A Method for Facilitating 4D Modeling by Automating Task Information Generation and Mapping

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Abstract

4D modeling integrates 3D model with project time schedule to provide virtual simulation for identifying spatio-temporal problems earlier in construction projects. However, constructing a 4D model takes a significant amount of time and is prone to man-made errors due to its manual steps and repetitive nature. Therefore, in this study, a model based two-phase method is developed to facilitate linking 3D model with the schedule by automating the cumbersome steps. In the first phase, 4D Task IDs are created and assigned automatically to the model elements using a pattern that depends on their properties. In the second phase, using these IDs, the method generates a task ID list for scheduling and the search sets for simulation in order to map the model elements with the schedule tasks automatically, according to matching IDs. Hence, using shared IDs enhances the communication between 4D modeling tools. The efficiency of the method was tested with a well-known office building model constructed in Revit. The schedule was completed in Microsoft Project and 4D simulation is performed in Navisworks. The automated steps offered by the method were coded in Dynamo add-in of Revit. The analysis result showed that the developed method generated a 4D model in a shorter time compared to the manually performed one.

Keywords

Building information modeling • 4D modeling • Automated information generation • Dynamo

57.1 Introduction and Background

In construction projects, construction planning depends on numerous factors. This complicated nature imposes excessive burden for conventional scheduling approach to address spatio-temporal issues. Therefore, 4D modeling approach is developed to relate 3D model with project schedule for enabling virtual simulation by visualizing the sequence of the tasks with their linked model elements [1]. The simulation provides an observation on construction sequences; to improve the project stakeholders' understandings and communication [2, 3], to detect missing tasks and logical errors in the schedule [1], to identify time-space conflicts [4], and to allocate resources more efficiently [5]. Besides the visual examination, with the help of supportive algorithms, 4D model is also used to analyze; time dependent construction structural stability [6] and construction site accessibility [5] for constructability, and workspace safety [7]. Hence, these analyses provide early inspection before the construction to avoid possible problems causing delays in project, cost overruns, productivity decrease in workplace and safety problems.

Weldu and Knapp [8] divided the evolution of construction schedule generation and visualization into phases. In the first primitive phase, the schedule is developed using historical data and the scheduler's expertise. In the second phase, the

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schedule is integrated with 3D model to provide visualization and virtual simulation. Therefore, in this phase, the schedule tasks are linked with model elements manually; however, integrating 3D model with project schedule is quite repetitive, labor-intensive and time-consuming [1, 9, 10]. Hence, previous studies focus on accelerating this process by automating the linkages in a third phase. Park and Cai [11] offered a model based framework to provide compatibility between Element Breakdown Structure of BIM and Work Breakdown Structure (WBS) of the schedule for facilitating automated scheduling. According to their framework, information from model elements is extracted to generate the WBS lists and the precedence relationships between the model elements under the WBS levels. In order to provide compatibility between schedule tasks and model elements, the WBS lists are linked with the model elements for generating the schedule. Ciribini et al. [12] proposed an approach to semi-automatically match the schedule tasks with BIM elements via common identifier. In the study, the schedule is developed according to common identifiers and the linking identifier of the schedule tasks are defined as parameters in the model elements' properties. Therefore, using a predefined rule, the tasks are auto-matched with the elements considering their identifiers. This process overcomes the burden of manual linking of 3D model elements with the schedule tasks; however, assigning the identifiers to the model elements also requires time and may cause man–made errors due to its repetitive nature. In the fourth phase, focus of the studies is automating the processes of scheduling for 4D modeling. Therefore, by using spatial information, de Vries and Harink [13] proposed a knowledge based algorithm to determine the order of the building construction according to topology of 3D solid model. Similarly, Kim and Cho [14] developed more flexible algorithms to provide automatically generated precedence information between model elements according to their geometric relations for supporting construction schedule development. Furthermore, Weldu and Knapp [8] offered a rule based spatial reasoning method to generate construction sequences according to topological relations between the model elements considering the structural construction and hierarchy, material layers, and work access. Moreover, previous studies recommended the use of predefined construction methods [15] and process templates [16] to accelerate manually updated steps of the 4D modeling process.

