484	-48.7048	-4.05874	Rs 23,735.33	Rs 7,911.78	Rs 31,647.10	Rs 6,288.28	Rs 18,864.84	Rs 25,153.12	-Rs 6,493.98
202703	1.797842	0	0	Rs 17.98	Rs 239.71	Rs 257.69	Rs 239.71	Rs 17.98	Rs 257.69	Rs 0.00
202961	0.526577	0	0	Rs 5.27	Rs 87.76	Rs 93.03	Rs 87.76	Rs 5.27	Rs 93.03	Rs 0.00
203114	0.526577	0	0	Rs 5.27	Rs 87.76	Rs 93.03	Rs 87.76	Rs 5.27	Rs 93.03	Rs 0.00
203510	149.0978	52.9057	4.40881	Rs 961.92	Rs 3,078.15	Rs 4,040.07	Rs 4,771.13	Rs 1,490.98	Rs 6,262.11	Rs 2,222.04
203547	76.84412	-20.9512	-1.74594	Rs 977.95	Rs 3,129.45	Rs 4,107.40	Rs 2,459.01	Rs 768.44	Rs 3,227.45	-Rs 879.95
203846	1.483453	0	0	Rs 14.83	Rs 228.22	Rs 243.06	Rs 228.22	Rs 14.83	Rs 243.06	Rs 0.00

Figure 4.14 Report in Excel

xi. Visualize

The purpose of this button is to highlight the changes in the BIM model. It is to help user to visualize the changes and its corresponding ripple effect due to change order. The highlighting shows element in colour scheme categorized as increase (blue), decrease (orange) or location change (red). White or no highlighting shows no change in the element.

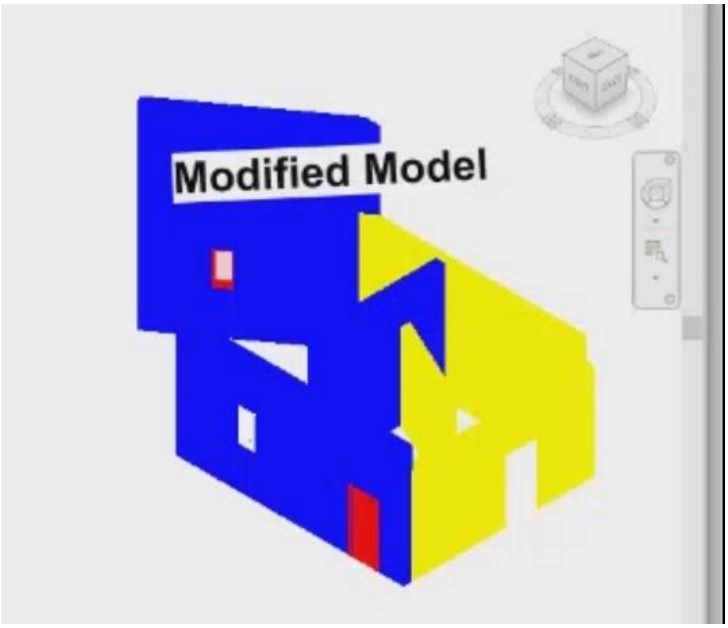


Figure 4.15 Visualization

4.5 Case Study

To elaborate our BIM-based tool, we decided to try out a case study to showcase and understand it features. We began by first designing a simple BIM model based on simple real housing project with simple four main outer walls, 2 inner wall, 2 plywood doors and 2 wooden windows. The outer walls are made of RCC whereas inner walls are simple brick masonry.

