BIM-Based Delay Analysis: A Framework

Zaki, Tarek[1], Hosny, Amir[1], Abouorban, Hoda[1], Hosny, Ossama[1], Nassar, Khaled[1], Zahran, Khaled[1]

[1] The American University in Cairo, Egypt

Abstract: Construction time-related claims are almost unavoidable in most if not all construction projects. Therefore, the analysis of the delays' impact on the projects' time for completion is vital and could be performed using several delay analysis techniques that are available. Even though the literature is rich with in depth studies about the different delay analysis techniques, few research efforts targeted the utilization of BIM technology in delay analysis. This paper presents a model for measuring project delays via attributing the amount of delays on the elemental level of the BIM project. The developed model uses an elemental graph generated for the BIM project that defines the construction logic in the form of dependencies between each of the model elements. Based on the generated elemental graph, the model then assigns the amount of delay of each of the BIM project elements from the total delay of the project and is also used to predict the total delay of the project based on the delay of one or more of the project's elements. Results from this paper highlight the potential utilization of BIM in the assessment of project delays compared to the conventional schedule-based assessment methods.

1 INTRODUCTION

Schedule delays in construction projects are almost inevitable; these delays usually end up giving rise to claims that might cause major disputes in the project. When a delay event has taken place, the parties usually has to deploy resources and spend a considerable amount of time in assessing the impacts of the delay on the project schedule. Forensic scheduling methods are used in the preparation/assessment of the claim for which the contractor believes he is entitled to an extension of time and/or cost because of this delay event.

For the assessment of delay impacts, there are various approaches for delay analysis; however, none of these approaches is free of flaws, as all of them enclose an element of subjectivity (AACEI 2011). Most of the delay analysis techniques require the analyst to make a number of assumptions that lead to impacts that are considered theoretical projections of the effect of the delay event. Thus, the selection of the proper delay analysis technique to use is rather a crucial aspect in the process of claim management. This selection is dictated firstly by the existence of a particular condition in the contract that specifies a specific approach to be used, then by a number of factors such as the reliability of the projects' programs, the availability of project updates, etc. Thus, the process of delay analysis has proven to be one of rather high complexity and this is why researches have started to venture into the potential aid that could be provided to the process by using computerized approaches.

An emerging computerized tool in the construction industry is Building Information Modelling (BIM). The need for the utilization of the BIM approach in the different aspects of construction projects has been growing as it provides practitioners in the field with a visual representation of the projects' information, which in turn makes it easier to interpret and communicate such information. As mentioned above, the uses of BIM can be diversified as it is used for a variety of purposes in construction projects. There are a number of available guidelines for the implementation of BIM in real construction projects, one of which is the BIM Project Execution Planning Guide that was developed by the Computer Integrated Construction Research

Program (CIC) in 2011 by the Pennsylvania State University. This CIC guideline identifies a number of uses of BIM in construction projects and states 4D modeling as one of these uses. The concept of 4D modelling is adding the dimension of time to the regular 3D project model that is built using BIM, it does so by integrating the projects' schedule with its 3D model to grant a visual representation of the timely execution of the project, thus easily depicting important project milestones. Even though such guidelines exist very few researches have examined the potential implementation of 4D modeling in analyzing project delays. This research then focuses on using 4D modelling to aid decision-makers in the process of delay analysis.

2   LITERATURE REVIEW

Succar (2009) presents what is called a "BIM Framework", this framework is an outline for how BIM could be implemented in the Architecture, Engineering, Construction and Operations (AECO) industry. In this research the author aims to define the BIM integration framework as shown in the table below.

Table 1: Definition of BIM Framework

BIM Framework Dimensions	Dimension Components
BIM Fields	• Technology Field: The field that specializes in software, equipment, hardware, and networking systems development. • Process Field: The field that specializes in design, construction, procurement, manufacturing, managing, and maintaining. • Policy Field: The field that specializes in conflict minimization, risk allocation, benefits distribution, research delivery, and practitioners' preparation.
BIM Stages	• Modelling: Building the model objects, for example, windows, doors, etc. of a building. • Collaboration: Building spatial relationships between these objects to create the full model. • Integration: Integrating project information with the model built.
BIM Lenses	• Disciplinary Lens: Generates filtered BIM views based on disciplines, for example, a process management lens filters specific roles and tasks. • Scoping Lens: Filters undesired information and focuses on a specific knowledge view by changing granularity. • Conceptual Lens: Applies conceptual filters, from the BIM ontology, to constraints, deliverables, tasks, triggers, and equipment.