In 4D modeling process, as explained above, manually associating schedule tasks with model elements takes a significant amount of time and this process is prone to human errors. Studies such as Ciribini et al. [12] as well as some of the current 4D tools like Navisworks, offer using common identifiers to semi-automatically link the tasks with model elements; however, in that approach, the unique common identifiers need to be assigned to each model element one by one. Therefore, the provided improvements in modeling process are not adequate to facilitate 4D modeling process significantly and this process is still open to the human errors due to the repetitive manual task id assignments. As a result, considering these drawbacks of the current practice and overall process of 4D modeling, we have developed a model based method to automate the error-prone and time-consuming steps of 4D model generation in order to (i) speed up 4D model generation process, (ii) avoid possible human errors in data generation and mapping and (ii) provide better communication between the modeling tools.

57.2 Methodology

In this study, first, 4D modeling process in current practice is examined to determine cumbersome steps that elongates the process and is prone to human errors due to manual processes and updates in the model. After this investigation, a method is developed to eliminate the drawbacks of these steps. Therefore, in the following section, the steps of 4D model generation are explained. In the next section, the logic behind the developed method and the improvements it brings are presented in detail.

57.2.1 4D Modeling Process

Today's 4D practice generally starts with project scheduling. The scheduler develops a time schedule using her expertise and according to calculations based on 2D drawings or the model. In parallel to this process, the 3D model is completed according to design decisions and/or 2D drawings. However, the scheduler and 3D modeler need to be coordinated to create a consistent 4D model where the granularity of 3D model is compatible with the level of details in the project schedule [12]. Then, in order to link schedule tasks with model elements to generate a 4D model, manual and semi-automated linking methods are followed.

In manual linking method, schedule tasks and model elements are collected in the same environment and each element is assigned to its linked task manually one by one. Therefore, this step (i) consumes quite time, (ii) requires special attention to avoid linking mistakes, and (iii) needs expertise to determine which element links to which task [10].

In semi-automated linking method, the model elements are attached to schedule tasks according to a unique common identifier. These identifiers are defined by the scheduler and shared with the 3D modeler to update the 3D model with these task IDs. The 3D modeler creates a task ID parameter for each element in the model and assigns relevant task IDs to the elements/groups of elements one by one. After that, the model is exported into simulation tool and the elements are grouped according to their task IDs by generating search sets for each task ID. Then, search sets map with schedule tasks via task IDs for linking 3D model with project schedule to generate the 4D model. In this linking method, the coordination between the scheduler and 3D modeler is quite important to generate all relevant task IDs. Therefore, the scheduler should be familiar with the 3D model. Moreover, (i) assigning task IDs to model elements and (ii) generating search sets, are manually performed bottleneck steps of 4D modeling process that consume time and probably generate inaccurate 4D models due to missing task IDs or improper task ID assignments for some elements.

Revisions in construction projects require updates in the 4D model. Therefore, in any update that is causing change in the 3D model, all cumbersome steps are again followed to reflect the changes in the 4D model. Hence, these steps need to be improved to generate accurate 4D models in a shorter time.

57.2.2 A Method for Facilitating 4D Modeling Process

A method is developed to automate the manually performed, repetitive, and error-prone steps of 4D modeling process. The method offers a two-phase solution to facilitate 4D modeling. In the first phase, 4D Task IDs are automatically generated for all model elements in the 3D model using their own properties. In the second phase, these IDs are used to automatically generate inputs for scheduling (task list) and simulation tool (search sets), to improve bottleneck steps and to facilitate integration of 4D modeling tools. In the current practice and the relevant studies, 4D modeling starts with the manually created 4D Task IDs by the scheduler; however, in our method, the 3D model is the starting point and the properties of the elements in the model determine the task IDs. In the second phase, the method lists all element based (physical) task IDs to facilitate the scheduler's work. The schedule is developed using the given task ID list. Moreover, using same 4D Task IDs, search sets are generated automatically to transfer 4D Task IDs from the model to the simulation tool. Both search sets and schedule tasks are imported into the simulation tool to link the elements with schedule tasks directly according to matching IDs. Thus, 4D Task IDs govern the modeling process and automate bottleneck steps. As a result, possible human errors in the modeling process are eliminated to generate an accurate 4D model output.