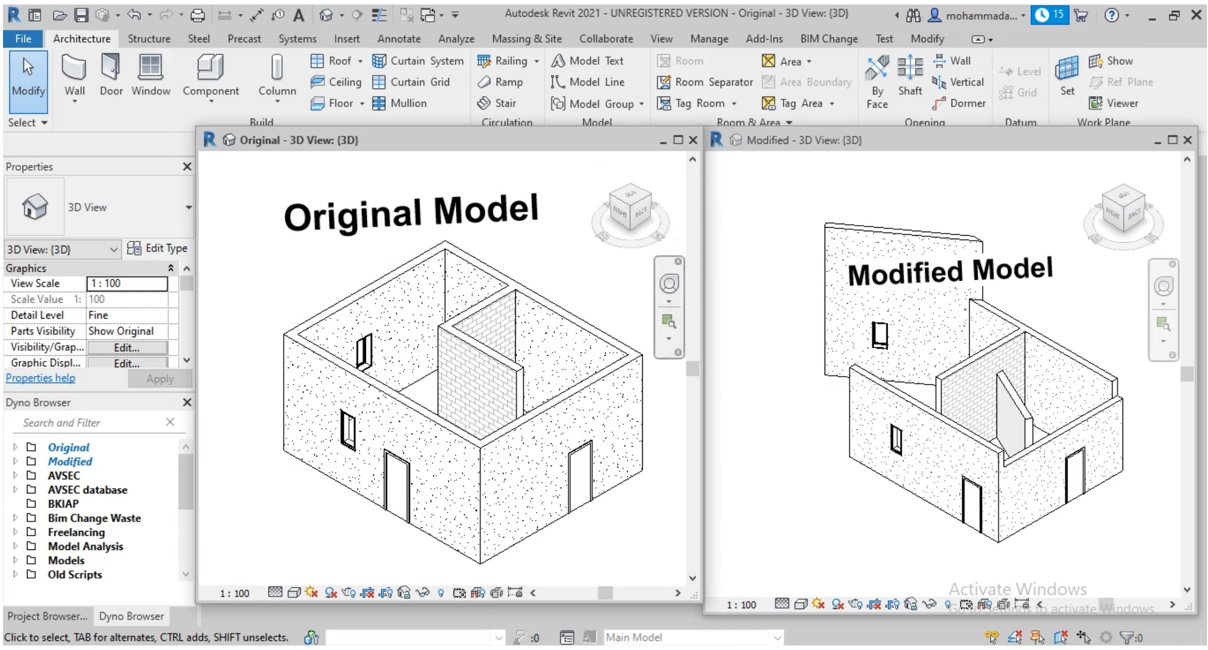


Figure 4.16 Case Study: BIM Models

This is assigned as original model and considered as the model before any changes is made due to variation order. This can be seen in the left most panel of the screen as shown above.

Modified model is after the change order has been received and the desired changes is made to the model. As in this case, one of each outer and inner wall are increased in height or length as well one of each outer and inner wall is decreased in height. This can be view in the second window open in the figure above. Also, one of the increased outer wall is rotated in an angle.

The next step would be to open the BIM Change tool bar and select ‘Before’ button for Original Model window. After its processing is complete, select the modified model panel window and then select ‘After’ button to complete it process. The BIM Change toolbar has completed it processing and the results will be ready in the desired conditions.

The result can be visualized as shown below.

