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METHODOLOGY FOR AUTOMATED GENERATION OF 4D BIM

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Abstract: Lack of adequate visualization of project construction operations often causes project parties to struggle with large amount of data. 3D Building Information Modeling (BIM) is a static model, built for representing the geometry of a constructed building and its respective information. However, construction processes are dynamic and require dynamic representation. 4D BIM is gaining more momentum in construction research and in industry. There are commercial packages that can generate 4D BIM and numerous researchers have used 4D BIM in their research. However, related literature does not disclose the methodology used or the know-how of creating 4D BIM. This paper presents an automated methodology and describes how to construct a 4D BIM. The automated methodology maps the 3D BIM objects to project schedule activities through a newly added attribute to each 3D BIM object. As such, different groups of objects within the 3D BIM are assigned to different activities. For each group, a series of decisions are made to classify whether it belongs to completed activity, activity in progress or activity to be executed in the future. The developed methodology was implemented in prototype software. Autodesk Revit has been customized so that the integration between 3D BIM and project schedule be applied using Revit Application Programming Interface (API). The developed automated methodology and software were applied to a construction project in Montreal area to demonstrate its use. The developed methodology is straightforward and easy to use. It is expected to facilitate the utilization of 4D BIM in research and in practice.

Keywords: Automation, Project Visualization, Building Information Modeling & 4D BIM

1. INTRODUCTION

Construction Industry Institute (CII) studies showed that the cost of rework could range from zero to 25% of the installed cost of construction. However, the use of visualization representations such as 3D models by management team can reduce that amount of rework by 65% on average. The efficient use of space on a construction site is a site-specific, difficult task and is often left to the intuition of construction managers. Poor spatial planning has been deemed one of the major sources of productivity loss (Thabet and Beliveau 1997). On large construction projects, project management teams often suffer from not being able to mentally visualize a project complexity. Thus, they are frequently not able to make the best decisions to mitigate risks. Visual representation is one way to overcome this problem. Visual models represent the spatial aspects of schedules and communicate schedules more effectively than traditional methods such as bar charts (Kang et al., 2007). Building information modeling (BIM) is gaining momentum in the architecture/engineering/construction (AEC) industry, especially since owners such as the US Army Corps of Engineers (USACE) implemented initiatives requiring future projects involving the design and construction of facilities include BIM. In 2005, the United States General Services

Administration (GSA) announced that starting 2006, AEC firms would be required to provide a building information model with their designs (McCuen, 2008).

By themselves, 3D models do not have the ability to show the exact status of a project at a specific point in time, and so are of little help in progress control. In order to create a construction schedule from 2D drawings, planners have to visualize the sequence of construction in their minds. This is an extremely difficult task since workspace logistics and resource utilization are highly dynamic by nature. Most site organizations plan their works based on conceptual site layout and drawings, which are rarely updated during the project execution. Thus, site managers have not fully benefited from recent advancements in visualization-information technologies (Chau et al., 2005). 3D models have some basic knowledge that results from shapes, sizes and locations. This is the geometric database, where each element has geometric attributes. In addition to the geometric attributes, which describe the physical 3D model, each element in the model can have any number of non-geometric attributes associated with it. One non-geometric attribute might be the construction method or specifications (Aslani et al., 2009).

The goal of adopting a BIM is to provide a comprehensive view of the building by including (drawings, specification, details, etc.) in a single-source model (Krygiel et al., 2008). BIM databases contain physical and functional characteristics of a structure since a BIM model is composed of smart objects rather than lines, arcs, and text. All of these characteristics are mainly due to BIM's capability to realize the building through all of the stages in the form of a database (Fu et al., 2006). BIM users can obtain information about any single element, or for all elements in a project, to inform decisions about the project. Examples of data included with an element are material quantities, costs of elements, time considerations related to the element, building performance, operations and maintenance, and several other items essential in the lifecycle of a constructed facility (McCuen, 2009 and Motamedi and Hammad, 2009). Montaser and Moselhi (2012) developed an automated methodology utilizing BIM and tablet PC for progress reporting in construction jobsites. They added the data taken from BIM database to RFID tags attached to the components. The idea of making components data readily available on the tags provides easy access for project and construction mangers through real-time connection to a central database or a portable device.

With its potential to assemble the whole project virtually before any actual construction begins, BIM adds a level of accuracy to both quantity and quality issues. Building materials can be demonstrated in real time scenarios rather than requiring manual analysis. By drawing building elements only once for a project in a plan view, the projections of all elevations and sections are generated automatically. One of the direct benefits is the reduction in drawing time; therefore, designers can mainly focus on other design issues (Krygiel et al., 2008). 3D BIM model is a static model, built to represent a building. This could be seen as a shortcoming for the construction process/operation since it is a dynamic process and merits a dynamic presentation. 4D BIM is a visual representation that combines an object oriented 3D BIM model with time. 4D BIM is information visualization that is easier to understand than traditional methods. Traditionally, project managers use 2D drawings, bar charts, and sketches to clarify the construction design, but these visualization methods do not integrate the temporal or spatial dimensions. 4D BIM models are a form of visual representation of a project that also takes into consideration the temporal aspect of how project teams plan to actually build a project, according to construction schedules. 4D BIM could be used strategically by on-site management for visualization (Hartmann et al., 2008).

