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Article

A Building Information Modeling (BIM)-Integrated System for Evaluating the Impact of Change Orders

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Abstract. Change orders are inevitable in most construction projects. The conventional change order practice is usually associated with 2D drawings and various paper-based documents, which cannot illustrate the existing and altered building conditions efficiently. This often leads to misinterpretation and miscommunication among project participants. In addition, cost and schedule information, which is basic inputs for analyzing the impact of change orders, is usually scattered and poorly organized resulting in difficulties in retrieving it. The evaluation of cost and schedule impacts is often subjective and unsystematic contributing to construction disputes. Building information modeling (BIM) is widely used in modern construction projects. BIM is a promising construction information management tool, which can address the aforementioned challenges. In this paper, we develop the *BIM-Integrated System for Evaluating the Impacts of Construction Change Orders (BIM-ISICO)*, which can systematically analyze three main impacts of a change order: physical conditions, schedule, and cost. The *BIM-ISICO* assists users in observing and visualizing the effect of a change order on building conditions systematically via 3D BIM models. The system can also evaluate the impacts of such change order on project cost and schedule. It establishes a new paradigm of delay and cost analysis by minimizing subjectivity and providing the auditing trails of change orders. To demonstrate its efficacy and practicality, the system is applied to an actual 18-story building project for analyzing the impact of a construction change order. The system can successfully assess and report all three aspects of change order impacts. These results can mitigate the conflicts between the project owner and the contractor about the construction claims resulting from change orders.

Keywords: Building information modeling (BIM), change order, time and cost impact assessment, change detection application, delay analysis, color-coded visualization.

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1. Introduction

A construction change order can be defined as any deviation from the scope of works stipulated in the contract documents [1]. It is commonly issued by the project owner or their representative. Due to the complexity of a construction project and the owner's desire to modify the facility, change orders are inevitable [2], but they are considered a tool to enhance and optimize the owner's benefit on the project [3]. Change orders are a primary cause of construction claims [4], which contribute to costly and time-consuming negotiations between the project owner and the contractor. Thus, it is necessary to manage construction change orders appropriately to avoid or mitigate their adverse impacts.

Since the conventional change orders practice is usually associated with 2D drawings and paper-based documents, it is difficult to retrieve information that is necessary for evaluating their consequences. Since the altered physical conditions of a building after executing a construction change order are often not clearly illustrated, project stakeholders may be unaware of the scope of the changed works. A failure to assimilate the scope of the changed works significantly influences the accuracy of time and cost impact assessment. For the conventional assessment, an analyst needs to modify the plans and estimate consequential costs. This process is subjective and time-consuming, and its results are often inaccurate. Since the results are narrative, it is challenging to communicate them to the stakeholders, leading to disagreements and conflicts.

Change order management can be improved by various approaches. Fundamentally, guidelines have been developed to integrate modern technologies with advanced modeling [5]. A basic guideline consists of a contractual aspect such as an effective change order clause [2] and the efficient performance criteria of change order practices [3]. An object-oriented information model based on Visual C++, namely CONSCOM, was introduced to evaluate cost and time impacts by utilizing the concept of time-cost trade-off [6]. Even though this system can evaluate the time and cost impacts of change orders, the adjustment of cost and time still relies heavily on the analyst's assumptions. An internet-based system was created to enhance communication and collaboration in change order processes [7]. It highlighted the importance of a centralized database, particularly on the concept of integrating the project information. Using artificial neural network (ANN) as a learning feature and case-based reasoning (CBR) as a similarity calculating feature, a system was created to predict potential litigation [8] and generate an early litigation warning [9]. This hybrid artificial intelligence can predict future consequences by assessing historical data. Recent studies show that advanced technologies played an essential role in improving the traditional practice. The graphical approach for evaluating the impacts of change orders such as Building Information Modeling (BIM) is still limited even though a number of previous studies confirmed that BIM can assist in tracking design changes across multi-disciplinary [10], contributing to successful construction projects [11].

BIM is a virtual representation of physical and functional building characteristics. BIM can yield various methods (BIM uses) for achieving specific objectives during the facility's life-cycle [12]. BIM authoring is a BIM use that creates a 3D virtual model of the facility [13]. Since 3D models can provide more comprehensive visualization than conventional 2D models, they can assist us in communicating and collaborating with other parties in a better environment [14]. This BIM benefit is expected to tackle the problem of the conventional change order practice, in which project participants are unaware of the modified building conditions due to an inefficient description of 2D drawings. However, non-automated BIM tools for tracking design changes are still time-consuming and inaccurate. A number of design change tracking systems have been developed such as creating an add-in utilizing *Revit.NET API* [15]. The current model checkers are commonly developed to solely examine the alteration of building elements. In fact, the accurate information of altered building elements is a stepping stone to evaluate time and cost impacts. Thus, it is necessary to create a direct link between the modified elements to the cost or additional activities. Not only can a new system perform design change tracking, but it should also be able to evaluate schedule and cost impacts by adopting the concept of integrated information. The flexibility to embed and extract multi-disciplinary information from BIM models allows us to establish a system [16] that can support various aspects of project management such as construction waste [17] and maintenance [18]. In addition, its ability to provide automated quantity take-off potentially improve the conventional practice [19]. Lastly, BIM adoption in construction projects needs the development of guidance such as detailed methodology, tools or frameworks [20]. This BIM paradigm is, therefore, promising to address the aforementioned problems in the traditional change order practice.

In this paper, we propose the *BIM-Integrated System for Evaluating the Impacts of Construction Change Orders (BIM-ISICO)*. The system is designed to evaluate three main impacts of change orders, namely, physical conditions of the facility, time, and cost. The results from the building condition assessment are integrated with other necessary information to evaluate schedule and cost impacts. For efficient presentations and communications, the system reports the outcomes using a color-coded concept, which transforms narratives into graphical results.

2. Literature Review on BIM for Construction Change Order Management

Various standards and guidelines are available to support BIM implementation. The National BIM Standard-United States Version 3 (NBIMS-U V3) [12] is a guideline that is widely used by project stakeholders to organize construction information and implement BIM. The AIA Document G202-2013: Project Building Information Modeling Protocol Form [21] provides the detailed framework of the attributes of BIM uses. BIM has been applied to several aspects of construction management such as design review using clash detection [22], supply chain management [23], project monitoring [24], and facility management [25]. For construction change order management, the applications of BIM have been limitedly examined. However, BIM has a potential for facilitating this important construction issue. This is because the building elements in BIM models can be authored and modified readily [26]. Through the information embedded in BIM models, quantity take-off and cost estimating can be carried out effortlessly and accurately [26]. BIM also facilitates the 3D visualization of detailed building elements [27]. These attributes render BIM a powerful tool to overcome various barriers in construction claim management such as storage and retrieval of necessary data and information [28]. Even though there have been some preliminary investigations of BIM for change order management, a comprehensive study has never been carried out before.

Previous research works related to BIM for construction claim management are as follows. Design change tracking encompassed creating an add-in utilizing *Revit.NET API* [15] and using *Solibri Model Checker* [10]. The model checker has also been extended for specific purposes such as spatial requirement checking [29] and regulation compliance checking [30]. However, these research works do not entail a direct link between the building conditions and the cost and schedule evaluation. Thus, it is necessary to equip the model checker with the concept of integrated information. Not only can this new framework be used for assessing the design change, but it can also provide a reference for cost adjustment and delay analysis.

The integration of 3D BIM model and schedule information renders a 4D BIM model, which can be used to identify scheduling problems such as contradictory logical sequences or constructability issues [31]. To evaluate the impact of a change order on schedule, as-planned 4D models are compared to as-built 4D models [32]. These 4D models can further be used for delay analysis, which can reduce the analyst's subjectivity and provide an auditing trail. Lastly, the new system should be able to display the analysis results that support communication and collaboration among all project participants. This can be achieved by reporting the results in the form of color-coded visualization.

3. Research Methodology

This paper presents the development of *the BIM-Integrated System for Evaluating the Impacts of Construction Change Orders (BIM-ISICO).* The proposed system is primarily designed to improve the traditional change order practice by focusing on measuring the impact of a change order on physical conditions as well as project time and cost. The system development process consists of three main steps.

1) Define the system context and framework

Relevant literature related to construction change order, BIM implementation, delay analysis, and cost evaluation were extensively reviewed. The research objective, research gap, and conceptual framework were defined. Existing BIM-based platforms were thoroughly investigated and compared to derive the one that most conforms with the conceptual framework defined previously. The platform was chosen based on the objective of the analysis and the flexibility of information exchange among the system components.

2) Develop the system components and supporting tools

The conceptual framework defined previously was elaborated in the form of the system architecture, including the system structure, guidance for all rules and specifications, and the workflow of the advanced methodology applied in the system. The system applications were created as supporting tools that simplify the workflow and assist the analyst in performing repetitive analyses. In this research, the system applications were developed by using *Dynamo* and *Visual Basic for Applications (VBA).*

3) Verify the system

To verify the proposed system, it was applied to an actual 18-story building construction project, which adopted BIM for supporting project design and construction. Among several change orders by the project owner, a change order issuance was chosen to demonstrate the application of the proposed system for evaluating its impacts on physical conditions, time, and cost. A group of construction experts, who have experience in both BIM-based construction and change order was asked to evaluate the performance of the system. The results were then discussed and the conclusion was drawn.

4. Structure of BIM-ISICO

The BIM-ISICO is a BIM-integrated tool to assess three primary impacts of a change order, namely, the physical conditions of the building, time, and cost [33, 34]. The BIM-ISICO comprises three main features, which can improve the conventional change order practice:

1) Systematic observation
   The BIM-ISICO can automatically track design changes and identify modified building elements, which help the analyst examine the building conditions completely and accurately [35].
2) Cost and schedule evaluation paradigm
   The BIM-ISICO then evaluates the cost and schedule impacts of a change order based on the outcomes from the systematic observational model. In other words, the time and cost impacts are automatically analyzed from the modified elements [36]. This integrated process minimizes the analyst's subjectivity and provides an auditing trail of each change order.
3) Color-coded visualization reporting
   To better communications of change order impacts among all parties, the analysis results are presented graphically through 3D BIM models, which are enhanced by color-coded visualization to highlight important information.

These three features define the framework of the BIM-ISICO, which is constituted by five interrelated modules:

1) Module 1: Data acquisition
2) Module 2: Change detection
3) Module 3: Schedule impact analysis
4) Module 4: Cost impact analysis
5) Module 5: Reporting

The development of the BIM-ISICO relies on the provisions about construction change (variation) orders of FIDIC Red Book 1999 [37]. According to Sub-Clause 13.3 [*Variation Procedure*], the contractor is deemed to submit a proposal to the owner containing an overview of the change order works, modification of schedule (if any), and cost evaluation prior to the work execution. The BIM-ISICO can assist the contractor in composing this proposal quickly and accurately. The proposal will later be used by the owner and its representative as a reference for their decision making. It also plays an important role in the negotiation process regarding the new design, execution time, and additional costs. The complete, accurate, clear change order impacts provided by the system will minimize conflicts among the parties and mitigate the potential risks resulting from such changes.

Once a change order is issued, the BIM-ISICO can be implemented to determine the impact of such change order. The system is designed to evaluate the impact of each single change order. However, as the project proceeds and other change orders are issued, the BIM-ISICO can be executed for every change order chronologically. The BIM-ISICO is not specifically built for certain project stakeholders. Contractors can employ the system to create a proposal for evaluating change order impacts. For the owner or its representative, this system can be used to review their decisions regarding changed works.

Several platforms are selected and integrated to develop the system, namely, *Autodesk Revit* as the BIM authoring platform, *Microsoft Excel* as both database and analysis sheets, and *Microsoft Project* as the scheduling program. In addition, *Dynamo* is used as an information exchange tool between *Autodesk Revit* and *Microsoft Excel*. It also serves as an automated color-coded tool, which improves the default BIM visualization. Lastly, *Visual Basic for Application (V*BA), which is embedded in *Microsoft Excel*, is scripted to perform repetitive analysis, filter data, and provide interactive user-interface in the spreadsheets.