The flowchart of 4D modeling with semi-automated linking is explained in Fig. 57.1. The colors in the figure indicate different tools the steps are implemented in, except the orange color representing the improved steps in this method. As figured out, after 3D model is constructed, 4D modeling process starts with stimulating this model to create a shared 4D Task ID parameter for BIM elements. Then, a pattern based on BIM elements' properties is followed to label task IDs, depending on the planned level of detail in the schedule. This pattern should also provide technical information to the scheduler for facilitating scheduling process. Using the pattern constructed in an order such as "Assembly Code (UniFormat II)–Family Name-Family Type-Level", information about the building element that needs to be constructed can also be given. For instance, the task ID "A4020-Foundation Slab-6″ Foundation Slab-L00" represents the foundation element with family type of 6″ Foundation Slab in a Structural Foundation Slab that rests on ground level with an assembly code of A4020 which means Structural Slab-on-Grade. After that 4D Task IDs are assigned to the element/element groups automatically. If the required information in the task ID pattern of any model element is missing, then some 4D Task IDs will be incomplete. Therefore, an inspection step is added to the method to check the model and warn the user by listing BIM elements with improper task IDs. Hence, the missing data in 3D model would be completed at this step. After that task IDs are re-assigned to BIM elements to complete implementation of the method's first phase. In the second phase, a unique list of task IDs are generated to create (i) search sets and (ii) task ID inputs for the project schedule.

In order to generate search sets automatically, data structures of different search sets are examined and task ID dependent patterns are detected. Therefore, a function is coded that takes the unique task ID list as an input and generates search set file as an output. The search sets can be imported to the simulation tool after opening the 3D model in the tool. Thus, BIM elements with same task IDs are grouped in the search sets within the simulation tool. For scheduling, our method offers a unique task ID list with its BIM element properties to the scheduler. The data structure of the list is adequate to construct a WBS easily. Therefore, the scheduler can directly import the list to the scheduling tool or rearrange this list according to her

