Tamap Journal of Engineering
http://www.tamap.org/

doi:10.29371/2018.3.63
Volume 2018, Article ID 63
Research Article

Assessment of the Capabilities of Commercial Tools to Develop 4D/5D Models

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Received: 19.11.2018 • **Accepted**: 03.12.2018 • **Published Online:** 04.02.2019

Abstract: Building Information Modeling (BIM), which is developed for improving the collaboration and interoperability in the construction sector has many dimensions. While "3D model" is developed to visualize the buildings, simulation-based "4D model" integrates 3D model with time and "5D model" is attained as a result of including cost in the 4D model. The purpose of this study is to define 5D modeling in detail and to assess the capacities of 4D/5D modeling software packages via comparison. To assess the capacities of 4D/5D modeling software packages, a test case was developed. A 3D model of a project was created in Autodesk Revit 2017 and 4D/5D models of the building were developed by using Autodesk Navisworks Manage 2017, Synchro Pro 2016.2 and Trimble Vico Office R6.0 software packages. In the test case, the stages and their durations when preparing 4D/5D models were identified and the advantages and disadvantages of each software package were determined. The results of the study could be used as a guide by the companies desiring to conduct 4D/5D application in the sector.

Keywords: BIM, 4D modeling, 5D modeling, cost estimation, building information modeling.

1. INTRODUCTION

Digitalization is the next development trend in the construction industry and more information is moved to digital media (Xu et al. 2013). Building Information Modeling (BIM) is a digital 3D representation of a building and it is developed for improving the collaboration and interoperability in the AEC industry (Eastman et al. 2011). BIM is a process development methodology that uses data to analyze and predict results across different phases of building life (Reddy 2012). It is an innovative approach, in which all the shareholders of a project can store the project related information in digital models and access this information through the life-cycle of a project. As a result of literature researches, studies on 4D / 5D modeling have been observed to focus on general features of 4D / 5D modeling elements. It has been determined that there are ambiguities and deficiencies particularly in the definition of the 5D model.

4D modeling integrates the schedule with 3D model and creates a simulation of the construction process based on the schedule. When creating the simulation, the schedule activities are linked with the building elements in the 3D model. Although 3D models and work schedules are available in contractors, 4D models are not yet widely used (Morkos et al. 2012). 5D modeling is integrating the 4D simulation with cost information. The purpose of

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this study is to define 5D modeling in detail and to assess the capacities of 4D/5D modeling software packages via comparison, and to assess the capacities of existing 4D/5D modeling software packages. To assess the capacities of 4D/5D modeling software packages, a test case was developed. A 3D model of a project was created in Autodesk Revit 2017 and 4D/5D models of the building were developed by using Autodesk Navisworks Manage 2017, Synchro Pro 2016.2 and Trimble Vico Office R6.0 software packages. In the test case, the stages and their durations when preparing 4D/5D models were identified and the advantages and disadvantages of each software package were determined.

2. Overview of the Test Case

The building that was modeled in BIM is an office building in Istanbul. It is a reinforced concrete structure and the total construction area is 26.000 m2. There are three basement floors, one ground floor, one mezzanine floor, 18 typical floors and one loft. In the first step, 3D model of the project was created in Autodesk Revit 2017. Three versions of the building model were created to determine the impact of different model sizes and disciplines in the study: (1) structural model of the basement, ground and mezzanine floors (Project1), (2) structural model of the entire building (Project 2), and (3) structural and architectural model of the entire building (Project 3) (Figure 1).