Figure 1 shows the system architecture of the BIM-ISICO. As can be seen, the two-dimensional matrix connects the five selected platforms to the five modules. Each module contains sub-modules, which elaborate analyses and information exchange.

The BIM-ISICO is equipped with several system applications, which perform different complex analyses. Without these system applications, the analyst must deal with a large amount of data while performing repetitive analyses. For example, a set of programs created by *Dynamo* allows users to control the designated parameters conveniently. As a result, information exchange can be performed efficiently.

The details of the five modules of the BIM-ISICO are as follows.

4.1. Module 1: Data Acquisition

This module defines the collected data, the system requirements, and the analysis preparation. It preconditions the designated data to conform with the system requirements, so they are ready for further analyses. As depicted in Fig. 1, this module is supported by four sub-modules: the *gathering*, *updating*, *integrating*, and *implementing instruction sub-modules*. These sub-modules create BIM models, schedule, and project costs. If the system requirements are fulfilled, they can yield accurate results with minimal errors.

The *gathering sub-module* features the data collection requirements and designates the rules for the collected data. This sub-module requires schedule and the cost information, which is provided by the BIM models. In other words, the elements in the BIM models must be associated with the schedule of construction activities and the database of construction cost items. Thus, an important step is to delineate a connection between each building element in the BIM models and the schedule and cost of associated activities. For example, for the brick wall elements located on the first floor, this sub-module must gather the elements to be included in activities and the cost items associated with such building element.

The *updating sub-module* reflects the latest conditions of the building prior to the issuance of a change order. The updating process incorporates any ongoing construction works, previous change orders, and any alteration of schedule information. The BIM models are updated based on the actual project conditions, while the schedule and cost information are adjusted to the current time and cost status of the project.

The *integrating sub-module* performs three main functions, as shown in Fig. 2. First, it assigns the codes for the BIM models, schedule, and cost database. The code is divided into two types: *cost ID* and *activity ID*. The cost ID interconnects the BIM models with the project cost database, whereas the activity ID links the 3D models to the schedule. The second function is to transfer the detailed cost and schedule information to the BIM models through a system application created by *Dynamo*. The schedule information (e.g., *activity name, duration, float*, and *progress*) and the cost information (e.g., *cost item, material cost,* and *labor cost*) are exported from the spreadsheets to the corresponding elements in the BIM models, which share the same values of schedule ID and cost ID, respectively. This sub-module yields the *basic BIM model*, in which each element contains detailed schedule and cost information.

In the last sub-module, the *implementing instruction sub-module*, change order instructions are gathered, compiled, and analyzed. If a change order is delivered orally, the analyst must transfer such instruction to the BIM models. The analyst edits the *basic BIM model* to reflect the change order instructions to derive the *modified BIM models*. The establishment of two different BIM models, which represent the facility condition prior to and after a change order instruction remarks the final part of Module 1.

4.2. Module 2: Change Detection

This module provides a systematic observational method for detecting the changed building conditions resulting from a construction change order. It first extracts the parameters from the BIM models and then filters the elements, the geometrical parameters of which are modified due to a change order. The findings will further be used for the schedule and cost impact analysis. The change detection module consists of two sub-modules: the *extracting* and *filtering sub-modules*, as shown in Fig. 1.

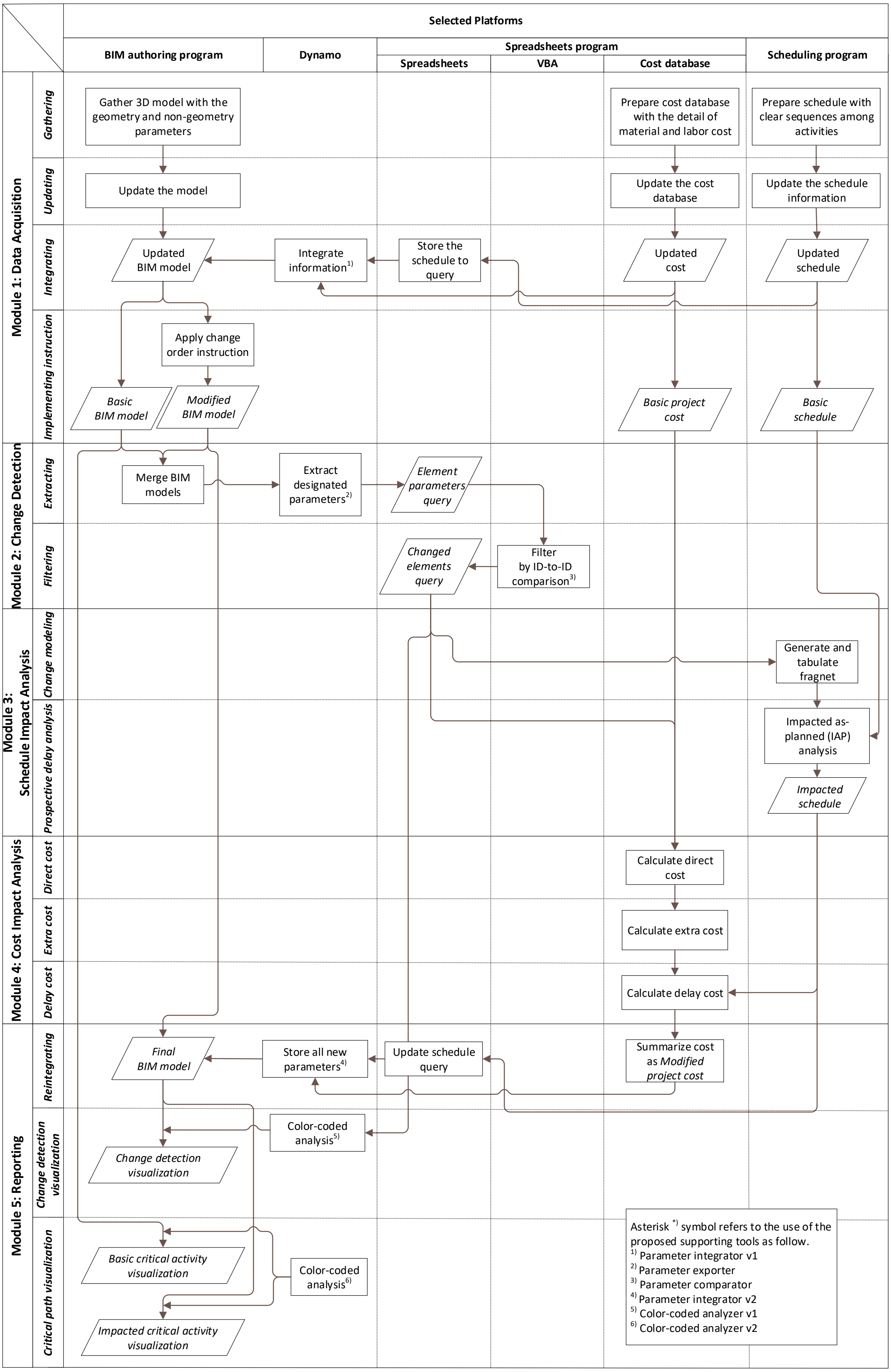


Fig. 1. System architecture of the BIM-ISICO.

The *extracting sub-module* requires the establishment of the *merged BIM models*, in which the *modified BIM models* is linked to the *basic BIM models*. In this paper, *Autodesk Revit* was used to insert the *basic BIM models* in the *modified BIM models* (i.e., an underlying model). Even though this process combines both BIM models, the information in both models is not compromised. Each BIM model still contains independent information. This BIM model is created to reduce the redundancy of analysis so we can extract the parameters of both *basic BIM models* and *modified BIM models* simultaneously. This parameter extraction process is facilitated by an application using *Dynamo*. We created a program file consisting of two sets of nodes, which are used to assess, extract, and transfer the designated parameters into the designated columns in a spreadsheet. Both node sets accommodate the extracting process for the *basic BIM models* and the *modified BIM models*. The redundancy can be avoided because the BIM-ISICO performs the compression and the extraction of the models at the same time. The extracted parameters consist of geometrical parameters (e.g., category, element ID, element name, level, material, quantity, and location), schedule parameters (e.g., activity name, activity ID, float, and progress), and cost parameters (e.g., cost item, cost ID, material cost, and labor cost).

The *filtering sub-module* determines the elements that are affected by the change order instruction. *VBA* is scripted to perform this analysis by comparing the geometrical parameters (e.g., element ID, material, quantity, and location) of each element from the *modified BIM model*s to those from the *basic BIM models*.

The filtering methodology is based on the following five types of construction change.

1) *Quantity modification*. For the same element ID, the system detects different values of the quantity parameters of the *basic BIM models* and the *modified BIM models*.
2) *Material alteration*. For the same element ID, the material parameters between both models are different.
3) *Relocation*. The element ID in both models are identical, but the location information is not identical.
4) *Deletion*. An element ID is detected in the *basic BIM models* but does not exist in the *modified BIM models*.
5) *Addition*. A new element ID is found in the *modified BIM models* but does not exist in the *basic BIM models*.

The BIM-ISICO can track the building modification by applying this filtering methodology. It can also detect the elements that are classified into many types of change such as *Quantity modification & Material alteration* or *Relocation & Material alteration*. This sub-module finally provides a list of modified elements, which is equipped with information such as the element identity (e.g., element ID, element name, and level), the change classification, the quantity deviation (before and after the change), the material deviation (before and after the change), the schedule parameters, and the cost parameters.

4.3. Module 3: Schedule Impact Analysis

This module forecasts any potential delay due to a change order by adopting a delay analysis method. It is supported by two sub-modules: the *change modeling* and *prospective delay analysis sub-modules*.

The *change modeling sub-module* transfers the results from Module 2 to the delay analysis performed in this module. This sub-module requires that the analyst examines the modified elements that are detected in Module 2 and transforms them into sub-network activities. A sub-network activity, which is called *fragnet*, is the representation of the disruption the contractor has to bear during the change order execution. A fragnet is developed based on the analyst's interpretation towards the modified elements combined with their tacit knowledge. The BIM-ISICO requires that the analyst tabulates the developed fragnets, which is equipped with the *fragnets ID* (following the format of the activity ID), *fragnet name, modified element number* (based on the result of Module 2)*, duration, predecessor,* and *successor*. The duration, predecessor, and successor information are solely based on the analyst's assumption. Since developing a fragnet depends upon the modified element (the result of Module 2), the information of the modified element is substantive information to support the assumption. In addition, the delay analysis in this paper incorporates the duration and the construction sequence of each additional work the contractor needs to perform.

For example, if an element is detected as "relocation" with the progress of 100% (i.e., completed work), the analyst must consider any additional activities such as demolition, re-installation, and finishing. Since Module 2 yields the correlation between the modified element and the schedule parameters, the fragnet can be easily determined.

The *prospective delay analysis sub-module* facilitates the delay analysis. There are many delay analysis methods available. Selecting an appropriate method is based on the availability of data, the available analysis time and fund, and the capabilities of the methodology [7]. The BIM-ISICO adopts the Modeled/Additive/Multi base [25] or the Time Impact Analysis (TIA) [1] method. This is because the TIA method conforms with the objectives and the requirements of our system. However, the system can also be integrated with most delay analysis methods.

The TIA method begins with the insertion of each fragnet in a chronological order. In this paper, we adopt the method of stepped insertion fragnet, instead of global insertion fragnet. The fragnets that have been created are inserted one by one. For each insertion, we record the alteration of project duration. Lastly, after the last fragnet is inserted, we examine the impacted project completion date. The fragnets are first inserted into the initial project schedule before a change order issuance (called the *basic schedule*). A new set of project schedule is then obtained and called the *impacted schedule*, which represents the project schedule after integrating the change order. The *basic schedule* and the *impacted schedule* are compared by examining the project duration and critical path.