Moreover, 4D BIM can assist site personnel in brainstorming sessions and discussions about access, storage and sequencing of works. Better visualization facilitates team collaboration in removing illogical relationships among activities in construction operations. Owners of the constructed facilities may have little experience in construction, and are often unable to truly participate in the development of construction plans unless a simple method of visualization and communication is made available to them. 4D BIM visualization seems to be an effective way of enhancing the many different types of human perception and it can help anticipate potential construction conflicts during the operational stages (Chan et al., 2004, and Staub-French et al., 2008). However, related literature does not disclose the methodology used or the know-how of creating 4D BIM. This paper presents an automated methodology and describes how to construct a 4D BIM.

2. DEVELOPED METHODOLOGY

4D BIM integrates the building project 3D model and its construction schedule. A realistic project baseline schedule should be developed, including project activities and their early start (ES) and early finish (EF) dates. The 3D BIM model, first, imports the planned data directly from scheduling software, in database format. Figure 1 depicts the flowchart of the procedure used to link the 3D BIM model to project schedule. It then maps the 3D BIM model objects to project schedule baseline activities. As such, different groups of these 3D BIM objects are assigned to its respective activities. Figure 2 shows the flow chart for manipulating 4D BIM for visualization purposes and the template creation process. For each group and according to current date, a series of decisions are made to classify whether it belongs to a finished activity, an activity in progress or an activity to be executed in the future. The automated procedure compares the current date to the ES and EF dates of each group, and controls each group's visibility accordingly. Future activities, those that have not yet started, are hidden from the developed 4D BIM. For finished activities, the 4D BIM checks if each group has been inspected and checked as being finished, or if according to the as-planned schedule it is finished but not yet checked or inspected. The 4D BIM makes the finished and checked activities visible in their final forms, and displays unchecked finished activities in a red highlighted form. The activities currently in progress are displayed in yellow. The activities displayed in red and yellow are divided spatially among identified zones. To facilitate data storage, fusion and processing a relational database was developed. The database has six entities; interconnected with one-to-many, many-to-one and many-to-many relationships. Due to space limitation, the Entity Relationship (ER) diagram is not included. For more details about the developed database, please refer to Montaser (2013).