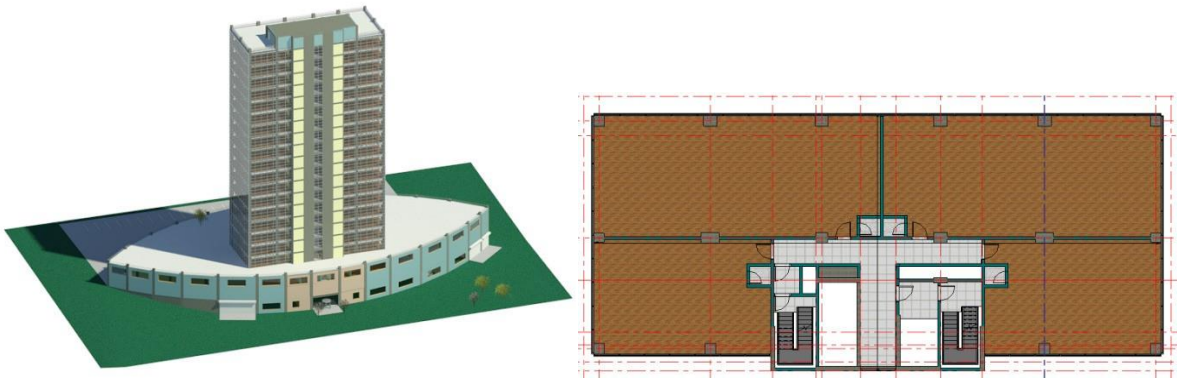


Figure 1: 3D rear view perspective and floor plan

In the second step, the schedules of each model were created using Oracle Primavera P6 Professional R16.1. Related resources and costs were assigned to the activities using the cost codes of the Ministry of Environment and Urbanization. The number of activities are 56 for Project 1, 170 for Project 2, and 470 for Project 3. Finally, 4D and 5D models were created in *Autodesk Navisworks Manage 2017, Synchro Pro 2016.2 and Trimble Vico Office R6.0.* The following steps were completed:

- Top: 2.5 cm;
- Creation of the 3D model in Revit 2017.
- Creation of the schedule including cost.
- Exporting the schedule from the Primavera P6 in the required format.
- Importing the 3D model and schedule in 4D/5D software packages (Navisworks, Synchro, Vico).
- Linking the 3D model elements and schedule activities.
- Preparation of 4D simulation.

3. Definition of 5D Modeling and Comparison of 5D Capacity

5D modeling is to produce the correct cost estimations from the components of the information model. 5D expressing a certain way of binding the data to an information model is a model based cost estimation method. Model based estimation expresses the se of the modeled elements and amounts of these elements as an important part of a cost plan. Three resources as model based estimation software, correctly constructed design model and cost data are needed to be able to conduct 5D modeling (Branz 2014). 5D BIM applications have been found to provide advantages in construction projects (1) fast and accurate takeoff, (2) fast and accurate cost planning, (3) full automation change management (Gülerses 2018).

Because it has been seen that the functions related to 5D has not been sufficiently explained in the literature, the applications in practice have been searched and 5D studies have been conducted on the sample project. As a result of this study, it has been seen that the cost burden models of Synchro have not been called as 5D. Functions necessary for a model to be able to be accepted as 5D have been determined by comparing to the software of Vico specified to have 5D capacity. In this respect, it has been determined that a direct connection should be provided among 3D, schedule and cost data for a model to be able to have 5D property and thanks to this connection, a change conducted on the model could automatically update the period and cost without any need for a manual process. For instance; let us plan that the starting concrete cost of a 100 m2 floor covering is 100 $ and the concrete casting period is 1 day in 3D model. Also, let us accept that after the establishment of the connection among the model, schedule and cost data, the floor covering model has been revised as 200 m2. In 5D modeling logic, there is need for any manual process to update the schedule and cost data according to the modification made in the model. It is seen that the floor covering concrete cost has risen to 200 $ and concrete casting period has risen to two days with the same resources automatically without conducting any process in the software. When considered in this respect; it is seen that the software items of Navisworks and Synchro do not have any structure directly updating the time and cost as in the software of Vico as well as containing the cost data. In summary; only the software of Vico could make 5D modeling among the used software items. Although the software items of Navisworks and Synchro contain some data related to the cost, they are not called as 5D modeling software items within BIM logic. Therefore, it is not a correct approach to say that 4D software items containing the data related to cost could make 5D modelling.

