

Fast Tracking Construction Process in a Mega Project Using Aerial Data Capturing and Building Information Modeling

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Nowadays, potential applicability and benefit of BIM in construction cannot be ignored undoubtedly. The complex nature of mega projects, and the requirement for integration of construction information in such projects, has encouraged many organizations to implement BIM processes and use fast methods of critical construction report generating. However, limitations in sharing and visualizing the latest construction progress information in a proper time because of enlargement of the project and information delay, make appropriate application of BIM in massive projects difficult. In this study, a process for fast-tracking construction of steel structure in a real mega project is developed. A drone is utilized to gather installation and implementation data. Also, a comprehensive database is developed to integrate those data and the 3d model of the project. The model is capable of providing information for project controlling such as project progress (both in numerical and visual mode) and quantity take-off in an acceptable time. Furthermore, the process is able to speed up construction information collecting and analyzing while it maintains the degree of information accuracy in such projects in a reasonable area.

Key Words: Building Information Modeling; Aerial Data Capturing; Automation; Project Control; Integration

Introduction

Precisely predicting key construction performance indicators of construction projects such as schedule and cost, has been more challenging than before due to the increasing complexity of such projects (Ham et al., 2016). New construction technologies (i.e., prefabrication out of the job site and fast installation of the produced construction parts) cause the projects to be constructed with significantly higher speed. In addition, sudden changes in project design during the construction phase is another challenging problem in the construction industry. Therefore, the success of such projects depends on superior controlling and better managing. Visual assessment of each construction components in the 3d model along with its controlling information (e.g., time and quality) can provide a true understanding of the project progress to the clients and managers and reduce multi-days analyzes to multi-minutes analyzes (Nawari, 2010). Four-dimensional (4D) building information modeling (BIM) is a powerful tool for visualizing and communicating construction plans and milestones (Computer Integrated Construction Research Group 2010). It is defined as 3D BIM plus time. Some usage of 4D BIM during the construction phase are construction planning, constructability analysis, and communications and collaborations with the clients and among project stakeholders (Mahalingam et al., 2010). Furthermore, 4D BIM is utilized for supporting daily construction operation (Chau et al., 2004). Taking into account that several projects are large scale and fast track, therefore it can be suitable to apply an integrated BIM model that is able to share numerical and visual information of every aspect of such projects in the shortest possible time to departments of the project. Moreover, this integrated BIM model may help project stakeholders to make wise decisions as soon as possible.

Transferring building codes into a format acquiescent for machine interpretation and application is one of the long historical interest concepts of studies (Nawari, 2011). In 1966, Fenves detected that decision tables could be utilized for representing design standard provision in a comprehensive form. The concept of Fenves study was used in AISC Specification (AISC, 1969) presented as a set of interrelated decision tables. Lopez et al. (Lopez & Elam, 1984; Lopez & Wright, 1985; Elam & Lopez, 1988; Lopez et al., 1989) used a software prototype which is capable of demonstrating the checking of designed components to conformance with design standards. This software prototype is labeled SICAD (Standards Interface for Computer Aided Design). In 1995, Singapore Building Officials started to consider code checking on 2D drawings. In the next phase, it changed with the CORENET system which is working with IFC (Industry Foundation Classes) building models in 1988 (Khemlani, 2005).

Application of 4D BIM modeling in construction planning was reviewed by Heesom and Mahdjoubi in 2004. They recognized that using 4D BIM has several inherent advantages and disadvantages. As a benefit, in addition to visualizing project information, 4D BIM models facilitate communicating and sharing information to clients and consultants. However, implementation of such models, the amount of data inputting by the user (depending on the details of the 3D model) will dramatically increase which results in more manpower utilization. Similar to the previous study, Mourgues et al. (2007) conducted a daily-basis test on a multi-purpose building to evaluate the influence of 3-dimensional and 4-dimensional model in the project area. In order to analyze the application of 4D technology in supply chain management, Porkka et al. (2010) implemented their study on a residential building in Finland. An application (4D-Live-Linker) was used to make the connection between the 3D model and supply chain planning. Then the output information converted to animation file and differences between the cost of two supply chain options (construction on job site and construction in the factory) were examined. In 2010, Sacks et al. presented the flow and information of construction process using an integrated system. They used BIM-based information to provide project managers, supervisors, and other project member's access to project statistics at any time. Also, they examined the benefits of the integrated system by means of several case studies in the U.K. and Finland.