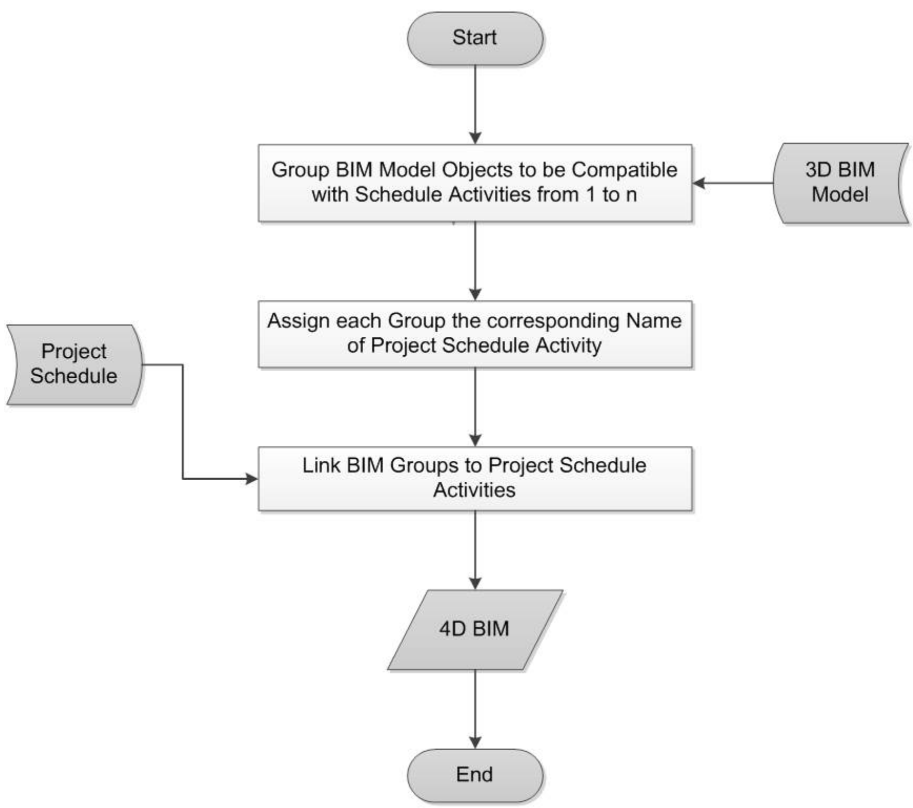

Figure 1: Linking the 3D BIM model to project schedule

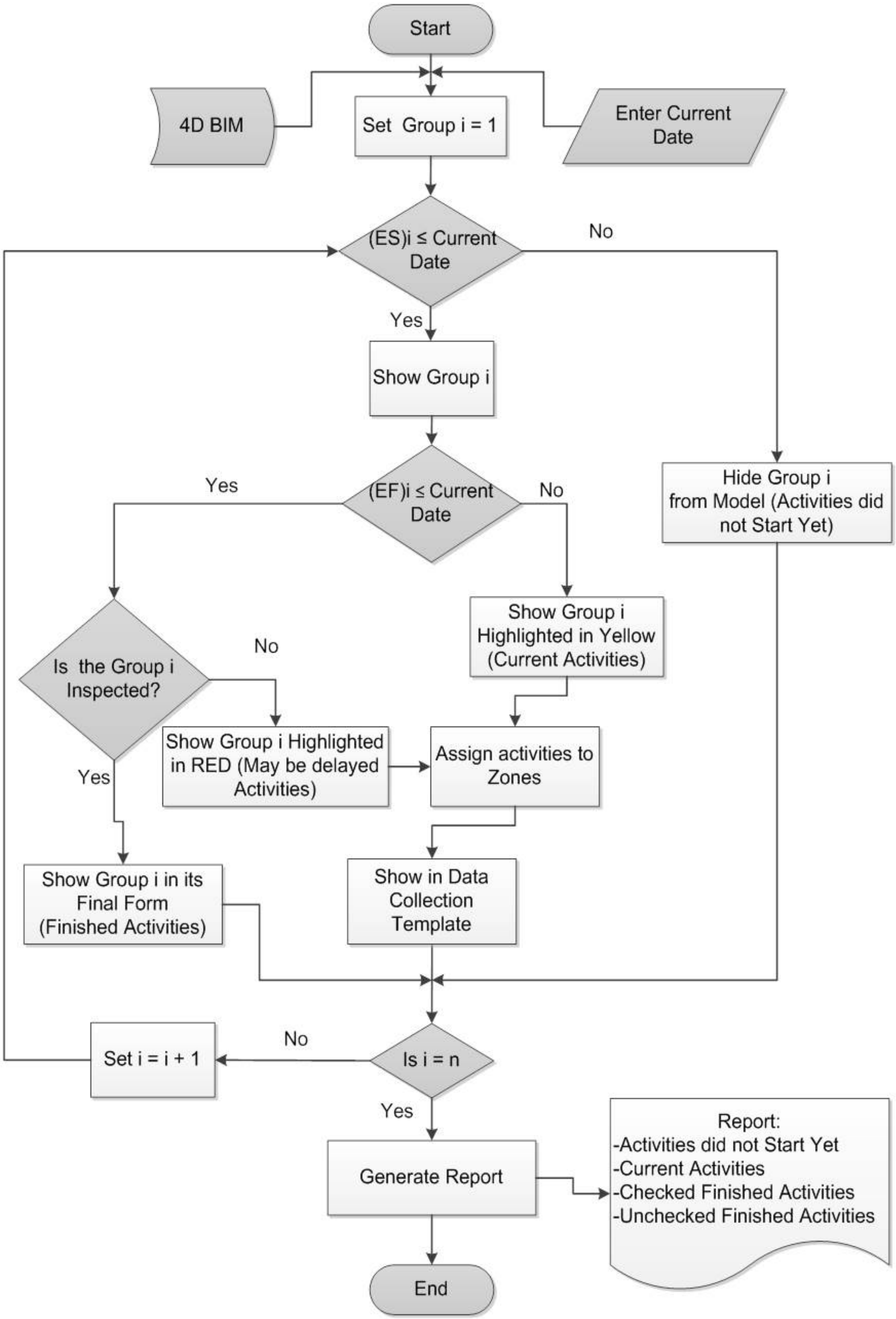

Figure 2: The process of 4D BIM model visualization

3. DEVELOPED SOFTWARE

The developed methodology was implemented in prototype software. BIM models are capable of recognizing building objects in its fixed asset hierarchy (Family - Type - Object) while being user-friendly for creating a building's indoor and outdoor zones. It links those objects to the zone that hosts them by relating an object's ID to a zone's ID. Different software developers such as Autodesk, Bentley and CATIA have applied the BIM concept. None of these systems' providers, however, describe any BIM web application. All of them are standalone applications installed on the user computer that could be connected to internet. Each has its pros and cons; however, Autodesk Revit customization capabilities have been significantly extended over the past few years. Revit Application Programming Interface (API) allows users to program with any .NET compliant language such as VB .NET and C# .NET. Revit has thus been selected here to be customized so that the integrated tablet PC data acquisition system be applied in its API and utilized as add-In.