The cost data entered as resource to the schedule in the software of Navisworks are directly taken with the schedule or formed by using four different resources as the material, labor, equipment and subcontractor costs in the software. Cost data are entered to the related activities separately and the connection of the cost with the model is indirectly established. Software indirectly loads the cost information it carried on the related activity to the element it is dependent on the model. Any revision possible to be conducted such as dimension change or the time changes in the schedule in the model do not cause to any change in the cost data. At one point, the connection of "model-schedule-cost" in the software cannot be exactly provided. The cost distribution belonging to the building could also be followed on the previously prepared simulation in the software items not providing the sufficient opportunity of reporting regarding the cost.

As in Navisworks, previously loaded costs could be taken to the software with the schedule in the software of Synchro. There are also some differences between two software items in terms of cost. Synchro giving opportunity to some reporting processes such as the usage of the assigned resources, resource distributions and earned value analyses also provides more flexible opportunities in terms of the intervention to the schedule when compared to Navisworks. Software provides opportunities for the formation of resources inside itself and assigning unit price and amount to these resources. Any modification to be made in the resource unit price or amount automatically changes the activity

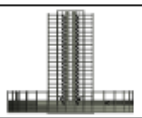
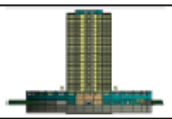
cost. While the resource (material, labor, equipment and subcontractor) cost could be entered in numbers in total or separately to the related activities, resources whose unit price and amount have been entered could be assigned to the related activities in Synchro. Despite some analysis and reporting properties related to the cost, it cannot be said that the software of Synchro could conduct 5D modeling; because, the model, schedule and cost connection necessary for 5D model cannot be exactly provided. Any change possible to be conducted on 3D model does not automatically reflect on the schedule and cost. Formation of resources will also take time as the number of detail and element in 3D increases. At this point, taking the costs to the software by loading them to the schedule is a method possible to be preferred to decrease the modeling time. In Vico, any modification possible to be made in 3D model automatically changes the time and cost.

4. Comparison of 4D/5D Software Packages

The performance of each software package (i.e., Navisworks, Synchro and Vico) was evaluated in terms of provided functionality and duration of each 4D/5D modeling step using three versions of the model. Table 2 presents the results of this comparison. The duration of schedule creation and 3D model creation was not included in the scope of this study. It has been observed that the durations of 4D modeling of all three versions of the model are close to each another for Navisworks and Synchro. For instance, 4D model of Project 3 was completed in one hour using Navisworks and in one hour and 5 minutes using Synchro. The linking of the schedule and 3D model takes the highest amount of time during 4D modeling. It has been detected that 78% and 86% of the total duration was spent on average to create 4D model in Synchro and Navisworks respectively. It should be noted that automatic connection methods was not used when linking the model with the 3D model elements and the activities. 4D simulation could not be exported in Vico since there is no export option of 4D simulation in Vico. It has been observed that the activity number in the schedule did not affect the durations of import and export due to the fact that they do not contain any visual data.

A certain period of time is needed for the entering some information, such as cost and material during 5D modeling, which could only be performed using Vico. When all the processes examined necessary to create 5D model are considered, the process for which the highest period of time has been spent is entering related cost data and linking them with the 5D modeling elements.