Database information can be stored in the BIM server or web hosting environment and can be provided to stakeholders with relevant access (Ramanthan & Sarker, 1988). A few researchers (e.g., Chen et al., 2016; Fassi et al., 2015) have come into the visualization of the BIM model in a web hosting environment. Chen et al. (2016) introduced a cloud-based system framework that allows viewing and analyzing massive BIM models. Most of the earlier studies have only focused on displaying the massive BIM models and facilitating the execution of the model regardless of the type and efficiency of databases, the quality of information, and the methodology for the creation of the database.

In case of integration of project control and BIM models, a few types of research have been done in the literature. Golparvar-Fard et al. (2009) used a 3D BIM model for monitoring progress. They developed a system that can automatically update the 3D model while monitoring progress. In 2004, Kang and Miranda planned the path of equipment for coordinating the motions of machinery equipment like cranes in the construction site. Also, Chin et al. (2008) integrated BIM and real-time systems for supply chain management. Although there are studies in this area, the integration of project progress (actual metrics and progress percentage) and BIM remain very low to date.

Despite the research done in the mentioned concepts, there are rarely studies that discuss an integrated BIM model which has simultaneously the visual and numerical information of complex and mega projects. Therefore, this paper develops an integrated BIM model which is capable of presenting construction information in the form of a management dashboard and visual files using analyzing and automatic coding of a mega project 3D model.

Research Objective

The objective of this paper is to present an appropriate mechanism for obtaining and organizing construction information in a three-dimensional model of a real large-scale project, so that it can be used to provide some important project information (such as work progress, planned and actual execution volumes, visualization of actual status of the project at different time, and etc.) in an integrated system. The model of this article is capable of categorizing different construction elements (beams, columns, slab, and other elements) with by assigning a unique code (developed with programming) to each element. Also, it can integrate construction information, bill of quantity, and visualization of project progress, concurrently. This mechanism can answer the following questions:

1. How can the information of construction progress in large-scale projects be automatically integrated into the 3D models?
2. How to incorporate the bill of quantity and project progress information as a dashboard alongside the visualized project status at desired intervals?

The implementation process of the models runs in four phases. (1) Construction information (parts installation and execution time) is obtained using aerial data capturing by a drone. (2) All the necessary information for each part are automatically extracted from the 3d model. The acquired information along with quantity information is stored in a database. Automatic encoding of the model parts is then executed at the final step of this phase. (3) The obtained information of parts installation and execution are transferred to the 3D model through the database. (4) All the transferred information is integrated and is produced as a dashboard and visual information. All the mentioned phases are described in the next section.