This section presents the developed automated tool, which was developed using the "Visual C# .NET" in Revit's API. Revit was selected to be customized and the developed software was implemented to the Center for Structural and Functional Genomics (CSFG) at Concordia University in Montreal as a proof of concept and for testing the developed software. The building consists of basement floor, ground floor, first floor, second floor, mechanical floor and roof. The total built up are is 6000 m2. The building is a reinforced concrete structure, except the mechanical and fire escape stairs, which are of steel structures. The contractual budget was $20 million with contractual duration of 12 months. The Architectural and Structural plans provided by Concordia University were in the form of 2D CAD drawings, and there was no BIM model for the building. A 3D BIM model was created as a part of the developed methodology. The BIM model was developed using the project 2D drawings. Revit Autodesk software was used to develop the 3D BIM model. The 3D BIM model has all of the parameters and attributes for building zones and objects. Each parameter and attribute is associated with a unique ID to avoid conflicts when dealing with data exchange and scheduling software, which is Microsoft Project 2013. The generated 3D BIM model feeds the developed software with data, such as the number of spaces, the area of each space, the object families and family types, in order to identify objects inside each space, and later facilitate integration of the 3D model with the construction schedule.

In addition to the unique ID that each object has, BIM objects also have two important characteristics that are family and type. Family represents the main description of objects such as wall, door, window, etc. While, type represents specific kind of a family object such as internal wall 1 hour fire rated or wooden door single flush panel. The developed software utilizes these two aspects of BIM objects to categorize the whole building. The software should be utilized by users, who are familiar with the project 3D BIM model and the construction schedule of the building being modeled such as project managers or project schedulers. The user is responsible for linking the Microsoft Project file to the 3D BIM model of the project and maps the 3D BIM objects to project activities through utilizing the control visibility options. Visibility options have three different use-cases that are show by activity, show and hid activities manually and show activities by date. "Show activities by date" use-case is considered the 4D BIM model that was customized in Revit. The visibility options given to the user facilitate the process of modifying or changing activities objects in case of any design modification or introduced change orders.

The user first activates the developed add-in menu in the Revit screen and subsequently selects from a pull-down menu "Set MS Project File" and completes the process depicted in Figure 3. The software closes the file explorer dialog and inserts the selected file path into displayed writable textbox. The user presses the "Done" button so, the developed tool checks if the file exists, which is part of the verification process. Then, it saves the new MS project path into the system configuration file to use it as default MS Project path and closes the change MS Project form. The second step, performed by the user, is to map 3D BIM objects to its respective activity. In creating group of elements, the user can link one object or a set of objects to one activity as diagrammatically shown in Figure 4. Prior to that linkage, MS Project schedule must be activated and verification is performed to make sure that the schedule has more than one activity. If the MS project file have list of activities, it displays two buttons "Finish" and "Close". Then, the system allows the user to select multiple objects from the 3D Revit model and link them to one of the activities being displayed. After selecting multiple objects, the user selects the MS Project activity from a pull-down menu “Choose Group Name” and completes the process depicted in Figure 4. Upon completion of the linking process, the object(s) inherits the attributes of the associated activity such as activity name, early start and early finish, which are then used for generating the 4D BIM model. This process is repeated until all 3D Revit objects are mapped to associated MS Project activities.