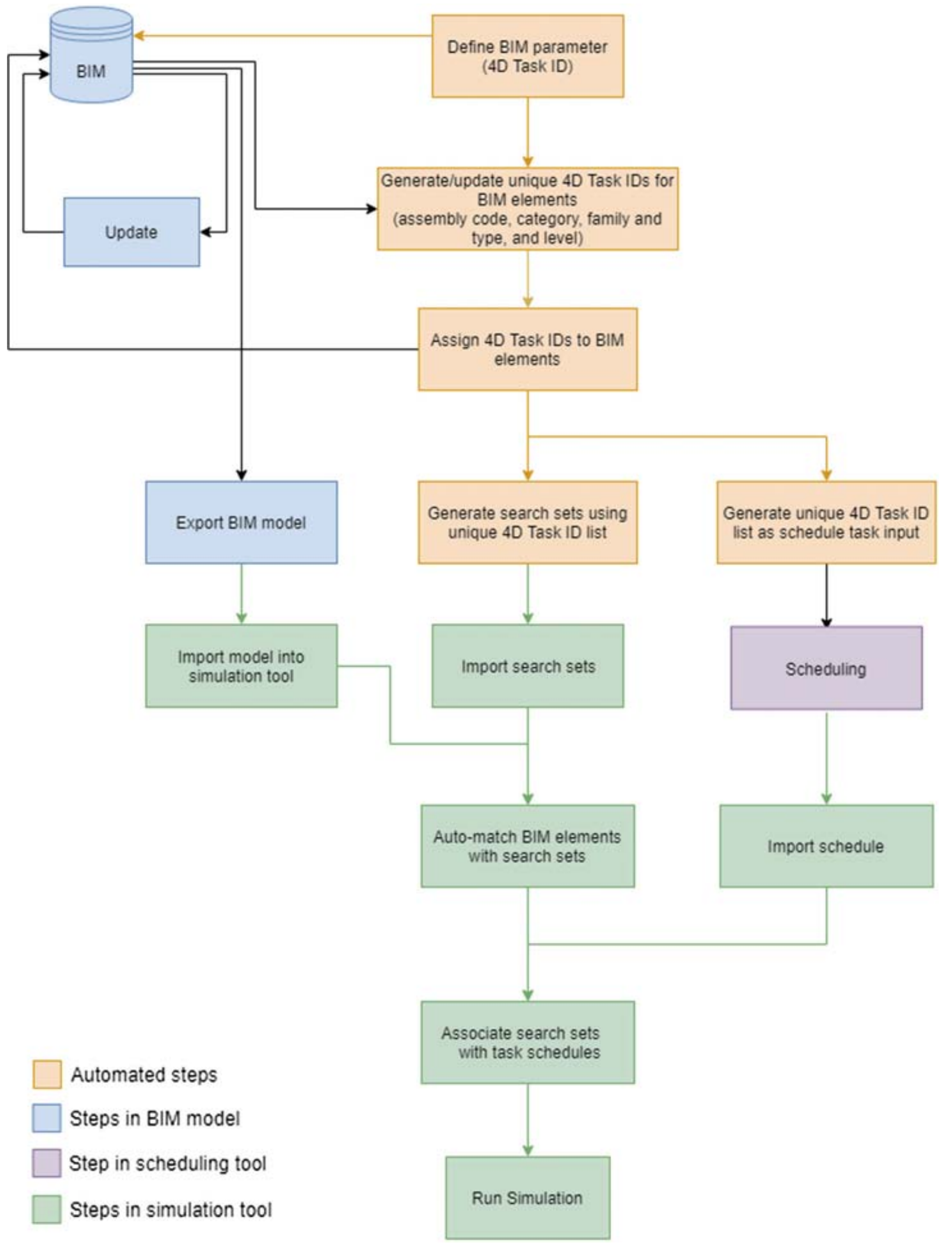


Fig. 57.1 Flowchart of the developed method in 4D modeling process

easiness to develop a WBS-based schedule. The scheduler can complete the plan by adding the tasks that are not or cannot be represented as elements in the model. Then, the scheduler develop the project plan by adding duration to each task and determining precedence relationships between the tasks. The next step is importing the schedule into the simulation tool and mapping the search sets with schedule tasks to provide automatic linking. After that, the 4D model is completed and it's ready to run the simulation.

This method also automatically updates the task IDs of BIM elements when the design is updated and generates the search sets file and the task ID list according to the revised model. Moreover, unique task ID lists of the base and the revised schedule are compared and new and pre-existing task IDs are identified to inform the scheduler for update of the schedule.

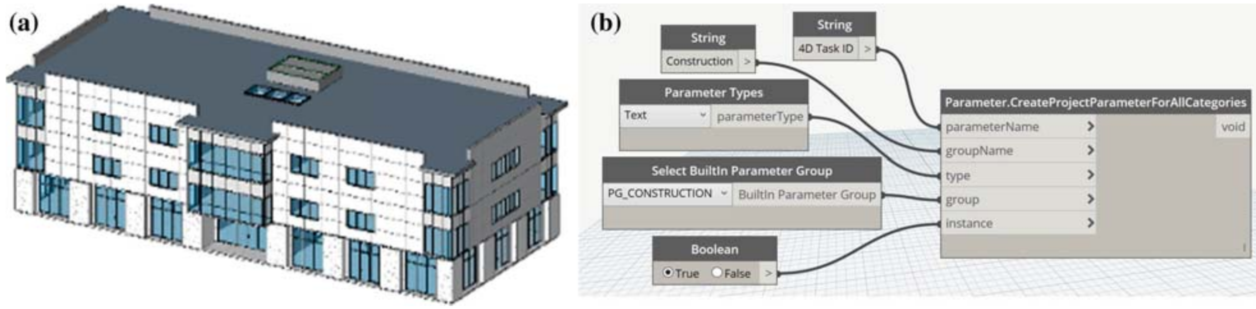


Fig. 57.2 **a** Test case office building and **b** coding of creating project parameter