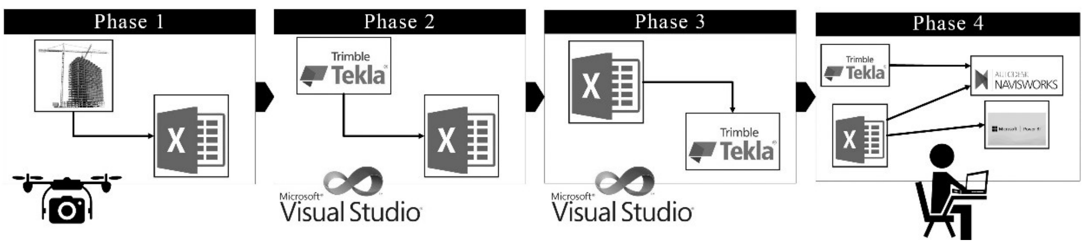

Figure 1: The process of the proposed mechanism

Research Methodology

In this paper, with the purpose of integrating the construction information and providing the mentioned outputs of the last section, a 4-Phased process that is shown in Fig. 1 needed to be implemented. According to Fig. 1, daily construction data gathering should be done in the first phase. A drone is utilized to take pictures of the whole project and then the constructed or installed elements information is entered into a database which is an excel file. In the second phase, properties of each component transferred to the database from the 3D model of the project created in Tekla software. This process is done through programming in VB.net language in the Visual Studio software environment. The execution information that was added to the excel database in the first phase, is transferred to the 3D model in the third phase. Similar to the second phase, the process in the third phase process is prepared by VB.net language in the Visual Studio software environment. In the last step of the proposed mechanism, the project information dashboard is generated using PowerBI software and the project visual information (4D Model) is created by Navisworks software. As can be seen in Fig. 1, both the PowerBI and Navisworks outputs need the proposed database shaped in phase two. In the following sections, all of the four steps are described in details.

Phase one: aerial data capturing

Over the past few years, unmanned aerial vehicle (UAVs) equipped with a camera has found a special place in the visual monitoring of construction and operation of the project (ENR, 2015). One of these vehicles (also known as a drone) purpose is to collect images or videos from the essential views on project job site (Ham, et al., 2016). In this study, a drone (DJI Phantom 2 GoPro) is used to take pictures of large-scale project site daily. The images are manually analyzed and the project progress is stored in an Excel file as a database. The date of execution of each element is obtained and transferred to the database.

Phase two: automatic coding and database creating

Smart coding extensively improves the ability to check information in the 3D model by facilitating access to the components of the model. Increase in the number and variety of elements in the 3D Model causes the manual coding to be accompanied by inaccuracy. Therefore, providing a dynamic and automatic coding of the 3D model has many advantages over manual coding. Coding elements based on design parameters enables clients and contractors to utilize essential information for their needs. Also, the uniqueness of the code for each element plays a key role in managing information as it facilitates accessing and analyzing the model in details. In fact, unique coding of elements not only offers common literature among engineers for the identification of parts but also can provide data exchange from information tables (database) to a 3D model. In this way, the ability to filter and categorize the 3D model arbitrary makes the different departments to use higher quality data and provide more accurate analyses of the project status and progress. Moreover, using automatic coding can be used to detect the mistakes and inaccuracies of the large data sets that cannot be manually monitored easily by comparing the filtered 3D model.

Fig. 2 presents the flowchart of the coding process and transferring the information to the database. The process implementation is such that the 3D model is provided in Tekla software and the main template of the database is created in Excel software. Using Application Programming Interface (API), all 3D model elements properties are read from the software in the next step. For instance, floor level of each element is calculated from the height of the element, zone (location) is computed by its coordinates, and so on, other characteristics of the elements such as the type of execution, type of the element and other properties are attained. After obtaining element information, the code related to each element is calculated using Eq. 1 and is placed inside the 3D model. Eventually, all of such information is located in a row of Excel file to form the database.

[1]. $Element\ Code = "Zone - Level - Execution\ method - Type\ of\ element - Counter$

For example, a thin concrete layer on top of the Hollow core slab in the level “P01” which is executed in-place and in the area of “Zone B” in the project, is coded according to the reading sequence of the elements in the software: “ZB-P01-In_Situ-Topping_Slab-7151144”

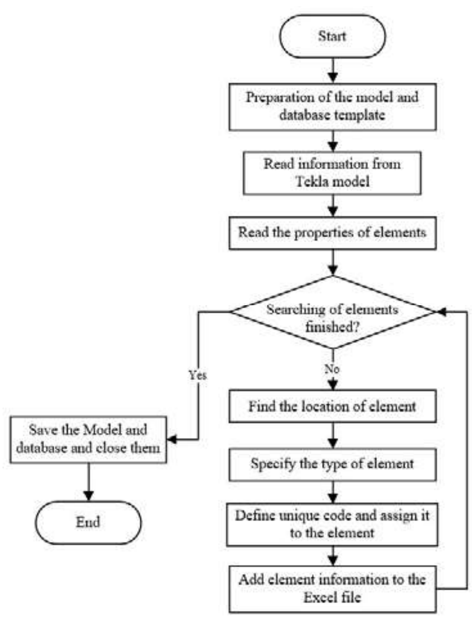

Figure 2: Flowchart of coding and transferring data to the database

Phase three: automatic transferring of construction information to the project 3D model