Finally, Succar (2009) discusses the proposed BIM ontology, as shown in Figure 1, which ties all of the above-mentioned dimensions in order to create the BIM framework that is required for the implementation of BIM in the industry.
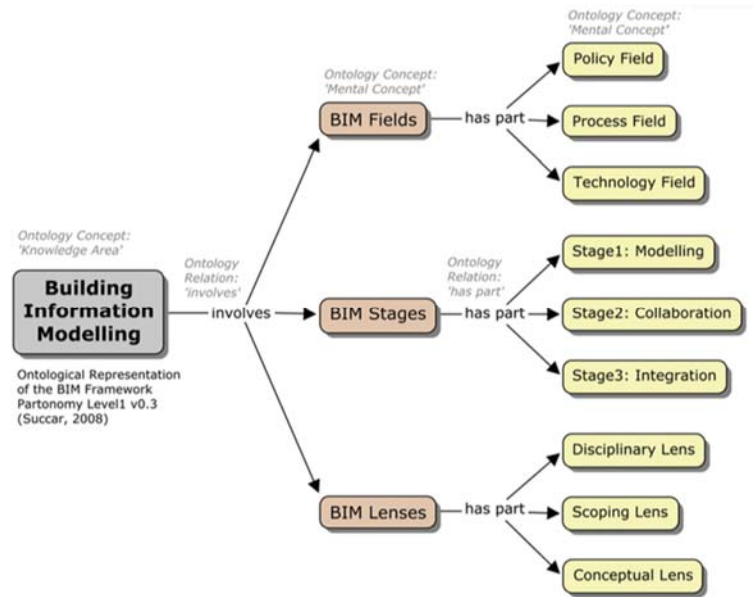
Figure 1: BIM Framework and Ontology (Succar, 2009)

Kreider and Messner (2013) attempt to classify the feasible uses of BIM by facility owners, they first categories the BIM uses into 2 major categories: Purposes and Characteristics. Under the Purposes category, they provide sub-categories as shown in Table 2.

Table 2: BIM Uses Purposes

BIM Use Purpose	Objective
Gather (collect and/or organize facility information)	1. Capture: Represent status of facility 2. Quantify: Measure facility elements 3. Monitor: Observe performance of elements 4. Qualify: Identify status of facility elements
Generate (create information about facility)	1. Prescribe: Specify need for facility elements. 2. Arrange: Configure position of facility elements 3. Size: Determine size of facility elements
Analyze (study elements of the facility)	1. Coordinate: Ensure efficiency of relationship between facility elements 2. Forecast: Simulate future performance of facility and elements 3. Validate: Confirm accuracy of information
Communicate	1. Visualize: Represent visually facility and elements 2. Transform: Change information to be used for another process 3. Draw: Create a symbolic representation of facility and elements 4. Document: Build a record of facility information
Realize	1. Fabricate: Manufacture facility elements 2. Assemble: Join separate facility elements by using facility information 3. Control: Manipulate operation of equipment 4. Regulate: Direct performance of a facility element

Bryde et al. (2013) builds on the potential uses of BIM, as well as the need for BIM integration in the construction industry and discusses the benefits of such integration. Data, regarding the benefit of BIM, was collected from projects that implemented BIM in managing their projects. A list of potential benefits was collected, with the major benefit being project time and cost control by building a 5D model that simulates the relative time and cost of the project by incorporating immediate project schedule and budget updates. A number of projects reported major cost and time control benefits from 5D BIM modeling followed by communication, coordination improvement and quality benefits. However, Bryde et al. (2013) mention that there were a few setbacks that these projects faced when trying to integrate BIM in the management process. The most common challenge was the change of the management system for the adoption of BIM.