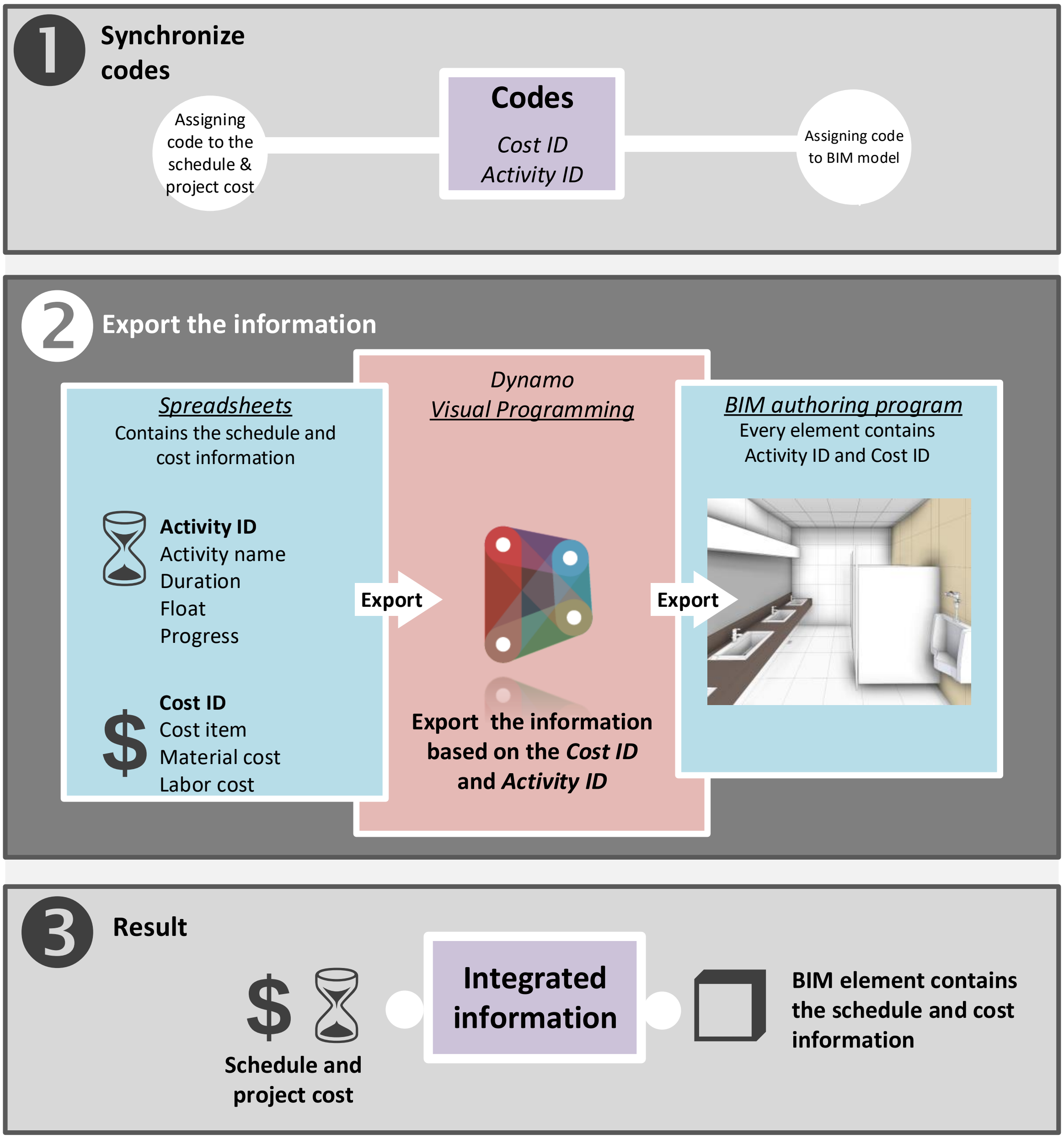


Fig. 2. Details of the integrating sub-module (modified from [35]).

The BIM-ISICO integrates the conditions of the facility due to a change order with the schedule analysis. There are also other external and administrative factors that may cause additional delay. These factors are however beyond the scope of this paper.

4.4. Module 4: Cost Impact Analysis

This module evaluates the impact of a change order on the project cost. It records any cost alterations resulting from the change such as direct cost, demolition cost, relocation cost, and delay cost. The module is supported by three main sub-module: the *direct cost, extra cost, and delay cost sub-modules*. These three sub-modules represents the three main cost types considered in this system. The modified element determined by Module 2 is the basis for calculating the direct cost and the extra cost. Table 1 illustrates examples of relations between the types of change and the cost calculation methods, which are determined by Module 2. It is based on an assumption that any works that have been done according to the *basic BIM model* must be reimbursed. The *direct cost sub-module* and the *extra cost sub-module* is executed by relying on the information of the change classification, progress, and the cost parameters provided by Module 2. Based on such information, the system adjusts the *basic project cost* (i.e., the project cost database before the change) to the *modified project cost* (i.e., the project cost database after the change).

As shown in Table 1, if the modified element is classified as "addition" with no record in the *basic project cost,* the system will establish a new cost item, cost ID, material cost, and labor cost. This new unregistered element is detected by the modified element without the cost ID. On the other hand, if a new element is classified as "Addition" and has been registered in the *basic project cost*, known by the embedded cost ID, the system will add the detected quantity into the database. Consequently, the quantity of the corresponding cost item is adjusted.

The *extra cost sub-module* calculates the additional cost that the contractor incurs as a result of a change order. In this paper, the additional cost includes the expenses of relocation and demolition. Based on the results from Module 2, the "deletion" and "quantity modification" categories combined with progress information of 100% lead to the demolition work. The quantity of an element that is identified as "deletion" or "quantity modification" with the progress of 100% demonstrates the volume of demolition work. Meanwhile, the unit price of demolition works should be derived from the analyst's assumptions. For the relocation work, the quantity is derived from the volume of any element detected as "relocation" with the progress of 100%. Since the work has already been completed, the element needs an extra cost for relocation or demolition if the element has to be rebuilt.

Another cost item determined by the BIM-ISICO is associated with the results from Module 3. The result from the delay prediction is converted to an allowance of the contractor for their extra efforts to finish the changed work. The delay cost encompasses the variable overhead cost and the preliminary cost per day. Since the delay cost is based on the contract provision, the subjective assessment by the analyst towards the conditions is necessary.

As the three cost components have been computed, the *basic project cost* is updated, and the *modified project cost* is derived. The updating of the cost database marks the completion of cost impact evaluation.

4.5. Module 5: Reporting

The final module of the system, the *reporting module*, compiles and presents the analysis results. It consists of three sub-modules: the *reintegrating, change detection visualization,* and *critical path visualization sub-modules.*

The *reintegrating sub-module* creates the *final BIM models*, which represents the eventual project conditions once all impacts of the change order have been incorporated. As discussed previously, Module 1 forms the *modified BIM models*, which displays the physical conditions of the building after the change has been executed. Yet, the schedule and cost parameters are still the representatives of the schedule and cost database prior to considering the change. Thus, it is necessary to add and override the schedule and cost parameters. This process is similar to the *integrating sub-module* of Module 1. However, this reintegration is applied to the *modified BIM model*, *impacted schedule*, and *modified project cost*. This sub-module introduces a new parameter, *impacted float*, in the *modified BIM model.* The result of the delay analysis will fill the impacted float parameter because every activity has a new value of float. A similar process is applied to the cost parameter, in which a new element possesses the completed cost parameter as the system will fill in the value. Thus, the modified conditions of the building after incorporating the change can be completely described in the *final BIM models*.

The *change detection visualization sub-module* is created to visualize the result of Module 2, which is a list of modified elements transferred into a virtual report. It is a system application using *Dynamo*. This sub-module accesses the element ID and its change classification determined by Module 2, searches the corresponding elements, and assigns the elements based on its change classification. The result is the color-coded BIM models, which highlight the elements that are impacted by the change order.

The *critical path visualization sub-module* is designed to visualize the result of Module 3. It assembles the colors into the elements in the BIM models that are associated with the critical path. Similar to the previous sub-modules, it is a system application built by *Dynamo*. Since the *basic BIM models* and the *final BIM models* contain the schedule parameters before and after incorporated with the change order, respectively, the comparison of the critical path can be determined. For the *basic BIM models*, the value of the float parameter is used to determine the critical element before the change order issuance. On the other side, the element of the *final BIM models* possesses both float and impacted float parameters, which can be used to highlight whether or not the element is critical before and after the change, or it remains the same. In the end, the change of the critical element due to the change order can be displayed clearly.

5. Application of the BIM-ISICO

An actual high-rise building project is chosen to demonstrate and verify the application of the BIM-ISICO. The project is a multipurpose eighteen-story building, which houses classrooms, laboratories, seminar halls, and sports facilities. The building is located in the Chulalongkorn University campus and occupies approximately 1,300 m^2 of the land and 22,905 m^2. The construction began in June 2015 and was mostly involved cast-in-place concrete for the structural work, bricks and precast panels for the walls, and aluminum composite for the façade. In this paper, the proposed system is applied to evaluate the impact of a change order on the architecture work of this project only. The system can, however, be used to examine the change order impact on other project works such as structural, mechanical, and electrical systems.

5.1. Overview of the Project Case Study

During the early period of the project, the owner was concerned about the space allocation of a pipeline shaft located next to the male restrooms. The building has typical male and female restrooms in every floor, and all of them are connected through this pipeline shaft. The male and female restrooms have separated shafts for easier maintenance. This became an issue when the owner realized that they had to maintain another pipeline shaft, which came from the shower room in the sports facility area. Due to limited maintenance resources available, the owner instructed the contractor to combine the pipeline from the shower room to that from the male toilet. As a result, a larger shaft was required, which led to the modification of the shaft area in the male toilet. Figure 3(a) displays the BIM models of the project and the scope of the modified work as instructed by the project owner.

The instruction on the shaft enlargement was certainly considered a change order. However, the owner would like to examine their decision objectively, so its impact would not severely impact the overall project progress. Thus, the owner instructed the contractor to evaluate the impact of this modification and asked them to submit a proposal as soon as applicable. The BIM-ISICO was implemented to help the contractor evaluate three impacts resulting from this change, including the physical impact on the architectural work, the schedule impact, and the cost impact.

5.2. Implementing the BIM-ISICO

The implementation of the BIM-ISICO began with executing Module 1, data acquisition. Based on the requirements of the *gathering sub-module*, project information, including the BIM models, schedule data, and cost data were collected. The connections between the elements in the BIM models and the schedule activities and cost items were mapped.

Table 1 Examples of relations between types of change and cost evaluation methods.

No	Change classification		Progress	Cost evaluation method
1	Addition	The element type is found in database	>0%	**Direct cost:** Increase the quantity using the *new quantity*
			0%	
		The element type is new	>0%	**Direct cost:** New cost item and unit price are added to the database
			0%	
2	Deletion		>0%	**Extra cost:** Demolition cost using the *current quantity*
			0%	**Direct cost:** Reduce the quantity using the *current quantity*
3	Relocation		>0%	**Extra cost:** Relocation cost using the *current quantity*
4	Quantity modification	The quantity is increased	>0%	**Direct cost:** Increase the quantity using Δ *quantity*
			0%	
		The quantity is decreased	>0%	**Extra cost:** Demolition cost using the Δ *quantity*
			0%	**Direct cost:** Reduce the quantity of using Δ *quantity*
5	Material alteration	The material is found in database	>0%	**Direct cost:** - Reduce the quantity of the current cost item using the *current quantity* - Increase the quantity of the new cost item **Extra cost:** - Demolition cost using the *current quantity*
			0%	**Direct cost:** - Reduce the quantity of the current cost item using the *current quantity* - Increase the quantity of the new cost item using the *new quantity*
		The material is new	>0%	**Direct cost:** - New cost item and the unit price are added to the database - Reduce the quantity of the current cost item using the *current quantity* **Extra cost:** Demolition cost using the *current quantity*
			0%	**Direct cost:** - New cost item and unit cost are added to the database - Reduce the quantity of the cost item using the *current quantity*

*) *New quantity* and *current quantity* are based on the result of Module 2

Table 1 Examples of relations between types of change and cost evaluation methods (cont.).