Smart coding can be too individually while it is not desirable to achieve a common language among engineers (Nawari, 2010). Precise standards can make coding more detailed and rigorous. In this phase daily construction information transfer to the database and 3D model. The sequence of this process according to Fig. 3 is that the code of each element is called from the 3D model. Then, this code is searched in the Excel database and construction information of the related element is read from the database. Given that the corresponding Numerical values of the dates are not the same in the Excel and Tekla calendars, the Numerical value of dates in Tekla software is obtained from the Eq. 2. This difference is due to the fact that a day in Tekla software expressed in seconds while in excel is expressed in days. Consequently, all information in the database is also stored in the 3D model.

[2]. $value\ of\ date\ in\ Tekla = ((value\ of\ date\ in\ Excel - 25595) \times 864000) + 22338$

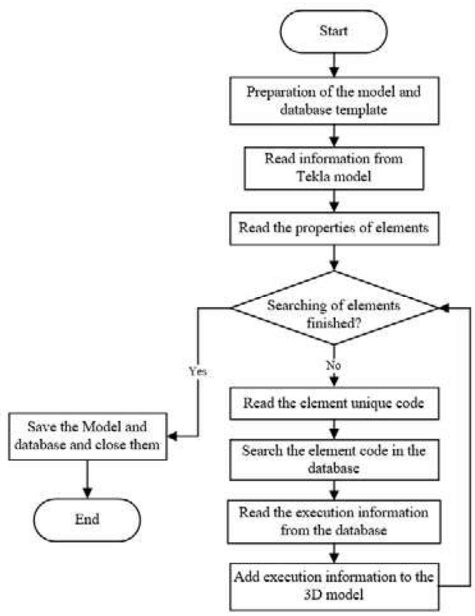

Figure 3: Flowchart of automatic transferring of execution information to the 3D model

Phase four: providing visual outputs and information dashboard

In this phase, using the obtained database as well as the updated 3D model, the outputs of the mechanism are delivered.

4D model

A 4D model is an influential tool for visualization of project progress. 4D model is capable of supporting daily construction operations and progress monitoring (Park et al., 2017). More precisely, the 4D model combines a project progress database (planned or actual) with a coded three-dimensional model. Considering that the 3D model in the first step is automatically coded and implementation information is transferred to the database, the actual status of the project can be visualized by Navisworks software as a 4D model.

Information Dashboard

Providing a comprehensive and administrative dashboard is one of the best ways to take advantage of the massive amount of information that is integrated into a database. The benefit of such dashboards is that various stakeholders and departments of the project (i.e., project manager, project control department, execution team, and procurement department) can easily access to specific information (partial or general information) in less than a few seconds. PowerBI is a superior software in the field of producing dashboards.

Case Study

The proposed process is applied to a real large-scale project in Iran. The project scope is to construct a concrete structure of 10-story parking with an area of 28,000 square meters. In this project, both pre-casting and in-place execution methods are used. Due to the size of the project, the project is divided into two zones (B and C). Also, the height of the floors is not the same in all stories. Concrete slabs are executed in three methods of in-place slabs, precast slabs, and hollow core slabs with a thin concrete coat. Fig. 4(a) shows a view of the project 3D model which has about 40,000 elements (Column, Beam, Slab, Hollow core, and etc.). Due to the high speed of implementation, control of the project progress, timing bill of quantity, observing the actual status of the project in the 3D model and many other points will be very difficult for project managers. Storing information of each element in the 3D model can solve this issue. Transferring execution information to TEKLA software increase the ability of fast analyzing of project progress for the managers. Fig. 4(b) presents a breakdown of the implemented and unexecuted elements of a story in a quick review that can be very suitable for project control department.