Dawood et al. (2014), developed a BIM based visualization system to facilitate tracking and monitoring construction progress. The model is applicable to small and medium construction projects. It enables nD visualization of project progress that provides decision makers with a visualization tool to take cost and progress related decisions in a timely manner.

Chou and Yang (2017), preliminarily evaluate the utilization of BIM in schedule delay analysis. They do so by extensively collecting data from literature regarding the potential uses of BIM and its ability to generate a 4D model by incorporating project schedules such as as-planned, as-built, adjusted, etc. which are all used in the different delay analysis techniques, thus providing an easier way to manage delays and their impact through visual representation. They highly recommend and encourage further research into using BIM in delay analysis.

3 PROBLEM STATEMENT

Ninety percent of the construction projects face unexpected events or changes that affect some of the project's activities and cause delays in the project (Alkass et al. 1996). Delay Analysis is a time consuming and exhausting method that planners use to track the changes or delays incurred in any project. Notwithstanding, the amount of time that takes it to prepare a revised schedule or/and claim to be prepared by the contractor. Moreover, most of the time schedules prepared in the project are focusing on the picture as a whole not focusing on the elemental analysis.

4 RESEARCH OBJECTIVE

The objective of this research is to develop a model that automatically generates delay analysis reports based on triggering unforeseen delay events on a BIM model without the need for having a construction program linked with the BIM project such as the case in most 4D BIM.

5 METHODOLOGY

A model was developed in the form of an add-in that runs on a native BIM projects to generate a delay report; calculating the impacts of user defined events on the building elements. The developed model the extends the concept of the Elemental Graph Data Model (EGDM), developed by Essawy and Nassar (2017) to be used in analyzing delay events on the BIM project. Autodesk® Revit® 2017 was used in this research as the BIM environment, while the add-in was coded using Revit® API using C# programming language. The developed model was structured on a set of three modules; inputs, engine and outputs as shown in Figure 2.
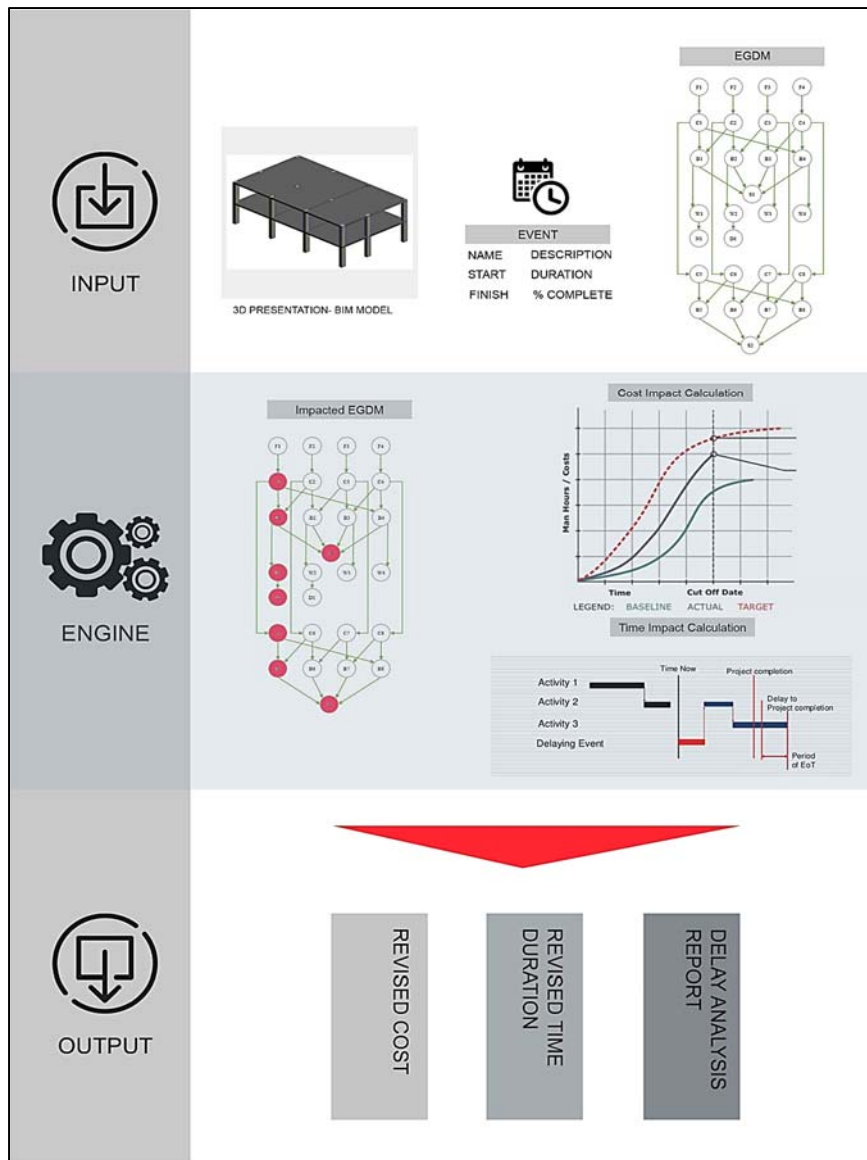
Figure 2 – Model Design