No	Change classification		Progress	Cost evaluation method
6	Quantity modification & Material alteration	- The quantity is increased - The material is found in database	>0%	**Direct cost:** Increase the quantity of the new cost item using the *new quantity* **Extra cost:** Demolition cost using the *current quantity*
			0%	**Direct cost:** - Reduce the quantity of the current cost item using the *current quantity* - Increase the quantity of the new cost item using the *new quantity*
		-The quantity is increased - The material is new	>0%	**Direct cost:** New cost item and unit price are added to the database **Extra cost:** Demolition cost using the *current quantity*
			0%	**Direct cost:** - New cost item and direct cost is added to the database - Reduce the quantity of the current cost item using the *current quantity*
		- The quantity is decreased - The material is found in database	>0%	**Direct cost:** Increase the quantity of the new cost item **Extra cost:** Demolition cost using the *current quantity*
			0%	**Direct cost:** - Reduce the quantity of the current cost item using the *current quantity* - Increase the quantity of the new cost item using the *new quantity*
		- The quantity is decreased - The material is new	>0%	**Direct cost:** New cost item and direct cost is added to the database **Extra cost:** Demolition cost using the *current quantity*
			0%	**Direct cost:** - New cost item and direct cost is added to the database using the *new quantity* - Reduce the quantity of the current cost item using the *current quantity*
7	Quantity modification & Relocation	- The quantity is increased - The quantity is decreased	>0%	**Direct cost:** Increase the quantity using the Δ *quantity* **Extra cost:** Relocation cost using the *current quantity*
			0%	**Direct cost:** Increase the quantity using the Δ *quantity*
			>0%	**Extra cost:** - Demolition cost using the Δ *quantity* - Relocation cost using the *new quantity*
			0%	**Direct cost:** Decrease the quantity using the Δ *quantity*

*) *New quantity* and *current quantity* are based on the result of Module 2

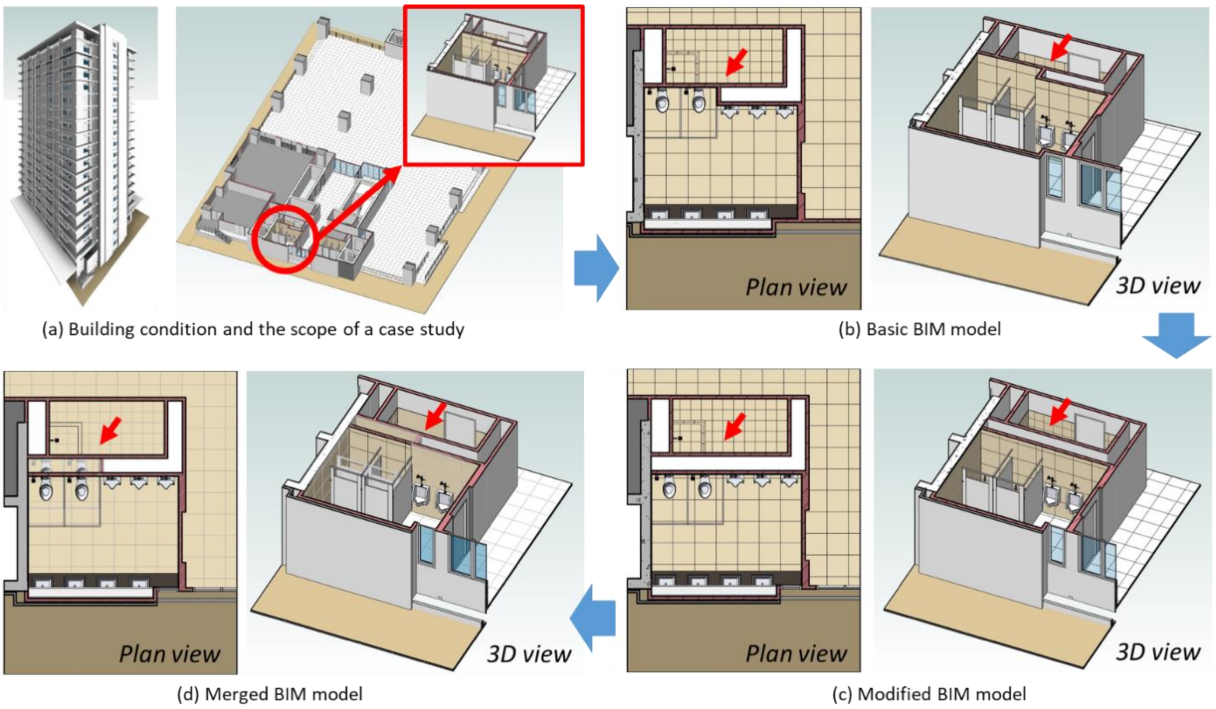


Fig. 3. BIM models of the project case study and the impact of the change order.

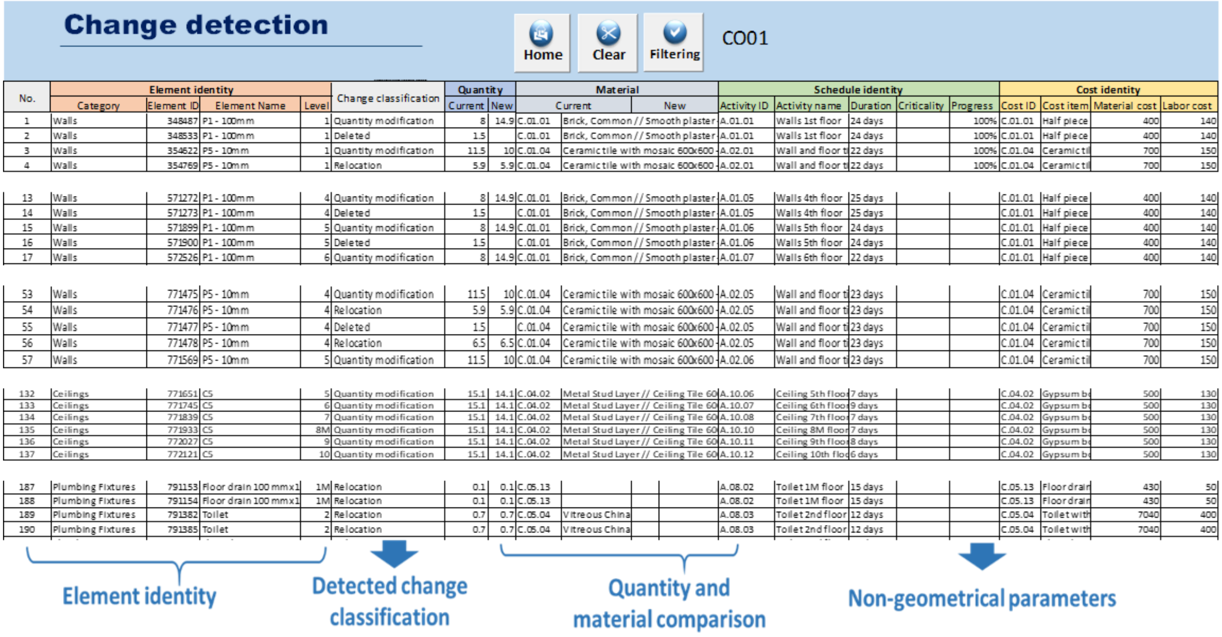
As required by the *updating sub-module*, the collected data were updated to reflect the latest condition of the construction work prior to issuance of this change instruction. The updating process was conducted in the three separate platforms (i.e., the BIM models in the BIM authoring program, schedule in the scheduling program, and cost in the spreadsheets). For example, the schedule must contain the overall progress of the project, which was approximately 14%. The construction project began on June 5, 2015, and the change order was issued on August 7, 2015. Within a month of the construction period, the contractor finished the wall works in the 1st, 1M, and 2nd floors; the tile works in the 1st and 1M floors; and the ceiling works in the 1st and 1M floors.

The *integrating sub-module* was applied by using the system application built in *Dynamo*. The latest schedule and cost information were stored into the BIM models to achieve the integrated data. As a result, every element in the BIM models contained not only geometrical but also non-geometrical parameters, which are the schedule and cost parameters. This integrated BIM model represents the *basic BIM model*, as depicted in Fig. 3(b).

Figure 3(b) portrays the initial design of the project before the change order issuance. The *implementing instruction sub-module* was executed by transforming the *basic BIM model* to the *modified BIM model*, as shown in Fig. 3(c). It should be noted that the shaft was enlarged and the sanitary wares such as toilet, floor drain, and toilet partition were relocated. The establishment of the *basic BIM model* and the *modified BIM model* marks the completion of Module 1.

Module 2 was then implemented by combining the *basic BIM model* with the *modified BIM model*, resulting in the *merged BIM model*, as depicted in Fig. 3(d). The *extracting* and *filtering sub-modules* were applied, and the result from the change detection analysis is shown in Fig. 4. The result was stored in a spreadsheet, which is complemented with the interacting analysis buttons. The analyst can, therefore, access *VBA* script to perform the analysis conveniently.

Figure 4 shows the list of the modified elements along with the geometrical and non-geometrical parameters, change classification, and comparison of material and quantity. The geometrical parameters help users understand the identity of the element. For example, the element ID can be used as a search key if the analyst would like to point out the element in the BIM models. The change classification helps the analyst to understand the condition of the element. The quantity and material comparison shows any alteration of quantity prior to and after the change order. For the material comparison, it shows the detail of any material changes. Lastly, the non-geometrical parameters show the relation of the building element and the schedule and cost information.