Table 1. Duration of 4D/5D modeling stages in three software packages

		 **Project 1** Structural Framework (Basement Floors - Ground Floor - Clerestory Floor) Construction Period: 7 month Activity Number: 56 ea Building Area: 14.500 m^2 Joint Number: 62 ea Simulation Period: 20 sec.	 **Project 2** Structural Framework (Basement Floors - Ground Floor - Clerestory Floor - Normal Floors - Garret Floor) Construction Period: 15 month Aktivity Number: 170 ea Building Area: 26.000 m^2 Joint Number: 176 ea Simulation Period: 40 sec.	 **Project 3** Structural & Architectural Construction Period: 21 month Aktivity Number: 470 ea Building Area: 26.000 m^2 Joint Number: 622 ea Simulation Period: 60 sec.
Save As (3D Model) .rvt	Revit	~ 8 sec.	~ 11 sec.	~ 16 sec.
Export (3D Model) .ifc	Revit	~ 12 sec.	~ 33 sec.	~ 1 min. 32 sec.
Export (Schedule) .xml	Primavera	~ 4 sec.	~ 5 sec.	~ 7 sec.
Import / Open (3D Model)	Navisworks .rvt	~ 17 sec.	~ 27 sec.	~ 1 min. 15 sec.
	Navisworks .ifc	~ 6 sec.	~ 16 sec.	~ 1 min. 22 sec.
	Synchro .ifc	~ 3 sec.	~ 8 sec.	~ 42 sec.
	Vico .ifc	~ 1 min. 45 sec.	~ 2 min. 52 sec.	~ 7 min. 13 sec.
	Vico Add-Ins in Revit	~ 1 min. 17 sec.	~ 1 min. 47 sec.	~ 5 min. 17 sec.
Import / Prepare (Schedule)	Navisworks .csv	Instant (~1 sec.)	Instant (~1 sec.)	Instant (~1 sec.)
	Synchro .xml	~ 6 sec.	~ 6 sec.	~ 6 sec.
	Vico	~ 14 min. 58 sec.	~ 48 min. 53 sec.	-
Schedule & 3D Model Connection	Navisworks .rte - .csv	~ 3 min. 30 sec.	~ 12 min. 37 sec.	~ 56 min. 29 sec.
	Synchro .ifc - .xml	~ 2 min. 56 sec.	~ 12 min. 8 sec.	~ 56 min. 6 sec.
	Vico	~ 1 min. 34 sec.	~ 5 min. 35 sec.	-
Visualisaiton	Navisworks	Instant (~3 sec.)	Instant (~3 sec.)	Instant (~3 sec.)
	Synchro	Instant (~3 sec.)	Instant (~3 sec.)	Instant (~3 sec.)
	Vico	Instant (~3 sec.)	Instant (~3 sec.)	-
4D Simulation Export	Navisworks .avi	~ 26 sec.	~ 43 sec.	~ 1 min 17 sec.
	Synchro .avi	~ 57 sec.	~ 2 min. 25 sec.	~ 6 min 50 sec.
	Vico [5]	-	-	-
Position-Material-Cost (5D Elements)	Vico	~ 14 min. 13 sec.	~ 30 min. 26 sec.	-

5. Challenges in Modeling

The challenges that were identified during 4D/5D modeling are as follows:

- There were no problems observed during the import of the schedule to Navisworks in CSV format and in Synchro in XML format. However, schedule could not be imported to Vico due to the fact that the import tab is not active. Therefore, the schedules were prepared again by using Vico Planner available in the software itself.
- The schedules prepared using Primavera and Ms Project could be directly imported in 4D/5D software items and they could also be prepared in certain amounts inside the software items. Connection between the activities cannot be provided in Navisworks in the schedule exported or prepared inside the software. Due to the lack of connection; when the starting and end dates of any activity are changed, other work items are not affected from this modification. Various resources such as labor, material, equipment and subcontractor could be entered as cost to the activities, but sufficient cost reports cannot be attained. Very flexible opportunities are provided to the users in the issue of the preparation of the schedule within the software by Synchro. Resources could also be assigned as well as the establishment of the connection between the prepared schedule activities. Software also provides opportunities for some cost reporting such as the usage of the assigned resources, resource distributions and gained value analyses. In Vico, the schedules are prepared with the use of Vico Planner. The most important specifications separating Vico from Synchro software are the submission of more comprehensive cost reporting and having march chart display.
- When the stages in 4D modeling are considered, it has been detected that the highest period of time has been spent for the connections of the model elements and the activities after the preparation of 3D model and the schedule. There also occurs an increase in the time needed for the connection as the 3D level detail level and activity number increase. The sets formed in 4D software items and some

formulations are among the factors decreasing this connection period. Users will need convenient sets they will prepare and model-compatible schedule for the purpose of not losing so much time at this stage.