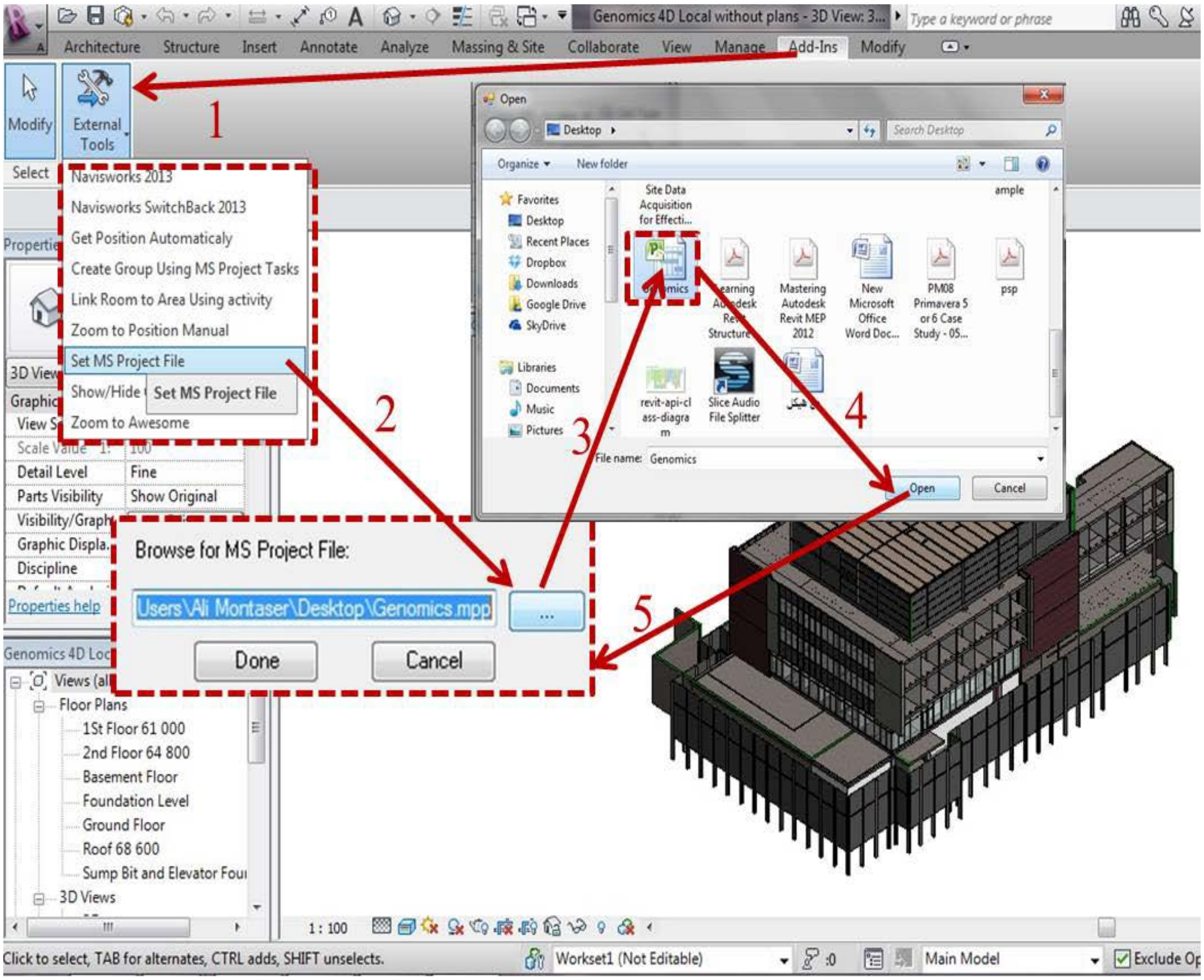

Figure 3: Linking Microsoft Project file to 3D BIM

Each object in Revit, referred to here as element, has a set of attributes such as ID, family, type. These attributes vary from object to another and they are either generic or specific. A new attribute was added to all Revit objects to facilitate the linking process, as shown in Figure 5. It is referred to it as “Group”, which represents one object or a set of objects. The user selects a set of objects such as supported deep excavation piles, as shown in Figure 4, then; the name of “Group” is made identical to the activity name. The sequence of this process was designed and implemented to be from outside to inside and from top to bottom. Upon finishing one group, objects of that group will be hidden to provide access to the other objects. The mechanics of linking identified objects to relevant scheduled activities are performed interactively as shown in Figure 6.