No.	Element identity				Change classification	Quantity		Material			Schedule identity					Cost identity			
	Category	Element ID	Element Name	Level		Current	New	Current		New	Activity ID	Activity name	Duration	Criticality	Progress	Cost ID	Cost item	Material cost	Labor cost
1	Walls	348487	P1 - 100mm	1	Quantity modification	8	14.9	C.01.01	Brick, Common // Smooth plaster		A.01.01	Walls 1st floor	24 days		100%	C.01.01	Half piece	400	140
2	Walls	348533	P1 - 100mm	1	Deleted	1.5		C.01.01	Brick, Common // Smooth plaster		A.01.01	Walls 1st floor	24 days		100%	C.01.01	Half piece	400	140
3	Walls	354622	P5 - 10mm	1	Quantity modification	11.5	10	C.01.04	Ceramic tile with mosaic 600x600		A.02.01	Wall and floor ti	22 days		100%	C.01.04	Ceramic til	700	150
4	Walls	354769	P5 - 10mm	1	Relocation	5.9	5.9	C.01.04	Ceramic tile with mosaic 600x600		A.02.01	Wall and floor ti	22 days		100%	C.01.04	Ceramic til	700	150
13	Walls	571272	P1 - 100mm	4	Quantity modification	8	14.9	C.01.01	Brick, Common // Smooth plaster		A.01.05	Walls 4th floor	25 days			C.01.01	Half piece	400	140
14	Walls	571273	P1 - 100mm	4	Deleted	1.5		C.01.01	Brick, Common // Smooth plaster		A.01.05	Walls 4th floor	25 days			C.01.01	Half piece	400	140
15	Walls	571899	P1 - 100mm	5	Quantity modification	8	14.9	C.01.01	Brick, Common // Smooth plaster		A.01.06	Walls 5th floor	24 days			C.01.01	Half piece	400	140
16	Walls	571900	P1 - 100mm	5	Deleted	1.5		C.01.01	Brick, Common // Smooth plaster		A.01.06	Walls 5th floor	24 days			C.01.01	Half piece	400	140
17	Walls	572526	P1 - 100mm	6	Quantity modification	8	14.9	C.01.01	Brick, Common // Smooth plaster		A.01.07	Walls 6th floor	22 days			C.01.01	Half piece	400	140
53	Walls	771475	P5 - 10mm	4	Quantity modification	11.5	10	C.01.04	Ceramic tile with mosaic 600x600		A.02.05	Wall and floor ti	23 days			C.01.04	Ceramic til	700	150
54	Walls	771476	P5 - 10mm	4	Relocation	5.9	5.9	C.01.04	Ceramic tile with mosaic 600x600		A.02.05	Wall and floor ti	23 days			C.01.04	Ceramic til	700	150
55	Walls	771477	P5 - 10mm	4	Deleted	1.5		C.01.04	Ceramic tile with mosaic 600x600		A.02.05	Wall and floor ti	23 days			C.01.04	Ceramic til	700	150
56	Walls	771478	P5 - 10mm	4	Relocation	6.5	6.5	C.01.04	Ceramic tile with mosaic 600x600		A.02.05	Wall and floor ti	23 days			C.01.04	Ceramic til	700	150
57	Walls	771569	P5 - 10mm	5	Quantity modification	11.5	10	C.01.04	Ceramic tile with mosaic 600x600		A.02.06	Wall and floor ti	23 days			C.01.04	Ceramic til	700	150
132	Ceilings	771651	CS	5	Quantity modification	15.1	14.1	C.04.02	Metal Stud Layer // Ceiling Tile 60		A.10.06	Ceiling 5th floor	7 days			C.04.02	Gypsum b	500	130
133	Ceilings	771745	CS	6	Quantity modification	15.1	14.1	C.04.02	Metal Stud Layer // Ceiling Tile 60		A.10.07	Ceiling 6th floor	9 days			C.04.02	Gypsum b	500	130
134	Ceilings	771839	CS	7	Quantity modification	15.1	14.1	C.04.02	Metal Stud Layer // Ceiling Tile 60		A.10.08	Ceiling 7th floor	7 days			C.04.02	Gypsum b	500	130
135	Ceilings	771933	CS	8M	Quantity modification	15.1	14.1	C.04.02	Metal Stud Layer // Ceiling Tile 60		A.10.10	Ceiling 8M floor	7 days			C.04.02	Gypsum b	500	130
136	Ceilings	772027	CS	9	Quantity modification	15.1	14.1	C.04.02	Metal Stud Layer // Ceiling Tile 60		A.10.11	Ceiling 9th floor	8 days			C.04.02	Gypsum b	500	130
137	Ceilings	772121	CS	10	Quantity modification	15.1	14.1	C.04.02	Metal Stud Layer // Ceiling Tile 60		A.10.12	Ceiling 10th floo	6 days			C.04.02	Gypsum b	500	130
187	Plumbing Fixtures	791153	Floor drain 100 mmx1	1M	Relocation	0.1	0.1	C.05.13			A.08.02	Toilet 1M floor	15 days			C.05.13	Floor drain	430	50
188	Plumbing Fixtures	791154	Floor drain 100 mmx1	1M	Relocation	0.1	0.1	C.05.13			A.08.02	Toilet 1M floor	15 days			C.05.13	Floor drain	430	50
189	Plumbing Fixtures	791382	Toilet	2	Relocation	0.7	0.7	C.05.04	Vitreous China		A.08.03	Toilet 2nd floor	12 days			C.05.04	Toilet with	7040	400
190	Plumbing Fixtures	791385	Toilet	2	Relocation	0.7	0.7	C.05.04	Vitreous China		A.08.03	Toilet 2nd floor	12 days			C.05.04	Toilet with	7040	400

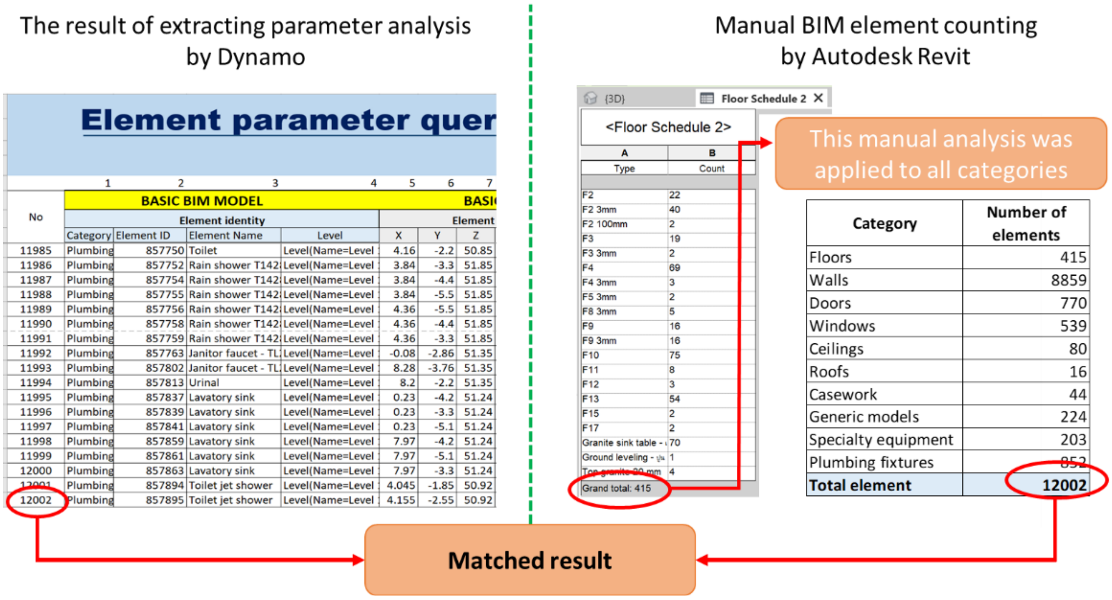
Fig. 4. Result from the change detection analysis by Module 2.

As can be seen, the first modified element is the wall of *P1–100mm* with the element ID of *348487* which is classified as "quantity modification." Due to the change order, this element must be enlarged from 8 m^2 to 14.9 m^2. It should also be noticed that this element has already been completed (i.e., the progress is 100%). This element belongs to *Walls 1st floor activity* and *Half piece brickwork cost item*. Based on this information, the analyst needs to perform additional calculations towards the building element that has been completed. Any equipment or plant movement can be postponed to avoid re-mobilization. Clearly, the BIM-ISICO also serves as a warning system for the contractor to mitigate any potential risks. Another virtue of the analysis result, especially as a reference for the subsequent analysis, will be elaborated in the following two modules.

The *extracting sub-module* is performed by a system application using *Dynamo*. Figure 5(a) shows the validation of this analysis. As can be seen, the analysis process using *Dynamo* can extract 12,002 elements, which match to the number of elements in the BIM model obtained from the manual checking performed on *Autodesk Revit*. It can be concluded that the system application can be used to analyze a large amount of data. It also shows that the system application supports the implementation of the BIM-ISICO and minimizes the redundant analysis.

Figure 5(b) illustrates the validation of the analysis result of the *filtering sub-module*. The analysis by the system application of the Module 2 was compared to the manual analysis using *Autodesk Revit*. For example, the result of the *filtering sub-module* identifies *P1-100mm wall* with element ID of *348533* located in *Level 1* as "deletion." Considering the same element ID, the manual search on the *basic BIM model* shows that the element exists, but the *modified BIM model* shows otherwise. Thus, the change detection analysis by the system shows the correct result.

The BIM-ISICO integrates a change order into the BIM environment. The virtual 3D BIM models provide better visualization of constructed facilities than the conventional 2D drawings. In addition, the 2D drawings cannot efficiently display the impact of a change order on the building conditions. The difficulties in retrieving the information from the conventional drawings can also lead to misinterpretation and inaccurate building condition assessment. A construction project is usually associated with a large number of building elements, the alteration of which can affect others. Even though introducing BIM to change order management can enhance visualization of modified buildings, without other supporting tools the impact assessment is still time-consuming and the result may be inaccurate. These problems have been explicitly addressed by Module 2, which comprises the systematic observational feature. It can identify and categorize every altered element in the building so the analyst obtains the detailed consequence of the change order impact on the building conditions. The analysis time is also reduced and the result is also more accurate.



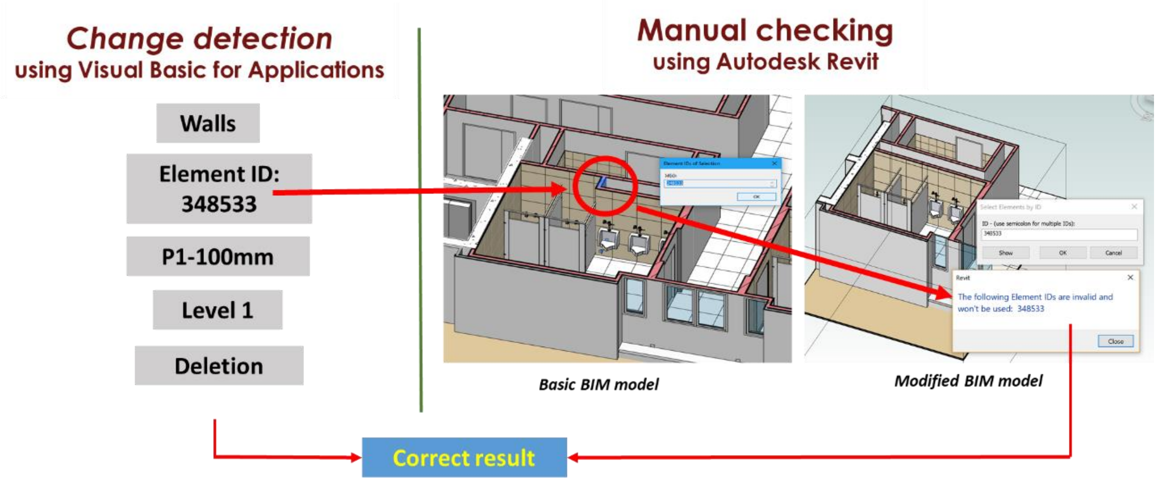
	1	2	3	4	5	6	7
No	BASIC BIM MODEL				BASI		
	Element identity				Element		
	Category	Element ID	Element Name	Level	X	Y	Z
11985	Plumbing	857750	Toilet	Level(Name=Level	4.16	-2.2	50.85
11986	Plumbing	857752	Rain shower T142	Level(Name=Level	3.84	-3.3	51.85
11987	Plumbing	857754	Rain shower T142	Level(Name=Level	3.84	-4.4	51.85
11988	Plumbing	857755	Rain shower T142	Level(Name=Level	3.84	-5.5	51.85
11989	Plumbing	857756	Rain shower T142	Level(Name=Level	4.36	-5.5	51.85
11990	Plumbing	857758	Rain shower T142	Level(Name=Level	4.36	-4.4	51.85
11991	Plumbing	857759	Rain shower T142	Level(Name=Level	4.36	-3.3	51.85
11992	Plumbing	857763	Janitor faucet - TL	Level(Name=Level	-0.08	-2.86	51.35
11993	Plumbing	857802	Janitor faucet - TL	Level(Name=Level	8.28	-3.76	51.35
11994	Plumbing	857813	Urinal	Level(Name=Level	8.2	-2.2	51.35
11995	Plumbing	857837	Lavatory sink	Level(Name=Level	0.23	-4.2	51.24
11996	Plumbing	857839	Lavatory sink	Level(Name=Level	0.23	-3.3	51.24
11997	Plumbing	857841	Lavatory sink	Level(Name=Level	0.23	-5.1	51.24
11998	Plumbing	857859	Lavatory sink	Level(Name=Level	7.97	-4.2	51.24
11999	Plumbing	857861	Lavatory sink	Level(Name=Level	7.97	-5.1	51.24
12000	Plumbing	857863	Lavatory sink	Level(Name=Level	7.97	-3.3	51.24
12001	Plumbing	857894	Toilet jet shower	Level(Name=Level	4.045	-1.85	50.92
12002	Plumbing	857895	Toilet jet shower	Level(Name=Level	4.155	-2.55	50.92