5.1 Inputs Module

Three inputs are first required by the Project Engineer for the model to start; (1) a native BIM project, (2) a change event, and (3) the project data tree provided by the EGDM add-in.

5.1.1 Native BIM Project

Native BIM project is the IFC BIM for the project under study, which is mostly drawn with an LOD300. This means that the maximum level of detail in the model shows the building elements (such as Columns, Slabs Walls …) and not the sub-elements as in LOD400 (such as steel rebar, Accessories…).

5.1.2 The EGDM algorithm

The EGDM algorithm works on mapping a data tree for all the model elements. This data tree retrieves parameters about the elements of the BIM project; such as the geometric properties (location, dimension, volume…) and other computed parameters (which are the focus of this research) such as the dependences of elements on each other, the number of elemental construction methods, the number of resources

required, the construction duration and the start and finish times. The core usage of the EGDM algorithm in this model is to generate a cost-loaded schedule for the BIM project. The project duration and finish date are based on tracing the longest path of duration calculation in the data tree as well as the summation of the elemental costs. Also, to define two new parameters on each element in the project; namely "delay" and "extra cost".

5.1.3   The Change Event

The change event is basically a trigger for the occurrence of an unforeseen event on the project. In this model, the change event is defined by the user on the elemental level. The Project Engineer initiates the Change Event add-in under the add-ins section in the Revit Interface. The building foundation of the add-in is a relational database designed with user interfaces. The first window is an interface, designed with a number of functions; creating new event, modifying existing event or highlight event in model as shown in Figure 3.
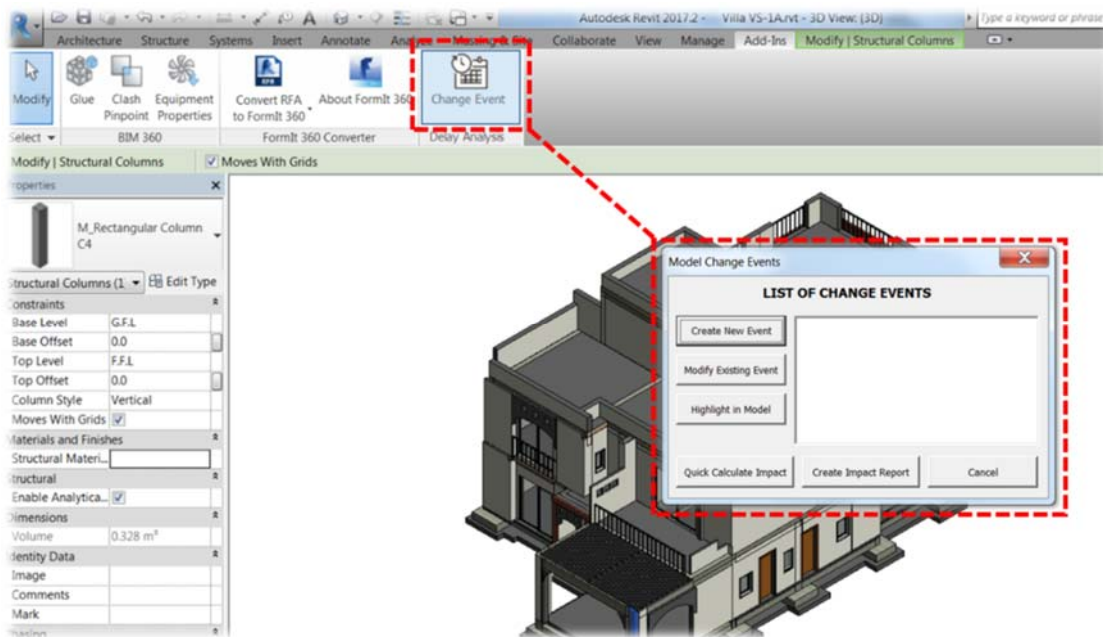