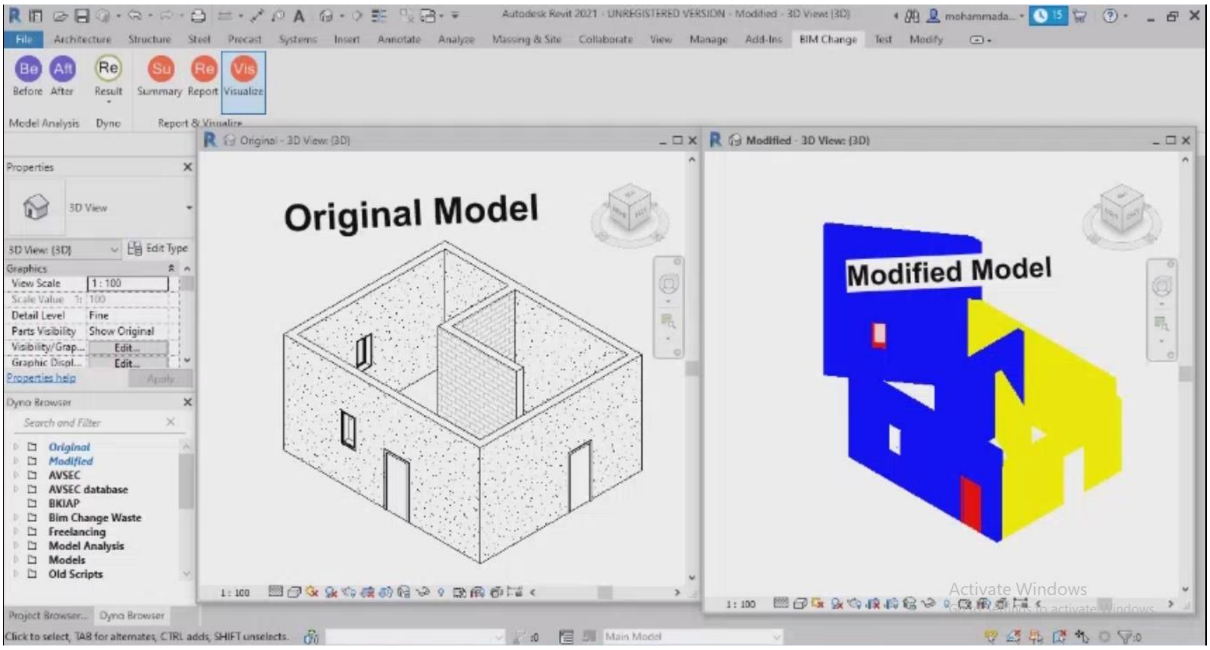


Figure 4.17 Case Study: Result and Visualization

Also the Change Order Impacts can be presented in Report format detailing the parameter changes. The report of this case study is attached as appendix 1. Along with the detail report, a short summary of the change order impact is given. This includes Difference in time, cost, construction waste and (if any) demolition waste. An important feature to note in the BIM Change tool is the ability to break down all material data of all elements on the view screen and combined them into one list of all the material being used in the project. Complex structures with different layers of different materials are also broken down and data is extracted for the BIM framework.

Details about the waste calculations are given in Appendix 2.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter closes the study with final remarks. The initial objectives of the study are revised and concluded on basis of literature review and framework creation. Recommendations for improvement are given.

5.2 Review of Research Objective

The main objectives were:

- To investigate strategies for enabling in the evaluation of time, cost and C&D waste during a construction project
- To develop a BIM-based framework for evaluation the impacts of a change order in terms of time, cost and C&D waste.
- Integrate the framework as a BIM-aided tool that can track and visualize the impacts of a change order on subject parameters.

The first objective was met by undertaking a detailed literature review for the varies methodology and techniques utilized to evaluate the effect of change orders on a construction project schedule, cost and C&D waste. Research from across the world were studied in detail to find most effective strategies that could be used further for computation. Second objective were met by creating a BIM framework that could be utilized those selected strategies and the advantages of BIM to quantify the impacts on the subject parameters. The third and final objective was achieved after integrating the BIM framework as a BIM based tool for engineers that can use to accurate track and visualize those impacts on a simulated BIM model. The second and the third objective was achieved using Autodesk Revit and supplementary software such as Dynamo and MS Office.

This BIM tool can also be used for design changes before the execution of the project is initiated. However, there are some limitations to the study as well. One of the main assumptions made to developing this framework was that the BIM projects are semi building that are residential or commercial. Also the BIM tool will be used by an engineer who has in depth knowledge of construction industry and waste management systems. The user needs to be knowledgeable about the different types of material being used in the project and its waste generation rates.