57.3 Test Case: 4D Modeling with Autodesk Office Building Example

In order to test the developed method, a well-known three-story Autodesk office building example model (Fig. 57.2a) which is created in Revit is selected to construct the 4D model; because, in Middle East Technical University, this model has been used to teach all steps of 4D modeling with semi-automatic linking within the scope of CE 4002 "Introduction to Building Information Modeling" course. Therefore, it is possible for the authors to implement the developed method on this model and inspect missing and incomplete steps in automated 4D modeling process. Moreover, the schedule tasks were planned in Microsoft Project and simulated in Navisworks. The method is encoded in Dynamo visual programming, the Add-in for Revit, as Dynamo can communicate with Revit model to filter and extract necessary information and to manipulate data in the model. Hence, Dynamo interacts with Revit model to create 4D Task ID parameters and to assign their values for each BIM element. Moreover, the code in Dynamo generates inputs for Microsoft Project and Navisworks. Thus, Dynamo facilitates the implementation of the method during the whole 4D modeling process.

The test case office building model consisted of 5005 model elements with 54 different family types initially; however, most of these were supportive model elements (grids, views etc.) to manage model efficiently. Therefore, using the logic "supportive model elements cannot be used in the cost analysis", where assembly code parameter is used in cost analysis to give brief information about model element category and location in the building envelope, the model elements without any assembly code value were filtered out. However, in this case the model elements with missing assembly codes would also be eliminated. Therefore, an early inspection step was added into Dynamo model to list unique family types of the eliminated elements and to detect the required model elements for updating their assembly code values. At the end of this process, number of elements and different family types were reduced to 1859 and 37, respectively. Therefore, parameters of these elements have been altered during 4D modeling process.

The initial step of 4D modeling is to create 4D Task ID parameter for all model elements. Compared to other steps, this is the simplest and shortest step of 4D modeling. Therefore, the user can either create the parameter in BIM model or generate the same parameter in Dynamo. In this study, 4D Task ID parameter was created in Dynamo using its own built-in function as shown in Fig. 57.2b.

The next steps are determining the pattern for labeling 4D Task IDs and assigning these task IDs to the filtered model elements. As a pattern, "Assembly Code—Family Name—Family Type—Level" was used to govern 4D modeling. This pattern groups model elements according to their family type and level information. Dynamo extracted the family name and family type of the model elements using their own parameters whereas assembly code was gathered from properties of the model elements' family types. Moreover, the used assembly code data in this model is the specialized format of UNIFORMAT II in Revit which gives more detailed information about building elements. The level information was obtained using different parameters such as "Level", "Base Constraint", "Base Level" and "Reference Level". Moreover, level ("Reference Level") of the beam elements in the model gives one level higher output. This is also same in manual process. Therefore, it is assumed that the scheduler is informed about the reference level information for beam elements. Hence, Dynamo extracted all necessary data to label task IDs and assigned the corresponding task IDs to the model elements automatically.

In the second phase of the method, Dynamo communicated with the model to obtain all task IDs and eliminate the duplicates to prepare a unique list of 4D Task IDs. After that an empty.xml file was created and its path was given as an input, together with unique task ID list, to the search set generation function. The function is run to generate search set

Fig. 57.3 Case study results: **a** scheduling sample input list, **b** project schedule, and **c** final 4D model in the simulation tool

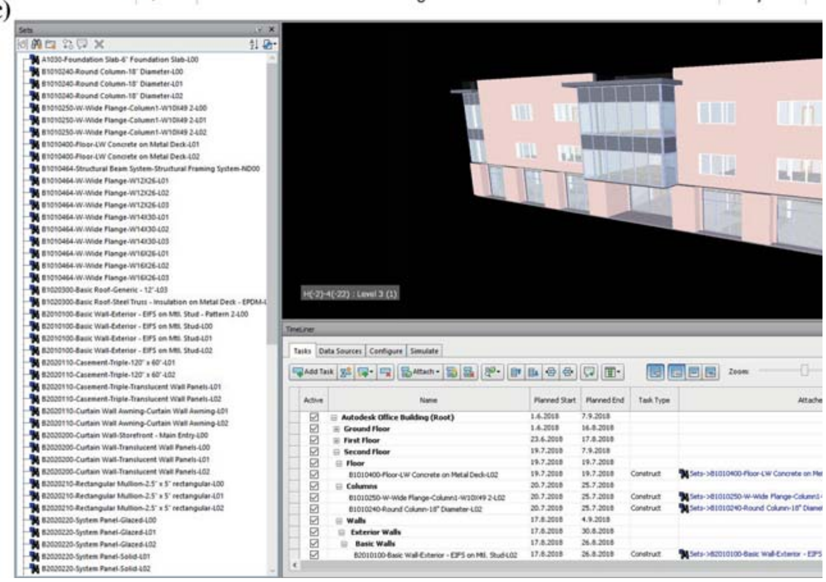
(a)