Figure 3 – Developed Delay Analysis Add-in: List of Change Events interface

On creating a new event or modifying an existing one, another "interface" pops-up titled "Element Change Event" as shown in Figure 4. This form was designed with four subsections. As mentioned earlier, events are triggered on the elemental level of the project; thus, the first requirement in this form is to select the model element where an event has occurred. Since elements in Revit have project based unique IDs, this means a change event is only triggered to the selected element and not to the whole family/type.

Thus, the first section is to select the element in the BIM project, where the selected element would have a unique ID and a Family & Type.

The second section is to define a description of the triggered event, which should have a reference, initiated date, title and description with its relevant facts. Events per unique ID are marked with keys, which are linked back to with the Model Change Events interface. The user may return to search and modify a stored event or can generate a delay report.
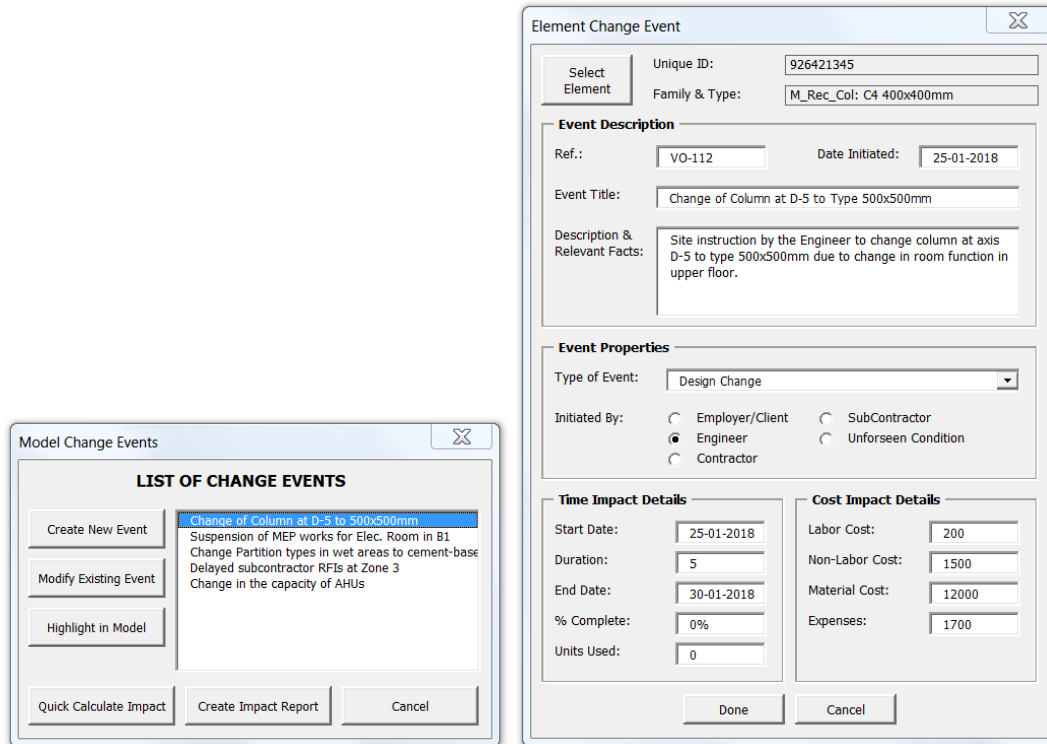
Figure 4 – Model Change Event and Element Change Event Interfaces

The third section is to define the type of event. This is a crucial part of the model where it calculates the concurrency between the events. The model was designed with different types of events that are initiated by each project party. The rationale behind this section is to categorize events as either excusable, non-excusable, compensable or/and non-compensable. The dropdown types of events list are included and categorized as per the following Table 3.