<Floor Schedule 2>

A	B
Type	Count
F2	22
F2 3mm	40
F2 100mm	2
F3	19
F3 3mm	2
F4	69
F4 3mm	3
F5 3mm	2
F8 3mm	5
F9	16
F9 3mm	16
F10	75
F11	8
F12	3
F13	54
F15	2
F17	2
Granite sink table -	70
Ground leveling -	1
Top granite 20 mm	4
Grand total: 415	

Category	Number of elements
Floors	415
Walls	8859
Doors	770
Windows	539
Ceilings	80
Roofs	16
Casework	44
Generic models	224
Specialty equipment	203
Plumbing fixtures	852
Total element	**12002**

(a) Validating the result of the *extracting sub-module*



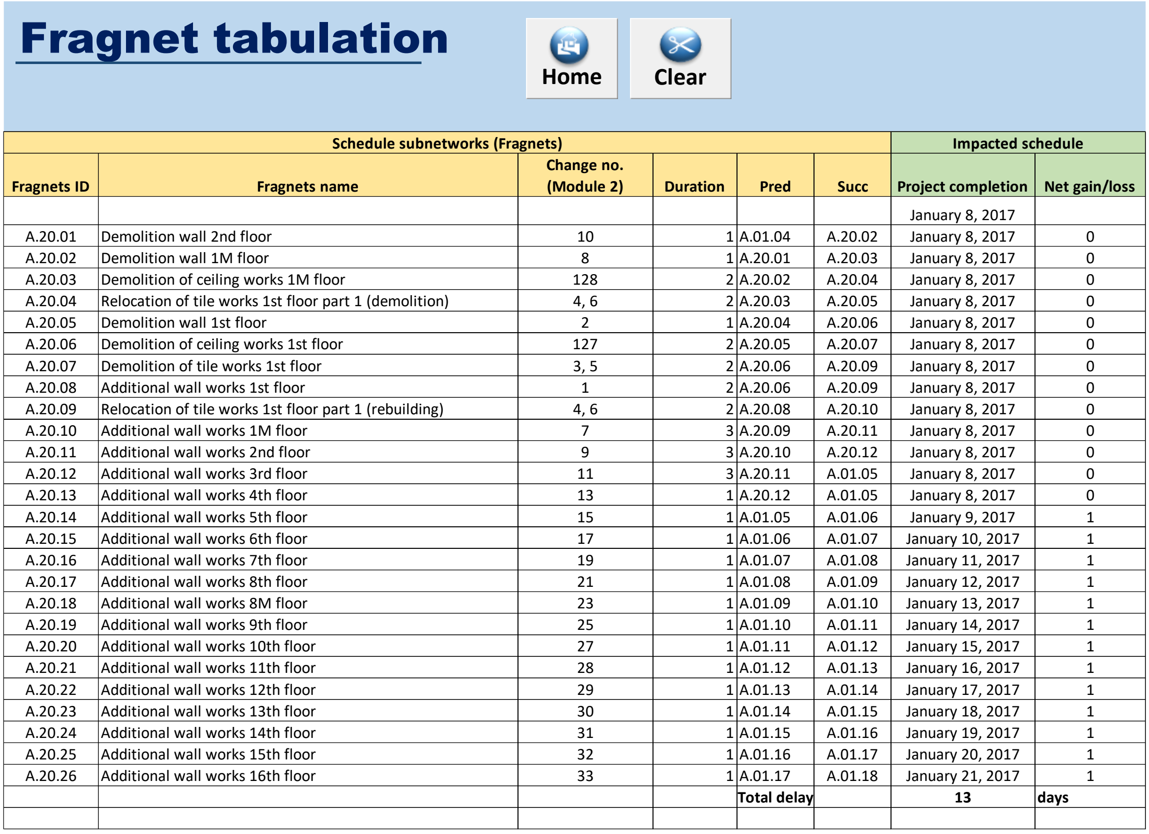
The following Element IDs are invalid and won't be used: 348533

(b) Validating the result of the *filtering sub-module*

Fig. 5. Validation of the analysis result from the change detection analysis by Module 2.

The analysis result of Module 2 was subsequently used in Module 3, *schedule impact analysis*, by first executing the *change modeling sub-module*. First, we interpreted each of the modified elements presented in Fig. 4. Transforming the modified elements into the fragnets involves the examination of the change classification, quantity, material, and schedule parameters. Figure 6 shows the analysis result of the *change modeling sub-module*.

For example, the 13th modified element in Fig. 4 is the *P1-100mm walls* with the element ID of *571272*. This element is located on the first floor and is categorized as "quantity modification" with the increasing quantity. Based on this information, it can be concluded that this modification encompasses additional works. Assume that the additional work (from 8 to 14.9 m^2) needs additional two work days. Consequently, the fragnet can be placed correctly to the activity that needs to be extended, which is the *wall 4th-floor activity*.



Schedule subnetworks (Fragnets)						Impacted schedule	
Fragnets ID	Fragnets name	Change no. (Module 2)	Duration	Pred	Succ	Project completion	Net gain/loss
						January 8, 2017	
A.20.01	Demolition wall 2nd floor	10	1	A.01.04	A.20.02	January 8, 2017	0
A.20.02	Demolition wall 1M floor	8	1	A.20.01	A.20.03	January 8, 2017	0
A.20.03	Demolition of ceiling works 1M floor	128	2	A.20.02	A.20.04	January 8, 2017	0
A.20.04	Relocation of tile works 1st floor part 1 (demolition)	4, 6	2	A.20.03	A.20.05	January 8, 2017	0
A.20.05	Demolition wall 1st floor	2	1	A.20.04	A.20.06	January 8, 2017	0
A.20.06	Demolition of ceiling works 1st floor	127	2	A.20.05	A.20.07	January 8, 2017	0
A.20.07	Demolition of tile works 1st floor	3, 5	2	A.20.06	A.20.09	January 8, 2017	0
A.20.08	Additional wall works 1st floor	1	2	A.20.06	A.20.09	January 8, 2017	0
A.20.09	Relocation of tile works 1st floor part 1 (rebuilding)	4, 6	2	A.20.08	A.20.10	January 8, 2017	0
A.20.10	Additional wall works 1M floor	7	3	A.20.09	A.20.11	January 8, 2017	0
A.20.11	Additional wall works 2nd floor	9	3	A.20.10	A.20.12	January 8, 2017	0
A.20.12	Additional wall works 3rd floor	11	3	A.20.11	A.01.05	January 8, 2017	0
A.20.13	Additional wall works 4th floor	13	1	A.20.12	A.01.05	January 8, 2017	0
A.20.14	Additional wall works 5th floor	15	1	A.01.05	A.01.06	January 9, 2017	1
A.20.15	Additional wall works 6th floor	17	1	A.01.06	A.01.07	January 10, 2017	1
A.20.16	Additional wall works 7th floor	19	1	A.01.07	A.01.08	January 11, 2017	1
A.20.17	Additional wall works 8th floor	21	1	A.01.08	A.01.09	January 12, 2017	1
A.20.18	Additional wall works 8M floor	23	1	A.01.09	A.01.10	January 13, 2017	1
A.20.19	Additional wall works 9th floor	25	1	A.01.10	A.01.11	January 14, 2017	1
A.20.20	Additional wall works 10th floor	27	1	A.01.11	A.01.12	January 15, 2017	1
A.20.21	Additional wall works 11th floor	28	1	A.01.12	A.01.13	January 16, 2017	1
A.20.22	Additional wall works 12th floor	29	1	A.01.13	A.01.14	January 17, 2017	1
A.20.23	Additional wall works 13th floor	30	1	A.01.14	A.01.15	January 18, 2017	1
A.20.24	Additional wall works 14th floor	31	1	A.01.15	A.01.16	January 19, 2017	1
A.20.25	Additional wall works 15th floor	32	1	A.01.16	A.01.17	January 20, 2017	1
A.20.26	Additional wall works 16th floor	33	1	A.01.17	A.01.18	January 21, 2017	1
				Total delay		13	days

Fig. 6. Modeling and recording the inserted fragnets.

The fragnet tabulation displayed in Fig. 6 shows the additional activities the contractor may have to perform to execute the change order work. The BIM-ISICO requires that the fragnets are equipped with the identity of the modified elements, so it creates a clear auditing trail. For example, the *additional wall works 4th floor* fragnet (fragnet ID is *A.20.13)* is associated with *change number 13*. By examining the result of Module 2 (Fig. 4), it is known that *change number 13* refers to the *P1-100mm walls* element, which is classified as "quantity modification" with the progress of 100%. It indicates that the *additional wall works 4th floor activity* is performed to facilitate the deletion of the element. This clear auditing system and a systematic analysis are a virtue of the BIM-ISICO.

The fragnet development based on the information of Module 2 demonstrates the direct link between building condition assessment and the delay analysis. Comparing to the conventional change order practice, the development of the fragnets fully depends on the analyst's interpretation towards the building conditions. The analyst must imagine the building condition or examine the 2D drawing with minimal information. Thus, the fragnet development heavily relies on the analyst's subjective judgment on additional works. This might cause disputes among the project stakeholders on the impacts of change orders. The BIM-ISICO supports and exploit their tacit knowledge by providing them with substantive information. The modified element provided by Module 2 is equipped by not only the type of change but also schedule information. The decision-making process concerning additional activities can be performed rigorously. In addition, the fragnet, which is recorded with the corresponding modified element, creates an auditing trail system, as shown in Fig. 6. The conventional practice does not possess this tracking system because the additional activities are derived from the analyst's assumptions. This system feature can certainly support every additional work that is claimed by the contractor during their negotiation with the project owner.

By executing the *prospective delay analysis sub-module*, the TIA method was performed by inserting the developed fragnets into the *basic schedule* to obtain the *impacted schedule*. Figure 7 summarizes the TIA analysis results using *Microsoft Project*. It also displays the comparison between the *basic schedule* and the *impacted schedule*. As can be seen, the project completion date is shifted to January 21, 2017 (13 days). In addition, the system also examines the change of critical activities due to the change order. It is found that the entire wall works from the 3rd floor to the 16th floor become critical. In contrast, the curtain wall works are no longer critical. As a result, the contractor needs to focus on these new critical activities.

Module 4, *cost impact analysis,* was then used to evaluate the cost impact of the change order. The analysis result from Module 2 (Fig. 4) was further analyzed in this step. Figure 8 shows the example results from the *direct cost sub-module*. As can be seen, the quantity of *half piece brickwork item* increases to 103 m^2. The increasing number of *half piece brickwork item* stems from the addition of the new part of the wall, namely, *P1-100mm* with the cost ID of *C.01.01*. The element is categorized as the *"quantity modification"* type, for which the quantity of work increases from 8 to 14.9 m^2 in each floor.

Given the unit price of the work, the total direct cost for the modified work can be calculated. This cost is 13,380 Thai Baht (THB) lower than that of the basic works due to the reduction of the ceramic tile walls, ceramic tile floors, and ceiling works.

Figure 9 shows the result of the *extra cost sub-module*. As can be seen, the contractor needs to demolish 4.5 m^2 of wall works, 3 m^2 of wall tiles, and 2 m^2 of ceiling works. This demolition work is determined from the elements that are classified as "deletion" or "quantity modification" (with the reduced quantity) with 100% progress (completed works). Their unit prices, which are assigned by the users, refer to the labor cost and the cleaning cost. For the relocation work, 12.4 m^2 of wall tiles encompasses the need of demolishing the walls and building the same wall specification and quantity at a new location. Thus, the relocation cost must be presumed based on the demolition works and the direct cost for constructing the same element. As shown in Fig. 9, the grand total of the extra cost is 34,300 THB.