5.3 Recommendations

This study aimed to develop a BIM aided tool for change management. There are some recommendations for future work which are:

a) Study and apply this research at other types of projects such as highways, bridges, industries etc

b) Apply this BIM framework and tool to multiple other projects and estimate the impact of change.

c) Provide more flexibility or features such use of Primavera or MS Project for elaborating Change Cost Impact Analysis.

d) Experiment and improve algorithm of this study.

References

Abudayyeh, O. & Al-Battaineh, H. T., 2003. As-Built Information Model for Bridge Maintenance. *Journal of Computing in Civil Engineering,* 17(2), pp. 105-112.

ACI 318, 2014. *Building Code Requirements for Structural Concrete (ACI 318-14),* s.l.: American Concrete Institute.

Adewuyi, T. & Otali, M., 2013. Evaluation of Causes of Construction Material Waste: Case of River State, Nigeria. *Ethiopian Journal of Environmental Studies and Management,* 6(6), pp. 746-753.

Adriaanse, A., Voordijk, H. & Dewulf, G., 2010. The use of interorganisational ICT in United States construction projects. *Automation in Construction,* 19(1), pp. 73-83.

Ahuja, V., Yang, J. & Shankar, R., 2009. Study of ICT adoption for building project management in the Indian construction industry. *Automation in Construction*, 18(2009), pp. 415-423.

Al-Hajj, A. & Hamani, K., 2011. Material waste in the UAE construction industry. *Main causes and minimization practices. Architectural engineering and design management,* pp. 7(4), 221-235..

Ali, T. H., 2006. Influence of national culture on construction safety climate in Pakistan.

Al-Maatouk, Q. & Othman, M. S., 2018. A Framework for Collaborative Information Management in Construction Industry.. *International Journal of Advanced Intelligence Paradigms,* 11(1-2).

Ameh, O. J. & Daniel, E. I., 2017. Human Resource Management in the Nigerian Construction Firms: Practices and Challenges. *Journal of Construction Business and Management*, 2(1), pp. 47-54.

Anderson, J. et al., 2000. A Framework for Measuring IT Innovation Benefits. *Journal of Information Technology in Construction,* Volume 5, pp. 57-72.

Anon., 2018. *Merriam-Webster's online dictionary.* [Online] Available at: http://www.merriam-webster.com [Accessed 15 10 2018].

Assaf, S. a. A. S., 2006. Causes of Delay in Large Construction Projects. *International Journal of Project Management*, pp. 24 (4), 349–357.

Azhar, N., Kang, Y. & Ahmad, I., 2014. Critical Look into the Relationship between Information and Communication Technology and Integrated Project Delivery in Public Sector Construction. *Journal of Management in Engineering*, pp. 04014091-1-12.

Aziz, F., Rankin, J. H. & Waugh, L. M., 2016. Construction Organizational-Level Information Management Framework. *Journal of Management in Engineering, ASCE,* 32(2), p. 04015043.

Bjork, B.-C., 2003. Electronic Document Management in Construction - Research Issues and Results. *ITcon,* 8(2003), pp. 105-117.

Bossink, B. & Brouwers, H., 1996. Construction waste: quantification and source evaluation. *Journal of construction engineering and management,* pp. 122(1), 55-60.

Bower, D., 2000. A systematic approach to the evaluation of indirect costs of contract variations. *Construction Management and Economics*, 18(3), pp. 263-268.

Brandon, P., Li, H. & Shen, Q., 2005. Construction IT and the 'tipping point'. *Automation in Construction,* 14(2005), pp. 281-286.

Cheng, J. C. & Ma, L. Y., 2013. A BIM-based system for demolition and renovation waste estimation and planning,. *Waste Management*, June, 33(6), pp. 1539-1551.

Choo, C. W., 2002. *Information Management for the Intelligent Organization: The Art of Scanning the Environment.* 3rd Edition ed. Medford, NJ: asis, ASIS Monograph Series.

Ciftcioglu, Ö., 2003. Classification of Construction Information with Fuzzy Attributes. *Construction Informatics Digital Library*.