Table 3 - Types of Events and their categorization

	Compensable	Non-Compensable
Excusable	Change orders, Suspension of Work, Delayed response of submittals, Additional project scope	Employer's Risks, Acts of God, Acts of Government
Non-Excusable	---	Failure to manage project, failure to coordinate, project mismanagement, subcontractor default

The fourth section is to define the expected time and cost impact of the event. The user specifies the start date of the event, the expected duration to finish the task or the finish date of the event. Another important input is to define the % complete. Given that elements may have had a % complete during the occurrence of the event which would affect the impact of the project. Similarly, for the cost impact, the user inputs the expected additional costs due to such event in terms of labor, non-labor, material and expenses.

5.2 Engine Module

After the user defines the events on all the project elements and the events are stored in the list of events, two functions can be performed; either generate a quick calculation of the impacts or generate impact report. The engine module works on two sequential sub-modules; impacted EGDM algorithm and T&C impact calculator. To compute the effect of each event and the caused delays, the model is designed with the "Impact As-Planned" delay analysis algorithm.

5.2.1 Impacted EGDM Algorithm

The EGDM defines three new parameters to each element in the BIM project; "delay", "extra cost" and "initiated". A set of IF-THEN rules define the category (as per Table 1) of each event allocated on the element so as for the algorithm to either commute the delay or extra cost or a combination of both.

In any case, the value of the "delay" of events may still fall on elements that are not on the longest path in the elemental tree of the project. In other words, elements not on the critical path, thus the impact would be only cost-based and not time based as if the event has occurred on an activity with enough consumable total float. This is based on the assumption that the Employer owns the float of the schedule. Thus, the project cost would be affected.

5.2.2 Impacted As-Planned Algorithm

The impact as-planned algorithm treats the output from the EGDM algorithm as the project baseline schedule and the impacted EGDM algorithm as the impacted schedule with delays on each element. The total project duration is commuted as the summation of durations on the longest path in the data tree. The Employer-caused delays, denoted as ECD, is the summation of the "delay" parameter allocated on each elemental node if the delay is marked as Employer delay. And similarly, for the Contractor-caused delay, denoted by CCD. The Employer responsible delays are commuted as the difference between the employer impacted and as-planned while the contractor responsible delay is commuted as the difference between the contractor impacted. Even though the Impact As-planned is a relatively a simple method for the quick calculation of delays, it has some shortcomings which part of the limitations of the current model is.

5.3 Outputs Module

The outputs module generates the commuted time and cost impacts either as a quick calculation or in the form of a tabular delay report, sorted by both Employer-caused delays and Contractor-caused delays.

6 CASE STUDY

A Pilot construction project was used as a case study to validate the developed model. The presented case study is a six-story building project designed on Autodesk® Revit® 2017. The Structural Package was considered in this case for simplicity purposes and to demonstrate the effectiveness of the developed model. The structural model was drawn in LOD300 with a number of construction zones as shown in Figure 5. The structural model is a six-floor building with isolated footing foundation system, flat-slab with hidden beams structural system and with a built-up area around 12,000m^2.