The analysis of the *delay cost sub-module* is directly connected to the result of Module 3 (Fig. 7). This sub-module facilitates the condition in which the contractor is allowed to claim the prolonged duration due to a change order. As previously discussed, the delay analysis yields 13 days potential delay, the contractor will need approximately 70,006 THB to cover their overhead cost, as displayed in Fig. 9.

The BIM-ISICO is programmed to perform automated quantity take-off and cost estimating. It can automatically calculate construction work quantities and costs that are more accurate than those from the traditional approach, which are based on manual calculations and 2D drawings. In addition, the BIM-ISICO also supports dynamic updating of project costs so it can be used for cost monitoring throughout the project life cycle.

For the last module, the *reporting module*, the BIM-ISICO introduces an extended analysis report using color-coded visualization. This module improves the current BIM visualization by coloring each element based on its type of change. Figure 10 displays the modified elements, which are detected by Module 2. Different colors represent different types of change. For example, the yellow color is assigned for the ceramic tiles, toilet, and toilet partition, which must be relocated. Since the change order is instructed for all bathrooms, the color-coded result (i.e., yellow and green) is shown in an entire building section.

Another color-coded visualization is used to elaborate the alteration of the critical path due to a change order, as shown in Fig. 11. As can be seen, the building elements on the critical path prior to issuing the change order is highlighted in the red color. Per this state, the contractor must focus on the curtain wall and façade works, which are the critical activities. Once the change order was issued, the wall works from the 3rd to 16th floors became the critical activities. Yet, the façade works still remained critical.

Even though the typical BIM visualization can illustrate building conditions in the 3D form, the BIM-ISICO enhances the efficacy by integrating a color-coded system into visualization. This allows us to pinpoint important analysis results such as the modified elements or the critical elements, which are vital information for project monitoring and control.

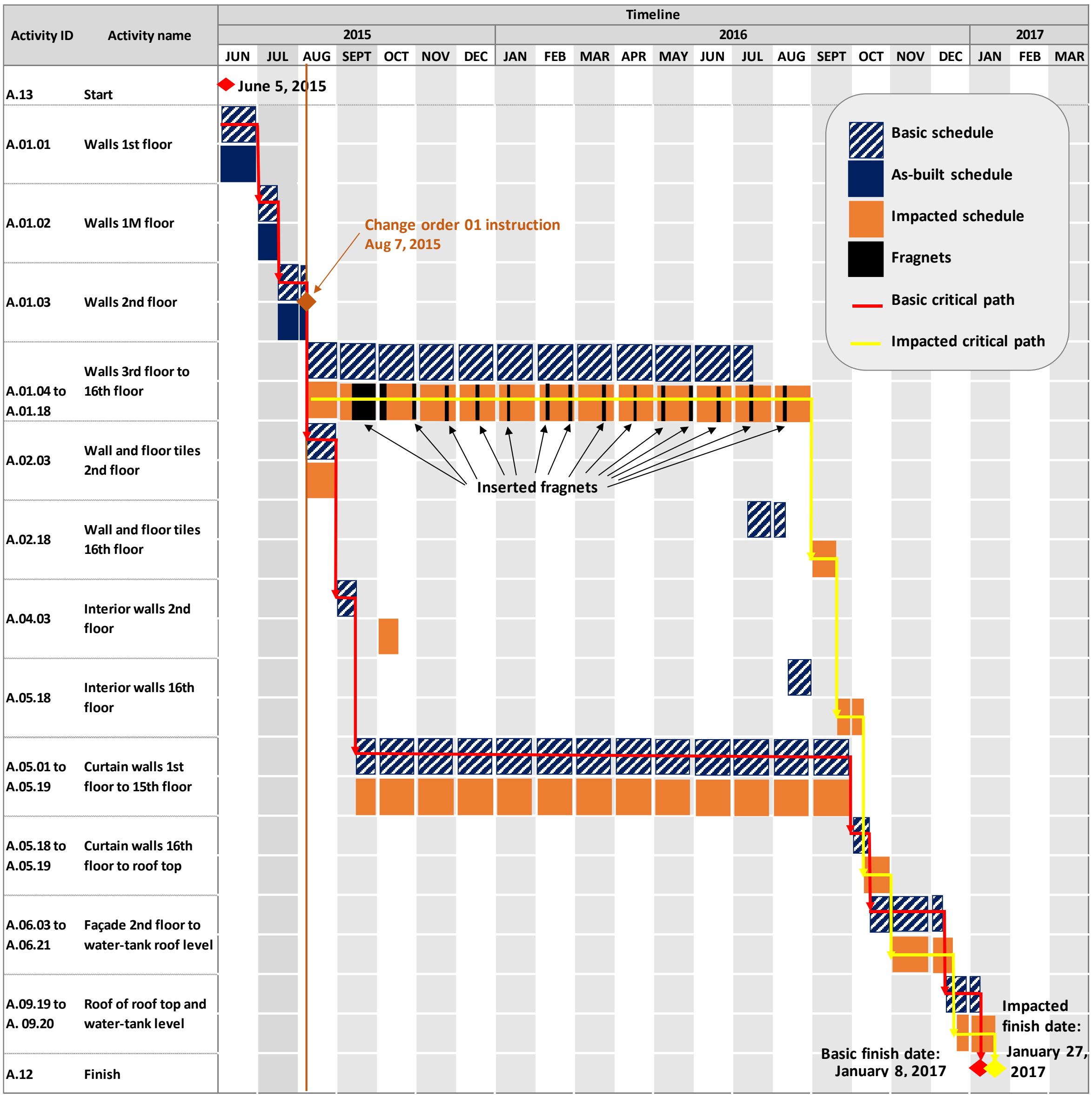
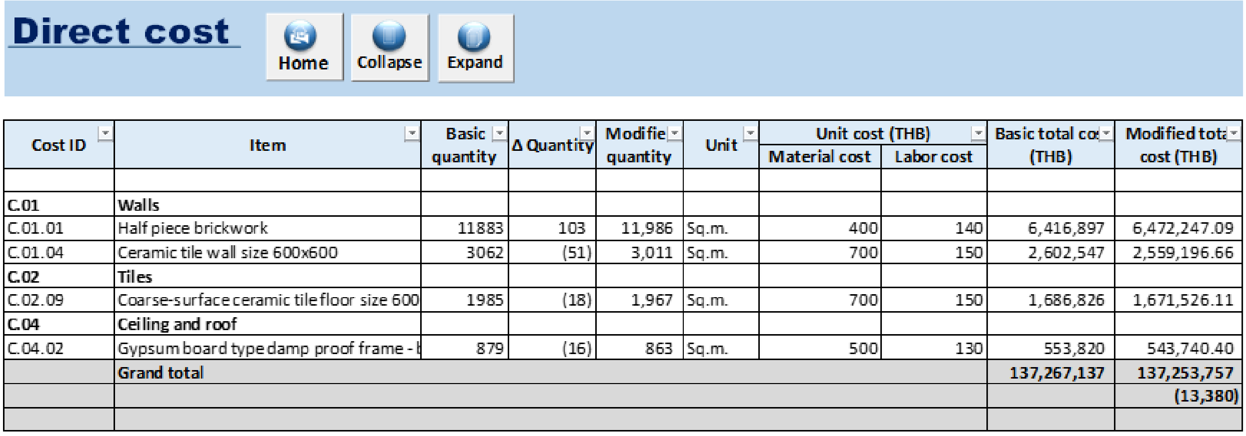
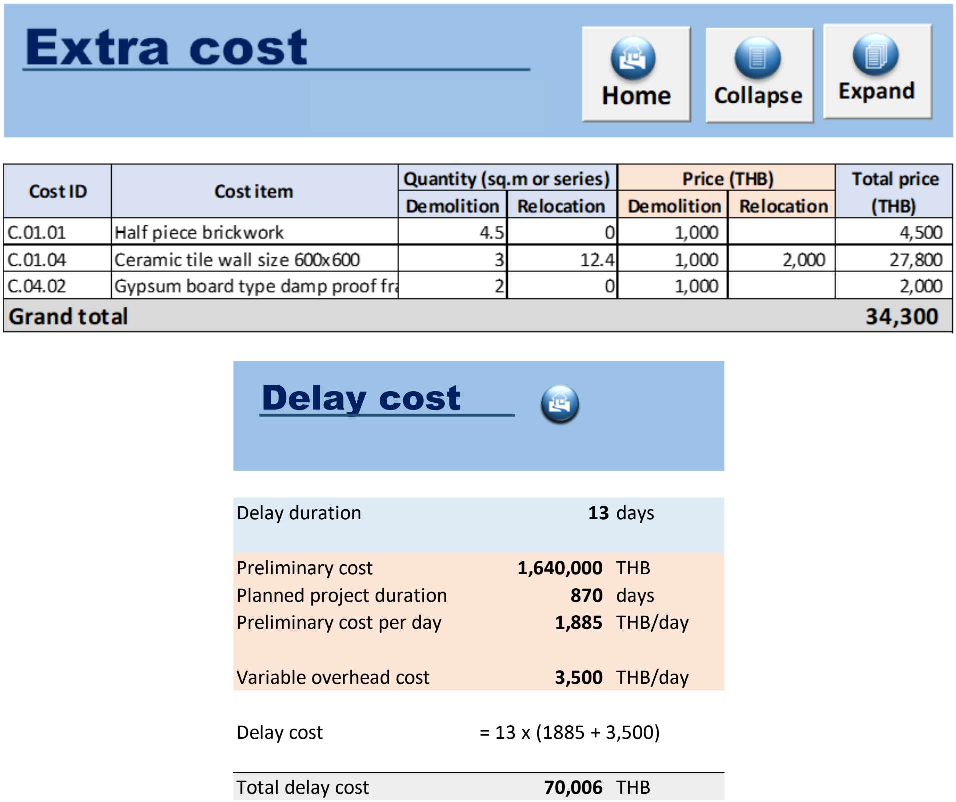


Fig. 7. Fragnet insertion and critical path assessment.



Cost ID	Item	Basic quantity	Δ Quantity	Modifie quantity	Unit	Unit cost (THB)		Basic total co (THB)	Modified tota cost (THB)
						Material cost	Labor cost		
C.01	**Walls**								
C.01.01	Half piece brickwork	11883	103	11,986	Sq.m.	400	140	6,416,897	6,472,247.09
C.01.04	Ceramic tile wall size 600x600	3062	(51)	3,011	Sq.m.	700	150	2,602,547	2,559,196.66
C.02	**Tiles**								
C.02.09	Coarse-surface ceramic tile floor size 600	1985	(18)	1,967	Sq.m.	700	150	1,686,826	1,671,526.11
C.04	**Ceiling and roof**								
C.04.02	Gypsum board type damp proof frame -	879	(16)	863	Sq.m.	500	130	553,820	543,740.40
	Grand total							**137,267,137**	**137,253,757**
									(13,380)

Fig. 8. Analysis result of the direct cost sub-module.



Extra cost

Cost ID	Cost item	Quantity (sq.m or series)		Price (THB)		Total price (THB)
		Demolition	Relocation	Demolition	Relocation	
C.01.01	Half piece brickwork	4.5	0	1,000		4,500
C.01.04	Ceramic tile wall size 600x600	3	12.4	1,000	2,000	27,800
C.04.02	Gypsum board type damp proof fr	2	0	1,000		2,000
Grand total						**34,300**

Delay cost

Delay duration	**13**	days
Preliminary cost	**1,640,000**	THB
Planned project duration	**870**	days
Preliminary cost per day	**1,885**	THB/day
Variable overhead cost	**3,500**	THB/day
Delay cost	= 13 x (1885 + 3,500)	
Total delay cost	**70,006**	THB

Fig. 9. Analysis result of the extra cost and delay cost sub-modules.