CII, 2000. Construction Industry Insitute. In: *Quantifying the Cumulative Impact of Change Orders for Electrical and Mechanical Contractor.* s.l.:University of Texas, Austin USA.

Dawood, N., Akinsola, A. & Hobbs, B., 2002. Development of automated communication of system for managing site information using internet technology. *Automation in Construction,* 11(2002), pp. 557-572.

Dehlin, S. & Olofsson, T., 2008. An Evaluation Model for ICT Investments in Construction Projects. *IT Con,* Volume 13, pp. 343-361.

Demian, P. & Walters, D., 2014. The advantages of information management through building information modelling. *Construction Management and Economics,* 32(12), pp. 1153-1165.

Detlor, B., 2010. Information management. *International Journal of Information Management,* 30(2010), pp. 103-108.

DTIE, U., 2009. *Buildings and Climate Change: A Summary for decision makers,* Paris France: s.n.

Ekanayake, L. a. O. G., 2000. *Construction material waste source evaluation.* Pretoria, Proceedings of Strategies for a Sustainable Built Environment.

Farooqui, R. U. & Ahmed, S. M., 2008. Assessment of Pakistani Construction Industry - Current Performance and the Way Forward. *Journal for the Advancement of Performance Information and Value,* 1(1), pp. 51-72.

Feibel, J. B., 2003. *Investment Performance Measurement.* New York: Wiley Finance.

Fisk, E. .. .., 1997. *Construction Project Administration 5th Edn.,* .

Gao , T. et al., 2012. Development of a Framework for Identifying Information Bottlenecks and Evaluating Different Data Capture Technologies to Support Proactive Productivity Management. *Construction Research Congress, ASCE*, pp. 356-365.

Giel, K. B. & Issa, R. R., 2013. Return on Investment Analysis of Using Building Information Modeling in Construction. *Journal of Computing in Civil Engineering,* Volume 27, pp. 511-521.

Golparvar-Fard, M., Peña-Mora, F., Arboleda, C. A. & Lee, S., 2009. Visualization of Construction Progress Monitoring with 4D Simulation Model Overlaid on Time-Lapsed Photographs. *Journal of Computing in Civil Engineering, ASCE,* Nov-Dec, 23(6), pp. 391-404.

Hallock, B., 2006. Managing Change vs. Administering the Change Order Process. *Nielsen-Wurster Communique,* p. 1 (6).

Hegazy, T. & Abdel-Monem, M., 2012. Email-based system for documenting construction as-built details. *Automation in Construction,* 24(2012), pp. 130-137.

Hester, W., Kuprenas, A. J. & Chang, T., 1991. *Construction Changes and Change Orders: Their Magnitude and Impact. CII Source Document No.66,* Berkeley: s.n.

Ibbs, C. W. C. K. a. K. Y., 2001. Project Change Management System. *Journal of Management in Engineering,* pp. 17 (3), 159-165..

International Telecommunication Union, 2017. *Measuring the Information Society Report 2017.* [Online]
Available at: http://www.itu.int/net4/ITU-D/idi/2017/

Karim, A. & Adeli, H., 1999. CONSCOM: An OO construction scheduling and change management system. *Journal of Construction Engineering and Management,* pp. 125(5), 368-376.

Kelley, J., 2002. *Knowledge Nirvana.* 1st ed. Fairfax(VA): Xulon Press.

Khan, K. I. A., Flanagan, R. & Lu, S.-L., 2016. Managing information complexity using system dynamics on construction projects. *Construction Maangement and Economics,* 34(3), pp. 192-204.

Kumaraswamy, M. M., 1998. Claims for Extensions of Time in Civil Engineering Projects. *Construction Management and Economics,* pp. 16 (3), 283-294..

Kumar, B. & Cheng, J. C. P., 2010. *Cloud computing and its implications for construction IT.* Nottingham, UK, The 13th International Conference on Computing in Civil and Building Engineering (ICCCBE XIII).