Category	Family Name	Type Name	Assembly Code	Level	4D Task
Structural Columns	W-Wide Flange-Column1	W10X49 2	B1010250	Level 1	B10102
Columns	Round Column	18" Diameter	B1010240	Level 1	B10102
Structural Foundations	Foundation Slab	6" Foundation Slab	A1030	Level 1	A1030-
Floors	Floor	LW Concrete on Metal Deck	B1010400	Level 2	B10104
Structural Columns	W-Wide Flange-Column1	W10X49 2	B1010250	Level 2	B10102
Columns	Round Column	18" Diameter	B1010240	Level 2	B10102
Floors	Floor	LW Concrete on Metal Deck	B1010400	Level 3	B10104
Structural Columns	W-Wide Flange-Column1	W10X49 2	B1010250	Level 3	B10102
Columns	Round Column	18" Diameter	B1010240	Level 3	B10102
Walls	Basic Wall	Exterior - EIFS on Mtl. Stud - Pattern 2	B2010100	Level 1	B20101
Walls	Basic Wall	Interior - 4 7/8" Partition (1-hr)	C1010145	Level 1	C10101
Walls	Basic Wall	Interior - Core Walls	C1010145	Level 1	C10101
Doors	Single-Flush	32" x 84"	C1020300	Level 1	C10203
Stairs	Stair	8" max riser 11" tread	C2010	Level 1	C2010-
Railings	Railing	Rail Only	C2010400		C20104

(b)

Task Mode	Task Name	Duration	St
	Case Study: Autodesk Office Building	**99 days**	**Fr**
	Ground Floor	**77 days**	**Fri**
	First Floor	**56 days**	**Sa**
	Second Floor	**51 days**	**Th**
	Floor	**1 day**	**Th**
	Columns	**6 days**	**Fri**
	B1010250-W-Wide Flange-Column1-W10X49 2-L02	6 days	Fri
	B1010240-Round Column-18" Diameter-L02	6 days	Fri
	Walls	**19 days**	**Fri**
	Exterior Walls	**14 days**	**Fri**
	Basic Walls	**10 days**	**Fri**
	B2010100-Basic Wall-Exterior - EIFS on Mtl. Stud-L02	10 days	Fri
	Curtain Walls	**4 days**	**M**
	B2020200-Curtain Wall-Translucent Wall Panels-L02	4 days	M
	Interior Walls	**5 days**	**Fri**
	Basic Walls	**5 days**	**Fri**
	Doors	**1 day**	**W**
	Interior Doors	**1 day**	**W**
	Windows	**2 days**	**Fri**
	Ceilings	**2 days**	**Th**
	C3030210-Compound Ceiling-2' x 2' ACT System-L03	2 days	Th
	Railing	**1 day**	**Fri**
	C2010400-Railing-Guardrail - Pipe-L02	1 day	Fri
	D1010-Elevator-Center-80" x 51" ADA min.-L02	1 day	Sa
	Beams	**15 days**	**Th**
	B1010464-W-Wide Flange-W12X26-L03	15 days	Th
	B1010464-W-Wide Flange-W14X30-L03	15 days	Th
	B1010464-W-Wide Flange-W16X26-L03	15 days	Th

(c)



pattern and to write this pattern into the.xml file. Next, the model and.xml file were imported into Navisworks successively to generate search sets automatically. Hence, all the model elements were assigned to search sets according to their task IDs.