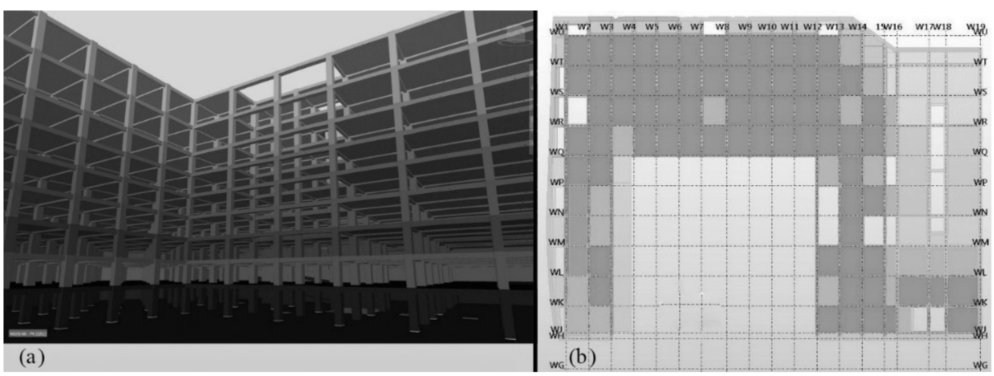

Figure 4: (a): a view of the project 3D model (b): executed (dark grey) and not implemented (light grey) elements

Results

According to the points mentioned in the previous sections, the results of the presented mechanism are obtained and examined. Fig. 5 presented an image that is taken by the drone in order to track and collect the project progress information. The execution time captured by the drone is about 30 minutes per day for the introduced mega project. The drone takes the pictures of project day by day. The programming environment presented in Fig. 6 comprises analyzing and encoding model procedure. It took about 15 minutes to analyze and encoding the 3D model elements. As can be seen in Fig. 7, after running the program, the database containing 40,000 elements is obtained. Each row of the database includes several specifications of elements in the 3D model (i.e., execution method, level, type, execution zone, etc.). In the next step of the programming, the date of implementation and installation of each component has entered the database as well as the 3D model. It should be noticed that entering information by the user varies from day to day with respect to the daily performance of the implementation. Fig. 8 presents a component in Tekla software environment that includes specifications and date of execution.

Figure 5: Template image was taken by the drone

```
Imports TSM = Tekla.Structures.Model
Imports Excel = Microsoft.Office.Interop.Excel
Imports System.Math

2 references
Public Class Form1

    0 references
    Private Sub Button1_Click(sender As Object, e As EventArgs) Handles Button1.Click
        Dim lstResults As List(Of TSM.Part)
        lstResults = GetPartsWithClass()

    End Sub
    ''' <summary>
    ''' Returns reference to first concrete part found in model
    ''' </summary>
    ''' <remarks></remarks>
    1 reference
    Private Function GetPartsWithClass() As List(Of TSM.Part) ...

    0 references
    Private Function IsCoded(ByRef objBeam As TSM.Part) As Boolean ...

    0 references
    Private Function GetElv(ByRef objBeam As TSM.Part) As String ...

    0 references
    Private Function GetZone(ByRef objBeam As TSM.Part) As String ...


End Class
```

Figure 6: Programming environment of the introduced process

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	CODE	Elevation	Y1	X1	Y2	X2	COG_X	COG_Y	Type	Sub_Type	Volume(m3)	Zone	Summary Type
2	ZC-P02-S-Wall-17223	P01	Q	16	P	16	-428500	-48062.2	In-Situ	Shear Wall	101.4	ZC	Shear Wall
3	ZC-P01-PMB01-PJ-18811	P01	N	16	P	16	-428500	-59957.20708	Pre-Cast	Main-Beam	6.27332968	ZC	Beam
4	ZC-P01-CIP-PART-OF-BEAM-13751	P01	N	16	N	16	-428500	-64607.20707	In-Situ	CIP-Slab	0.413599989	ZC	CIP
5	ZC-P01-CIP-PART-OF-BEAM-13750	P01	N	16	N	16	-428500	-63819.70707	In-Situ	CIP-Slab	0.61275	ZC	CIP
6	ZC-P01-CIP-PART-OF-BEAM-13749	P01	P	16	P	16	-428500	-55307.21293	In-Situ	CIP-Slab	0.413599989	ZC	CIP
7	ZC-P01-CIP-PART-OF-BEAM-13748	P01	P	16	P	16	-428500	-56094.71293	In-Situ	CIP-Slab	0.61275	ZC	CIP