Lee, D.-Y.et al., 2016. A linked data system framework for sharing construction defect information using ontologies and BIM environments. *Automation in Construction,* 68(2016), pp. 102-113.

Lee, N. & Kim, Y., 2018. A Conceptual Framework for Effective Communication in Construction Management: Information Processing and Visual Communication. *Construction Research Congress, ASCE,* pp. 531-541.

Lee, S.-K. & Yu, J.-H., 2012. Success model of project management information system in construction. *Automation in Construction,* 25(2012), pp. 82-93.

Liew, A., 2007. Understanding Data, Information, Knowledge And Their Inter-Relationships. *Journal of Knowledge Management Practice,* 7(2).

Love, P. E. & Li, H., 2000. Quantifying the causes and costs of rework in construction. *Construction Management & Economics,* pp. 18(4), 479-490. .

Lundkvist, R., Meiling, J. H. & Sandberg, M., 2014. A proactive plan-do-check-act approach to defect management based on a Swedish construction project. *Construction Management and Economics,* 32(11), pp. 1051-1065.

Lu, W., Huang, G. Q. & Li, H., 2011. Scenarios for applying RFID technology in construction project management. *Automation in Construction,* 20(2011), pp. 101-106.

Madhavarao, B., Mahindra, K. & Asadi, S., 2018. A critical analysis of material management techniques in construction project. *International Journal of Civil Engineering and Technology,* 9(4), pp. 826-835.

Marsh, L. & Flanagan, R., 2000. Measuring the costs and benefits of information technology in construction. *Engineering, Construction and Architectural Management* , 7(4), pp. 423-435.

Martinez-Rojas, M., Marin, N. & Vila, M. A., 2015. The role of information technologies to address data handling in construction project management. *Journal of Compting in Civil Engineering, ASCE,* 30(4), pp. 04015064-1-20.

Mbazor, D. N. & Adedayo, A. M., 2018. The imperativeness of information management on housing project delivery. *International Journal of Advanced Engineering and Management Research,* 3(2), pp. 76-86.

Mell, P. & Grance, T., 2011. *The NIST Definition of Cloud Computing,* s.l.: National Institute of Standards and Technology.

Miettinen, R. & Paavola, S., 2014. Beyond the BIM utopia: Approaches to the development and implementation of building information modeling. *Automation in Construction,* 43(2014), pp. 84-91.

Ming, S. M. S. &. C. A., 2004. *Managing Changes in Construction Projects Industrial Report 7-10,* Bristol: University of the West of England, .

Ministry of Finance, 2017. *Overview of the Economy, 2016-17,* s.l.: s.n.

Motawa, I. A. J. L. S. P.-M. F., 2007. An Integrated System for Change Management in Construction. *Automation in Construction,* pp. 16 (3), 368-377.

O'Brien, J. J., 1998. Construction change orders.

Ozorhon, B., Karatas, C. G. & Demirkesen, S., 2014. A Web-Based Database System for Managing Construction Project Knowledge. *Procedia - Social and Behavioral Sciences,* 119(2014), pp. 377-386.

Pruitt, W. B., 1999. The Value of the System Engineering Function in Configuration Control of a Major Technology Project. *Project Management Journal,* p. 30 (3).

Ruddock, L., 2006. ICT in the Construction Sector: Computing the Economic Benefits. *International Journal of Strategic Property Management,* Volume 10, pp. 39-50.

Saunders , M., Lewis, P. & Thornhill, A., 2009. *Research Methods for Business Students.* Fifth ed. Essex, England: Pearson Education Limited.

Senaratne, S. & Ruwanpura, M., 2016. Communication in construction: a management perspective through case studies in Sri Lanka. *Architectural Engineerinf and Design Management,* 12(1), pp. 3-18.