- It is also possible to export the prepared simulation and submit it to the knowledge of the project participants. It is possible to export the simulation in the desired properties in Navisworks and Synchro and this process takes a certain time depending on the dimension of the file. The option of the export of the simulation which is a very important property is not existent in Vico. Simulation could only be monitored within the software, but it cannot be exported.
- All three examined software items contain the data related to cost at a certain ratio. It will be fruitful for the people who will prefer the software to determine what they expect from the software regarding the cost. If the update of all the budget data and schedule is expected in an automatic way instead of a manual process following a revision to be made on the model, it will be correct to prefer Vico; if some reportings such as earned value analyses and resource inputs to 4D/5D software items are desired, it will be correct to prefer Synchro and if it is desired to see only the change of the cost data depending on time in 4D simulation, then it will be correct to prefer Navisworks.

Consequently; it cannot be cited that all of the properties desired in 4D/5D modeling are existent in a single software. For instance; when the reports related to cost are considered, while the software of Vico is sufficient for the users, Navisworks software is insufficient at this point. In the contrary case, it has been observed that learning the software of Navisworks is easier when compared to the software of Vico (Table 2).

Table 2. Comparison of the Software Packages

	Navisworks	**Synchro**	**Vico**
1	Clash detection	Schedule	Cost data and reportings
2	Easy to learn	4D simulation	5D capacity
3	Visuality	Cost data and	Schedule capacity

6. Conclusions

In this study, the first step was to define the characteristic features of 5D modeling. After that, durations of the 4D/5D modeling processes were determined and compared by using Autodesk Navisworks Manage 2017, Synchro Pro 2016.2 and Trimble Vico Office R6.0, which are the leading commercial software packages in 4D/5D modeling.

According to the results of the study; it has been determined that a direct connection should be provided among 3D, schedule and cost data for a model to be able to have 5D property and thanks to this connection, a change conducted on the model could automatically update the period and cost without any need for a manual process. Consequently; it has been detected that only the software of Vico could conduct 5D modeling among the used software items and the software items of Navisworks and Synchro have not been accepted as 5D modeling software items although they contain some information regarding the cost.

4D/5D model steps have been defined and their periods have been determined in the results of the study. When 4D modeling stages are considered, it has been detected that the highest period of time has been spent in the connection of 3D model elements and schedule items (81%) and it has been spent at the stage of the arrangement of cost data and entering them in the software (40%) in 5D modeling. It has been observed that each software has some leading properties when compared to others. While Navisworks is at the forefront with the properties of clash detection and the reporting of these results, Synchro catches the attention with the usage easiness of the schedule it provides to the users and Vico is prominent with the reportings it forms regarding the cost.

It will be beneficial for the companies to determine what they expect from the modeling before choosing the software they will use especially in 4D/5D modeling. When the fact that the software items will not meet all the

requests and expectations of the users is taken into consideration, it is important for the modelers not to neglect this point so as not to have any problem in the modeling and reporting phases.

The results of this study will be able to be used as a guide by the companies desiring to conduct 4D/5D application in the sector. Within the scope of the study, the element modeling belonging to the mechanical and electrical disciplines have not been conducted. Neglecting the preparation periods of the schedule and 3D model, manual performance of the schedule and 3D model connection and no examination of Project3 in the software of Vico are other limitations of the study. It is thought that similar studies will be conducted in a more detailed way for the projects in which all discipline elements such as statics, architecture, electricity and mechanics are modeled.

ACKNOWLEDGEMENTS. This paper was presented to 5th International Project and Construction Management Conference (IPCMC2018) Cyprus International University, Faculty of Engineering, Civil Engineering Department, North Cyprus.

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