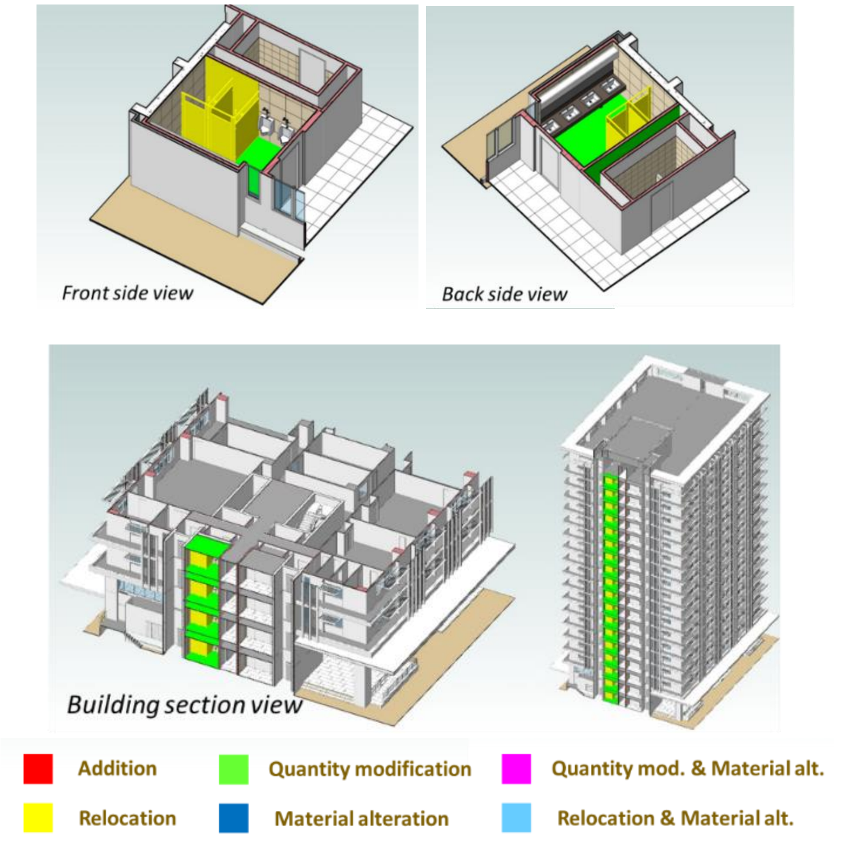
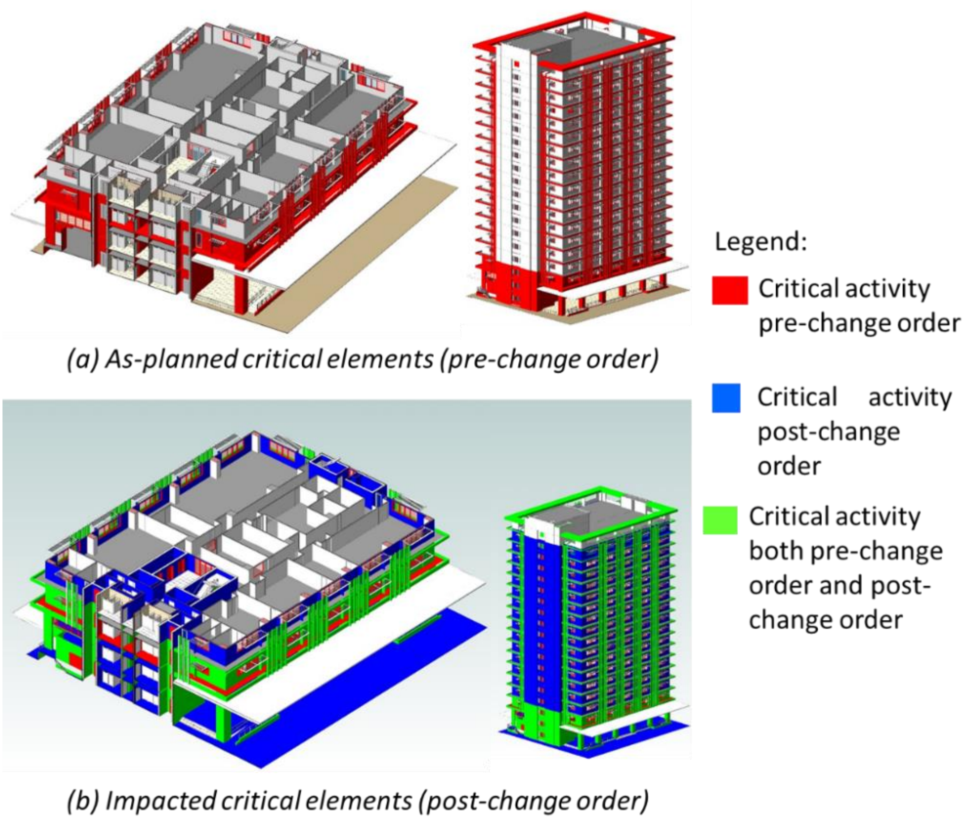


Fig. 10. Color-coded visualization for different types of change.



(a) As-planned critical elements (pre-change order)

(b) Impacted critical elements (post-change order)

Fig. 11. Color-coded visualization for critical construction activities.

5.3. System Evaluation by the Experts

The performance of the BIM-ISICO is not only illustrated through its application to an actual building project, but it was also evaluated by a group of experts. Herein, we invited six experts who have extensive experience in construction change order management and BIM to participate in this research. Table 2 shows their profile. The BIM-ISICO structure, components, and its application to the case study were presented to them in detail. We then conducted in-depth interviews with them for obtaining their feedback on the system's performance and their opinion for improving this system.

Table 2 Profile of the six experts.

No.	Field of expertise	Experience	Highest Education
1	Construction claim consultant	20 years	Ph.D.
2	BIM consultant	12 years	Ph.D.
3	BIM manager of a construction company	12 years	Bachelor Degree
4	BIM manager of a construction company	10 years	Bachelor Degree
5	BIM manager a real estate development company	8 years	Master's Degree
6	Lecturer/Building owner and designer	30 years	Master's Degree

All the experts agreed that Module 2 introduces a new concept of the design review in BIM environment, which they previously used for clash detection only. They also emphasized that change is inevitable in construction projects and it adversely affects the productivity of construction works. Thus, it is necessary to develop an automated tool that can evaluate the impact of change orders.

According to the claim consultant (expert 1), integrating the Time Impact Analysis (TIA) in this system complies with the real practice. The TIA method is considered a reliable method, which facilitates the dynamic change of the activity logic and critical path. The substantive information provided by the BIM-ISICO certainly benefits the evaluation of change impacts and the claim process.

The experts valued the demolition and relocation costs determined by this system. They agreed that introducing the project progress information and the change category into the analysis makes the estimated costs more realistically. In practice, they accepted that contractors might fail to include them. The proposed system, therefore, can significantly contribute to the time and cost impact analysis for change orders.

Lastly, all the experts agreed that the color-coded visualization, which highlights the critical activities in the 3D model, can be used to improve the current practice, which typically relies on simple bar charts. The experts also commented that this new communicative tool can help every party understand the impact of change orders better.

5.4. Barrier and Challenge

Module 1 (data acquisition), which defines the system requirements, integrates necessary information from the BIM models and the schedule and cost information. This process can be a major challenge for users if their projects are not on 4D or 5D BIM platforms. The users may have to manually assign each building element to its corresponding activity and cost items, which will be extremely time-consuming and erroneous.

Module 2 (change detection) is based on the concept of systematic observation, which can address several shortcomings of the traditional change order practice such as inaccurate data, misinterpretation by parties, and lengthy analysis time. As discussed previously, the BIM-ISICO can automatically detect the consequence of modification and can quickly and accurately determine its impacts on the overall project. Since a modern construction project is usually associated with complex and a large amount of data, the system applications need to be supported by powerful computer hardware and software, which might be costly.

Module 3 (schedule impact analysis) improves the existing delay analysis by providing auditing trails and relying on minimum subjectivity. In the case study presented previously, there are about 300 modified elements. The analyst needs to filter them in accordance with the defined change categories. The proposed system can, therefore, be improved by introducing a methodology that can automatically interpret and categorize the modified elements.

5.5. Research Highlight

The BIM-ISICO is based on the integrated information by which the BIM elements are connected to the schedule or cost information. The system enhances the efficacy of the change order impact evaluation by introducing the concept of systematic observation for assessing the physical conditions of a building. Delay and cost impact analysis is characterized by an auditing trail system and minimum subjectivity, a cost recording system, and color-coded visualization.

The BIM-ISICO tracks the modification of the building elements as a result of a change order. Even though BIM is a promising concept to visualize the building conditions [17], the manual assessment of the building modification can be time-consuming and inaccurate. This automatic change detection is achieved by executing the system applications using *Dynamo* and *VBA*. The analysis result can be served an early warning for project control and inputs for the subsequent analysis (i.e., cost and schedule impact analysis). For an early warning, the BIM-ISICO can inform if a certain element needs to be relocated or altered. It reminds the contractor to take a prompt action to avoid any potential losses and reworks. In addition, the information of quantity modification combined with the schedule information can be transformed into the sub-network activities to model the disruption due to the change order. For the impact cost evaluation, the cost parameters help the contractor to recalculate the quantity and other expenses such as demolition or relocation costs.

The BIM-ISICO also introduces a new paradigm in which the development of fragnet should be based on the changed element. In practice, the development of fragnet is quite based on the analyst's judgment. The BIM-ISICO provides substantive information that can be combined with the analyst's tacit knowledge to adjust the project schedule. With this integrated information, the subjectivity can be minimized. In addition, the requirement to tabulate the fragnet makes the delay analysis method transparent. It connects the developed fragnet and the modified element providing the auditing trail so the claim report can be easily audited.

The similar concept is applied to cost evaluation. The integration of building condition assessment and cost evaluation leads to a comprehensive cost quantification. The proposed system automates quantity take-off for not only the variation of material and labor cost but also the extra cost such as relocation and demolition costs. The dynamic changing of construction costs can be recorded throughout the project life-cycle.

Lastly, the BIM-ISICO improves the current BIM visualization by proposing a color-coded visualization, which highlights the building element according to the pre-defined criteria. The implementation of color-coded visualization is impossible without an automated tool [32]. Thus, the BIM-ISICO is equipped with the system applications to address this problem. The visualization helps the project stakeholders focus on the modified element and the critical element. In addition, it also can be an early warning for the project stakeholders to treat the critical element carefully.

6. Conclusion

In this paper, the BIM-ISICO is developed and implemented in an actual construction project to quantify the impacts of a change order. The impact assessment focuses on three aspects: physical conditions of the building, time, and cost. The BIM-ISICO is elaborated by the system architecture, which converts the proposed methodology to the sub-system (module) level and provides the interrelations among the selected platforms. The system consists of five main models: (1) data acquisition, (2) change detection, (3) schedule impact analysis, (4) cost impact analysis, and (5) reporting. A number of system applications are introduced to equip the system for dealing with complex and complicated data. Lastly, the efficacy and practicality of the BIM-ISICO are verified through a project case study and confirmed by a group of experts.

The BIM-ISICO contributes to a new approach to observe the altered building conditions caused by a change order. This systematic observation tool is extended to an early warning for project control and a reference for the subsequent analysis (schedule and cost evaluation). It also introduces a new paradigm of delay analysis with minimal subjectivity and transparent analysis. The proposed system also improves the automated quantity take-off into project cost recording for not only the additional direct cost but also demolition and relocation costs. The BIM-ISICO enhances the narrative evaluation report of change orders with the color-coded visualization which provides a clear description of the analysis results.

This research can significantly benefit the current practice of construction change management. The comprehensive evaluation of the three main aspects of change impact using BIM technologies opens the opportunity to further investigate other aspects such as productivity and safety. In addition, this research also contributes to expanding the area of BIM implementation. The integration of BIM and change order management is just a beginning point for innovating BIM as a modern tool in addressing other challenges in construction project management.

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