Sepasgozar, S. M. E., Lim, S., Shirowzhan, S. & Kim, Y. M., 2014. *Implementation of As-Built Information Modelling Using Mobile and Terrestrial Lidar Systems.* Sydney, The 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC 2014), pp. 876-883.

Shahi, A., Haas, C. T., West, J. S. & Akinci, B., 2014. Workflow-Based Construction Research Data Management and Dissemination. *Journal of Computing in Civil Engineering, ASCE,* 28(2), pp. 244-252.

Shelbourn, M. A., Bouchlaghem, D., Anumba, C. & Carrillo, P., 2007. A framework for effective collaborative working in construction. *Management, Procurement and Law,* Issue MP0, pp. 1-9.

Solis, F. A. M., Howe, J. & O'Brien, W. J., 2015. Integration of Information Technologies into Field Managers' Activities: A Cognitive Perspective. *Journal of Management in Engineering, ASCE,* 31(1), p. A4014001.

Symons, V. J., 1991. Impacts of information systems: four perspectives. *Information and Software Technology,* 33(3), pp. 181-190.

Tsai, M.-K., Yang, J.-B. & Lin, C.-Y., 2007. Integrating wireless and speech technologies for synchronous on-site data collection. *Automation in Construction,* 16(2007), pp. 378-391.

Vandenbergh, P., 1996. *The Impact of Change Orders on Mechanical Construction Labor Efficiency,* Madison: Wisconsin: s.n.

Viljamaa, E. & Peltomaa, I., 2014. Intensified construction process control using information integration. *Automation in Construction,* 39(2014), pp. 126-133.

Voordijk, H. & Adriaanse, A., 2016. Engaged scholarship in construction management research: the adoption of information and communications technology in construction projects. 34(7-8), pp. 536-551.

Wilkinson, A., Johnstone, S. & Townsend, K., 2012. Changing patterns of human resource management in construction. *Construction Management and Economics,* 30(7), pp. 507-512.

Zhang, D. et al., 2012. Construction Small-projects Rework Reduction for Capital Facilities. *Journal of Construction Engineering and Management,* pp. 138(12), 1377-1385.

Zhang, J. et al., 2017. A multi-server information-sharing environment for cross-party collaboration on a private cloud. *Automation in Construction,* 81(2017), pp. 180-195.