The following step is generating the input list for scheduling. The list includes information of element groups such as their category, family name and type, level and assembly code, and 4D Task ID. Dynamo generated this list and exported it into Excel file (Fig. 57.3a). The list was rearranged according to the scheduler preference to facilitate construction of WBS-based schedule and the schedule was developed by categorizing the tasks in the list under WBS structure in Microsoft Project (Fig. 57.3b). After the schedule has been completed, the project schedule file was imported into Navisworks. In Navisworks, applying auto-attach using the rule as "Name" of the activities matches with "Search Sets", the search sets were mapped with schedule activities automatically. The result showed that except 2 types of 4D Task IDs (curtain walls and structural beams systems), the rest of the search sets were auto-attached to their activities. Curtain wall system consists of mullions and panels and structural beam system is composed of beams. Therefore, the mullions, the panels, and the beams were assigned with different 4D Task IDs and no element existed for curtain walls and structural beam systems in Navisworks. Due to this, the search set did not find any elements to map the schedule tasks with. Finally, Task Type is selected as "Construct" and simulation options were adjusted and 4D simulation was run (Fig. 57.3c).

Throughout the implementation of automated 4D modeling with test case building, the output of each step was compared with the manually created model's outputs for checking the accuracy of the developed method. The differences between two model outputs in each step were examined and the comparison showed that same output can be correctly generated with the automated method. Moreover the repetitive actions in manually created 4D model, especially during task ID assignments in the model and search sets generation in the simulation tool, performed in a fraction of a time with the developed method.

57.4 Discussion and Conclusion

In this study, a model based method is developed to facilitate 4D modeling by automating the labor-intensive, time-consuming and error-prone steps. This method saves time, eliminates the possibility of man-made errors in the process and improves communication between 4D modeling tools. The performance of the developed method was tested with a well-known office building model. The results showed that improvements offered by this method enabled to automate the critical steps in 4D modeling and reduced the process time without any information loss.

The developed method conceptually offers a generalized solution to generate 4D models for different types of construction projects. However, besides the test case model, a good number of 4D models needs to be examined to develop a generalized encoded method which is applicable to any construction project.

This method presents accurate simulation results when the 3D model is complete. Therefore, missing information in model elements is checked via inspection step to detect the problems and complete the model; however, if incorrect data is entered into the model, this would result in generation of erroneous task ID information which may cause logical problems in 4D scheduling. Moreover, level of detail in BIM model determines the level of detail in 4D modeling and scheduling. For instance, if the temporary structures are modeled in BIM model, its effect can be analyzed in 4D modeling. Therefore, quality of BIM model is one of the main precondition for obtaining accurate and detailed simulation results.

This study offers automated task ID generation using model elements' properties; however, labeling of task IDs depends on the availability of the information in the 3D model and the required level of detail in the schedule. Hence, considering the compatibility of the model granularity with schedule details, the scheduling preferences should be taken into consideration for labelling task IDs. Therefore, a level of detail framework for 4D scheduling should be developed to determine (i) number and types of WBS levels and (ii) properties of the model elements that should be used to label task IDs in each level.

In theory, the method reveals that different 4D Task IDs can be assigned to same model elements; however, in current practice, as a one of the limitations of this study, only one 4D Task ID is assigned to each model element. Therefore, improvements are required in 4D Task ID generation/assignment process to enable assigning more than one 4D Task IDs (such as for; brick laying, insulation, plastering, painting, etc.) to the same model element (e.g. wall) to develop more realistic 4D models reflecting layers of elements or steps of construction methods. The other limitation of the developed method is that, it does not generate nonphysical tasks (e.g. procurement of the construction material) or physical tasks for elements that are not modeled (e.g. formwork) as inputs for the schedule. Therefore, process templates compatible with WBS as in [11] should be developed to complete missing tasks and facilitate the scheduling process.

In future studies, this method will be improved by (i) adding process templates to reflect the activities in the schedule for nonphysical tasks and physical task that are not modeled, (ii) assigning multiple task IDs to the same model element for more realistic scheduling, and (iii) developing a level of detail framework for determining the pattern to label task IDs for 4D scheduling; in order to provide a more comprehensive automated solution to 4D modeling process.

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