Figure 7: The obtained database environment

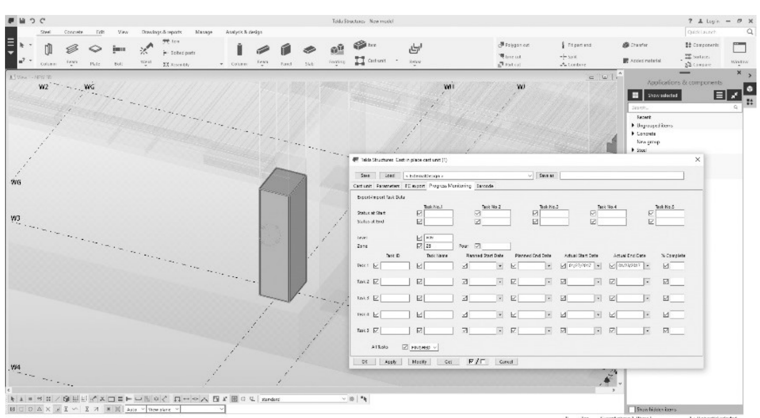

Figure 8: The image and specifications of a selected component in the Tekla software environment

The created database is entered to PowerBI software and the results are presented in Fig. 9. As can be seen in Fig. 9 until the last update time, about 31,280 tons of rebar have been used in the construction process. Also, estimated rebar needed for the project is about 40,300 tons. This value is obtained by the database information and calculated automatically. The presented dashboard has the ability to calculate the execution tasks volume of the project separately for all items and for any given period of the project duration. Moreover, the dashboard contains all the required values that are categorized into the floors, element type (column, beam, slab, etc.) and many other groups. Thus, every department of the project can access their essential and required project information through this dashboard in an integrated and proper environment. There is also a link in this dashboard to the project 4D pictures folder that facilities access to the visual information of the project. An example of the images shown at the various dates of the project is shown in Fig. 10. Consequently, an integrated environment located in the project servers is available to the entire project stakeholders in order to make all project technical information available in the shortest possible time.