APPENDIX 1

Category	Element ID	Element Name	Level	Type of Change	Old Quantity	New Quantity	Change in Quantity m^3	Old Duration	New Duration	Change (Hours)	Change (Days)	Old Total Material Cost	Old Total Labor Cost	Old Material + Labor	New Total Labor Cost	New Total Material Cost	New Material + Labor	Difference in Cost
Walls	201064	Foundation - 300mm Concrete	1	Increase & Location Change	8.626418	12.66595	4.039532	258.792526	379.9784873	121.186	10.09883	Rs 25,879.25	Rs 8,626.42	Rs 34,505.67	Rs 12,665.95	Rs 37,997.85	Rs 50,663.80	Rs 16,158.13
Walls	201099	Foundation - 300mm Concrete	1	Increase	9.579709	9.772093	0.192384	287.391267	293.1627958	5.771529	0.480961	Rs 28,739.13	Rs 9,579.71	Rs 38,318.84	Rs 9,772.09	Rs 29,316.28	Rs 39,088.37	Rs 769.54
Walls	202498	Foundation - 300mm Concrete	1	Decrease	10.00398	9.869064	-0.13492	300.119499	296.0719168	-4.04758	-0.3373	Rs 30,011.95	Rs 10,003.98	Rs 40,015.93	Rs 9,869.06	Rs 29,607.19	Rs 39,476.26	-Rs 539.68
Walls	202533	Foundation - 300mm Concrete	1	Decrease	7.911776	6.288281	-1.62349	237.353285	188.6484351	-48.7048	-4.05874	Rs 23,735.33	Rs 7,911.78	Rs 31,647.10	Rs 6,288.28	Rs 18,864.84	Rs 25,153.12	-Rs 6,493.98
Doors	202703	0915 x 2134mm	1	Location changed	0.119856	0.119856	0	1.79784165	1.79784165	0	0	Rs 17.98	Rs 239.71	Rs 257.69	Rs 239.71	Rs 17.98	Rs 257.69	Rs 0.00
Windows	202961	0610 x 1220mm	1	Location changed	0.043881	0.043881	0	0.52657728	0.52657728	0	0	Rs 5.27	Rs 87.76	Rs 93.03	Rs 87.76	Rs 5.27	Rs 93.03	Rs 0.00
Windows	203114	0610 x 1220mm	1	No change	0.043881	0.043881	0	0.52657728	0.52657728	0	0	Rs 5.27	Rs 87.76	Rs 93.03	Rs 87.76	Rs 5.27	Rs 93.03	Rs 0.00
Walls	203510	Generic - 300mm Masonry	1	Increase & Location Change	3.847686	5.963913	2.116227	96.1921472	149.0978282	52.90568	4.408807	Rs 961.92	Rs 3,078.15	Rs 4,040.07	Rs 4,771.13	Rs 1,490.98	Rs 6,262.11	Rs 2,222.04
Walls	203547	Generic - 300mm Masonry	1	Decrease & Location Change	3.911814	3.073765	-0.83805	97.7953497	76.8441191	-20.9512	-1.74594	Rs 977.95	Rs 3,129.45	Rs 4,107.40	Rs 2,459.01	Rs 768.44	Rs 3,227.45	-Rs 879.95
Doors	203846	0864 x 2134mm	1	No change	0.114112	0.114112	0	1.48345309	1.483453088	0	0	Rs 14.83	Rs 228.22	Rs 243.06	Rs 228.22	Rs 14.83	Rs 243.06	Rs 0.00

Summary

Impact	Original Model	Modified Model	Change
Time (Days)	1281.98	1388.14	8.85
Cost (Rs)	Rs 153,322	Rs 164,558	Rs 11,236
Construction Waste (tons)	6.48	7.05	0.57
Demolition Waste (tons)		8.989561785	

APPENDIX 2

Construction Waste

Material	Quantity	Reuse on Site	Recycled	Reuse in other projects	CW factor	CW Volume	Waste to Disposal facilities in m3	Density	Waste to Disposal facilities in ton
Concrete, Cast-in-Place gray	38.59538783	0	10	0	0.06	2.315723	-7.68428	0.5	-3.84214
Door - Frame	0.0403522	0	0	0	0.04	0.001614	0.001614	0.24	0.000387
Door - Panel	0.193615686	0	0	0	0.05	0.009681	0.009681	0.24	0.002323
Glass	0.012707904	0	0	0	0.0492	0.000625	0.000625	0.24	0.00015
Sash	0.075054976	0	0	0	0	0	0	0.7	0
Concrete Masonry Units	9.037677891	1	0	0	0.0682	0.61637	-0.38363	0.5	-0.19182
					0	0	0	0	0

Demolition Waste

Material	Quantity	Reuse on Site	Recycled	Reuse in other projects	DW factor	DW Volume	Waste to Disposal facilities in m3	Density	Waste to Disposal facilities in ton
Concrete, Cast-in-Place gray	38.59538783	0	10	0	2.4	92.62893079	82.62893079	0.5	41.3144654
Door - Frame	0.0403522	0	0	0	0.7	0.02824654	0.02824654	0.24	0.00677917
Door - Panel	0.193615686	0	0	0	0.7	0.13553098	0.13553098	0.24	0.032527435
Glass	0.012707904	0	0	0	2.5	0.03176976	0.03176976	0.24	0.007624742
Sash	0.075054976	0	0	0	0	0	0	0.7	0
Concrete Masonry Units	9.037677891	1	0	0	2.1	18.97912357	17.97912357	0.5	8.989561785
					0	0	0	0	0