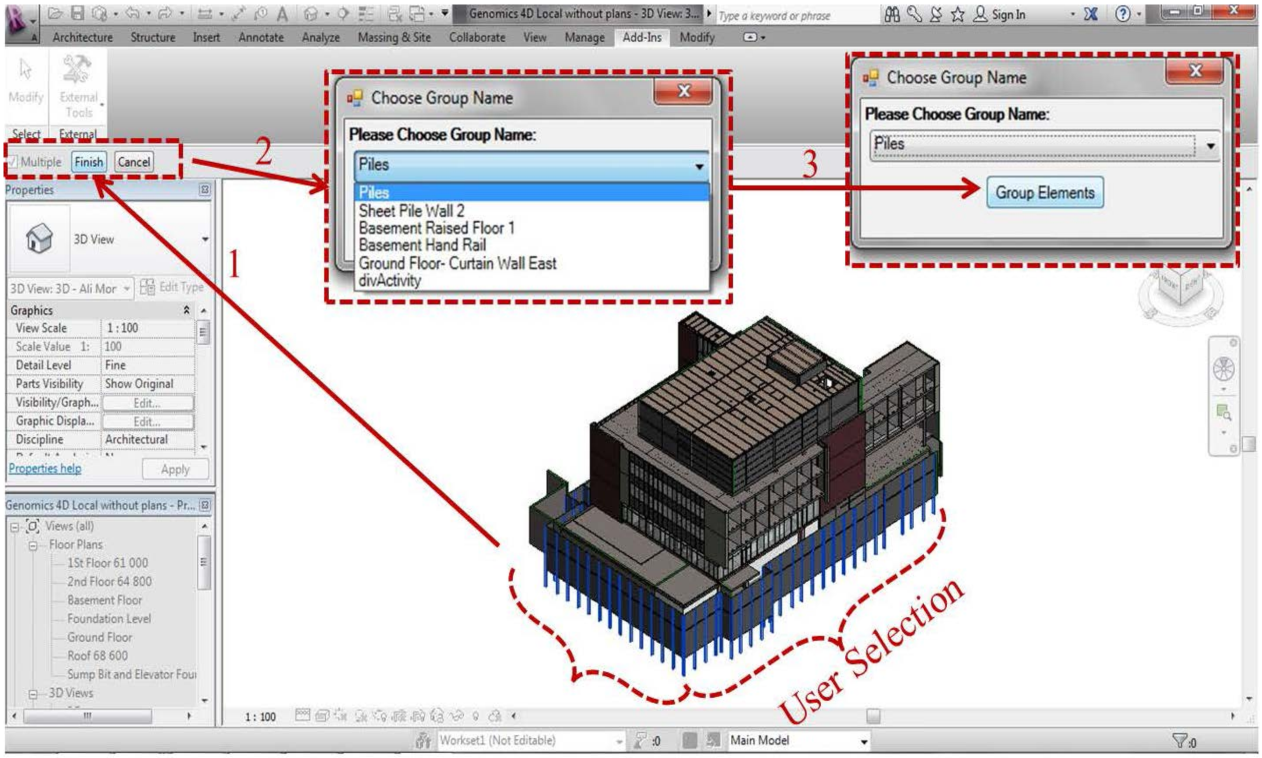

Figure 4: Mapping 3D Revit objects to project activities (part 2)