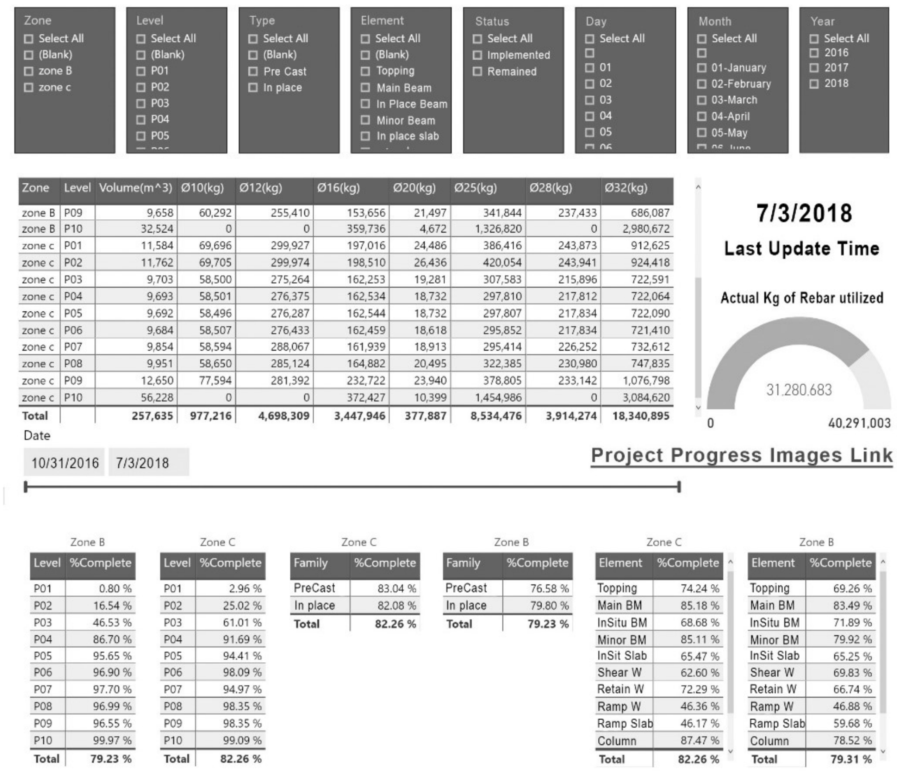

Figure 9: The dashboard produced by the mechanism in PowerBI software environment

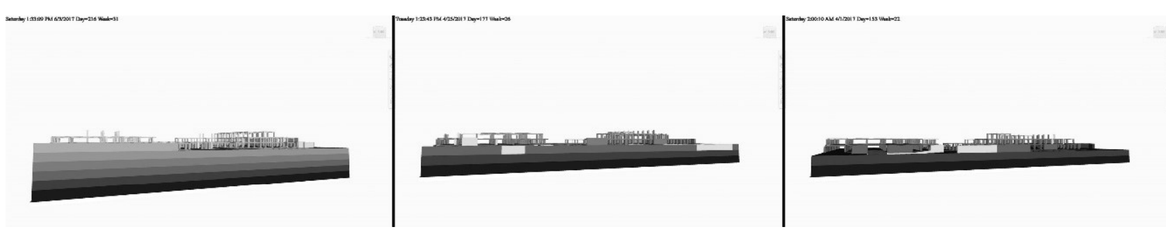

Figure 10: Actual status of the project at different dates

The proposed mechanism brings the vital construct information together in a 3D model and a dashboard. This can lead to an increase in the speed of project controlling and, ultimately, to identify the critical paths of the project during the construction phase. Therefore, any delays and reworks can be detected and be prevented from occurring. This can be a great help in reducing the budget as well as saving time in the project. Moreover, by presenting construction progress and actual metrics of the project using the 4D model, the level of satisfaction and interest of the client will also be higher.

Conclusion

In this paper, the whole elements of a real large-scale project 3D model are encoded using an automated encoding system and information of the elements are stored in a database. In addition, the construction and installation information of each element is automatically transferred to the 3D model of the project. This information is obtained by aerial data capturing using a drone to capture information of such extensive project in a reasonable time. Using the mentioned information, the actual status of the project is visualized as well as in the form of a management dashboard so that the project manager can study all the project information (in terms of visual, project execution process and project quantities) in a very short time and make proper decisions in order to drive the project successfully. The proposed mechanism can integrate all the information and share them with the users according to the type of their need. Therefore, discontinuity among existing project information is eliminated and it is not necessary to collect information from different sources and departments of the project separately. Also, the project manager can observe the status and the related information of the project in each desired period and zone.

Compared to traditional project control methods (i.e., not using the BIM model, gathering data information by a person, etc.) the proposed mechanism can be a novel and modern method to track project progress. The process presented in this study is capable of generalizing to any type of such construction projects, and each project department can use the outcomes of this process according to its needs. Thus, because of the information exchange through a comprehensive database, the processing time of information flow is minimized and the amount of interactions is also optimized. However, this research has some limitations. Despite the comprehensiveness of the proposed database, additional information can be added to expand this mechanism to other aspects of projects. Other information such as the quality of the executed elements (in the matter of Quality Control), entrance time of the steel or prefabricated elements to the site job, and etc. are good examples of proper project information which can be added to the 3D model and can enrich the model and make the model more useful to the whole departments of the project. Also, web-based integrated modeling can be considered as an appropriate proposition for the future study. A web-based integrated model allows users to access the information and model of the project anywhere via the internet and even through smartphones. Furthermore, automating the data gathering of the drones can speed up the project information collecting process.

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