The EGDM generated a 180-day baseline schedule for the model based on normal concrete production rates. A delay event was added to the model where a number of 18 columns were selected with the event *"suspension of works due to design changes in the function of the rooms with such columns"*. This change event was defined in the model with its description and expected impacts and the quick impact calculation was used.
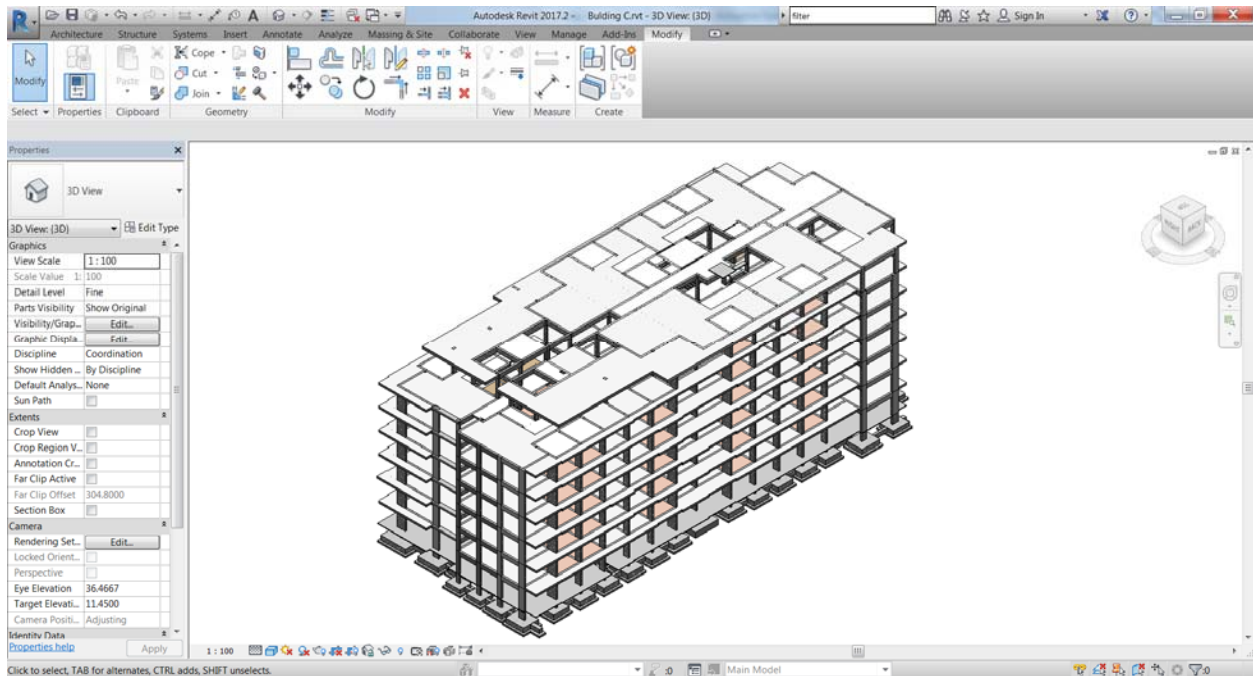
Figure 5 – Pilot BIM project

7   RESULTS AND ANALYSIS

Results from the Quick Impact calculate module show the baseline project duration and the As-built project commuted from the EGDM algorithm was 180 days and 270 days respectively. The model categorized the triggered event as an Employer-caused delay with a computed project duration to be 240 days. The Quick Calculate Impact window generated the durations of compensable delays and non-compensable delays as shown in Figure 6. The model computed the compensable delay duration to be 60 days, which is the difference between the Employer-caused impact: 240d and the original baseline: 180d. As for the non-compensable delays, the model computed a duration of 30 days, which is difference between the As-built duration 270d and the Employer-caused delay duration 240d.

Figure 6 – Quick calculate impact output

8 CONCULSION

This paper presents a model for commuting the project delays via attributing the amount of delays on the elemental level of the BIM project without using a 4D BIM software to link a schedule with the BIM project. The developed model uses an elemental graph generated for the BIM project that defines the construction logic in the form of dependencies between each of the model elements and allocates delays and extra costs on each element. The model allocates and categorizes the types of events and thus calculate the impacts in terms of time and cost by generating a delay report for both the Employer caused delays and the Contractor caused delays. The model was developed with only Impact As-Planned delay analysis method as a proof of concept; however, more delay analysis algorithms can be further developed in future research. Results from this paper highlight the potential utilization of BIM in the assessment of project delays compared to the conventional schedule-based assessment methods.

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