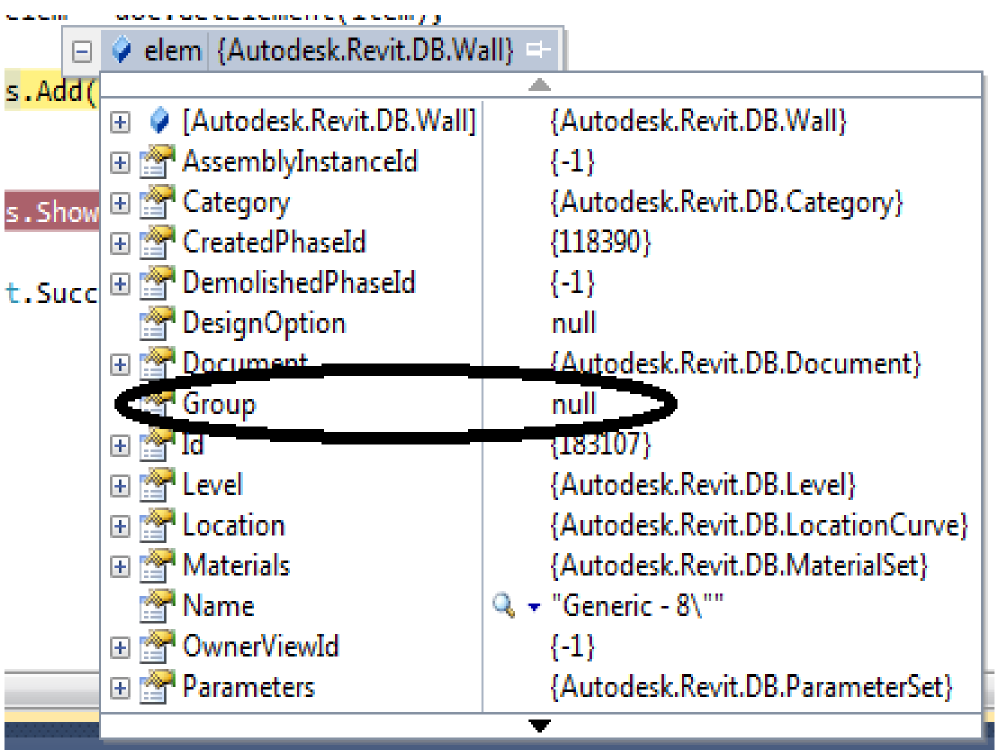

Figure 5: The added attribute “Group” to Revit object

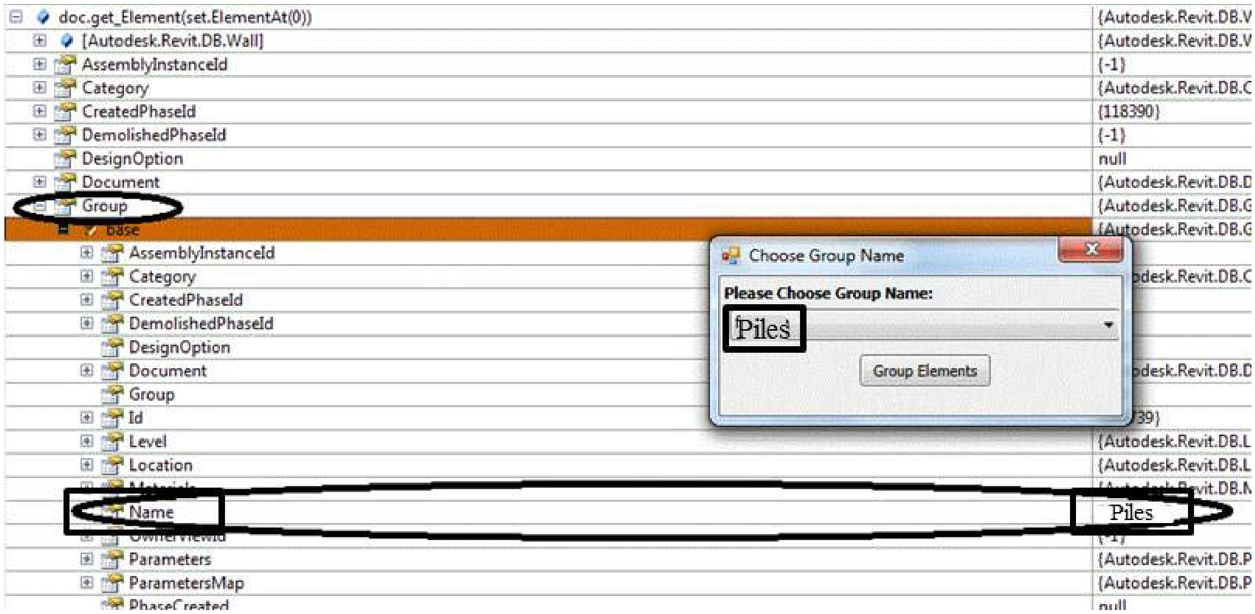

Figure 6: Assigning MS Project activity to Group name

Controlling visibility of activities is crucial in the developed automated tool. Therefore, three different options were developed to identify which activities are visible and which are hidden. To activate the visibility controls, the user activates the add-in menu and selects “Show/Hide Groups”. Then, the automated tool checks that at least one activity is linked to the 3D Revit objects. Otherwise, the system pops up an error message instructing the user to map the 3D Revit objects to the MS Project activities first. If this check is false then the system displays “Group Visibility Control” form. The form contains three different options, as shown in Figure 7. The user has to select one of the three options. If the user selects “Show/Hide Based on Activity” then it shows under that option a drop down list with all activities that were linked to 3D Revit objects. The user selects one activity that required to be displayed. It displays the selected activity on the current view and hides all other activities.

If the user selects “Show/Hide Based Manual” then the automated tool displays a form containing all displayed activities under the visible list and all hidden activities in other list. The user selects the needed activity to be displayed and press move or selects the needed activity to be hidden and press move. In addition, the user could select to move all activities from one list to the other and vice versa. The user presses done button to apply the above actions to Revit current view. Showing specific activity or activities become very handy to the experienced user specially, in the cases of design modification or change orders. Therefore, the user can isolate the activity objects, modify it, and link it again to the MS Project activity. The third option is to show/hide activities by date, as shown in Figure 7. This option represents the methodology for applying the 4D BIM concept inside Revit without the need for third party software. When the user selects s the option of “Show/Hide Based on date”, two calendars appear. The first calendar to specify the start date and the second calendar for the end date. The automated tool applies the algorithm explained earlier for showing and hiding activities on specific date range. Figure 8 shows pictures from the generated 4D Revit visualization.

4. CONCLUSION

Lack of adequate visual representation often causes construction managers to struggle with large, amounts of data. Such limitations of traditional tools on one side and the advances in visualization-information technologies on the other have stimulated various research and development efforts to advance new innovative construction visualization techniques that depict sequence of construction operations. Traditionally, project teams use 2D drawings, Gantt-charts, and sketches to provide the necessary details of construction sequence simulation. However, these tools do not provide the information required to generate 4D visualization of project progress. 4D BIM is the solution for this problem, which is generated by integrating the 3D BIM with project schedule. It allows a three dimension (3D) simulation of a building and its components that is called 4D BIM. This simulation goes beyond demonstrating how different building assemblies can be put together in the project. It can assist in predicting problems, show the construction variables associated with different building designs, and calculate material quantities. However the literature and current practice do not reveal a clear methodology or procedure to create a 4D BIM. Additionally, most of the work done in this area is through integrating 3BIM and schedule using third party software. This paper presents an automated methodology to create 4D BIM models. The methodology is generic, straightforward and easy to use. It is expected to facilitate the use of 4D BIM in research and in practice. The methodology has been implemented in a prototype software and was applied to a case study to demonstrate its use.

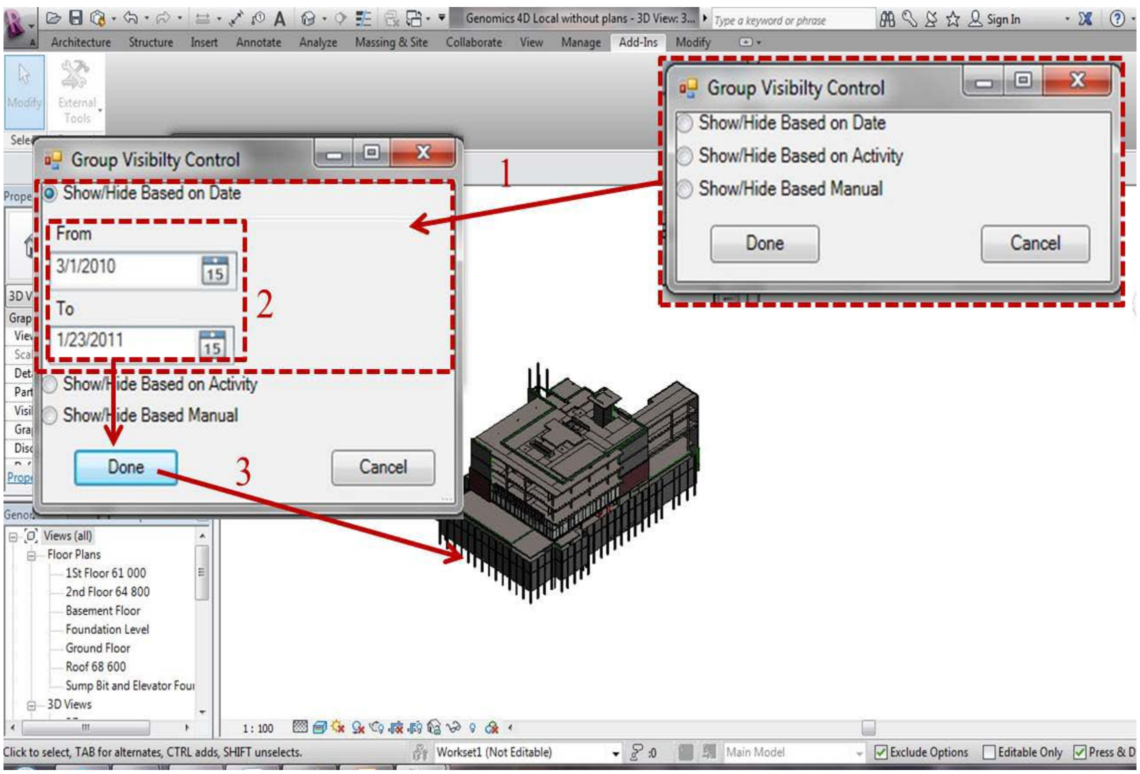

Figure 7: Show and hide activities by date (4D BIM)

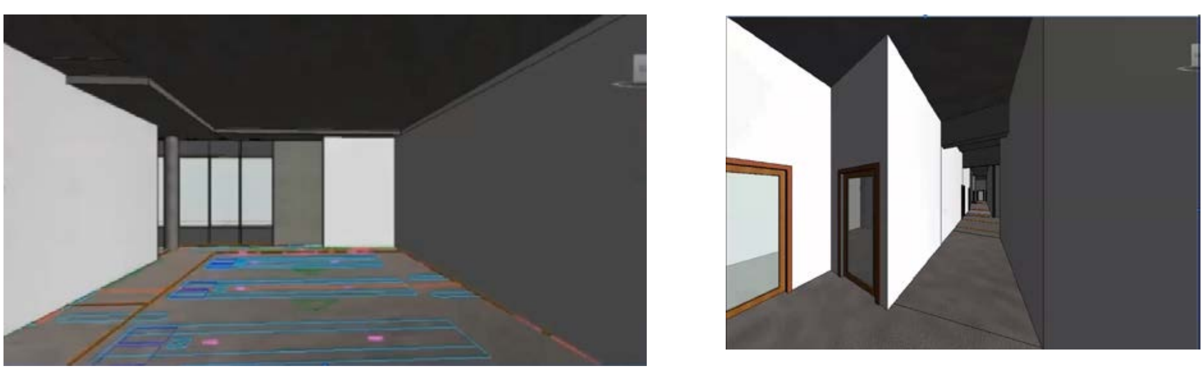

Figure 8: Pictures from the generated 4D Revit visualization

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