CONSTRUCTION PROGRESS VISUALIZATION FOR VARIED STAGES OF THE INDIVIDUAL ELEMENTS WITH BIM: A CASE STUDY

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Abstract

Building information modeling (BIM) is an intelligent 3D design and modeling process that gives architects, engineers, construction and facility managers the ability and tools to plan, design, construct and manage buildings more effectively and efficiently. Currently, the construction progress is monitored by comparing the baseline project schedules, which include the planned dates and resources, with the actual dates in the updated schedules. 4D scheduling is used in the construction industry for linking individual model elements with the schedule activities to visualize the progress of construction activities. However, the limitation of this approach is a need for the creation of a dedicated activity for monitoring each model element, which can result in an excessive number of activities. This paper presents a construction progress visualization method, which uses a custom developed add-in to present the status of building elements (e.g., planned, installed) without linking them with the schedule. The new tool enables a visual presentation of the progress of each element within the BIM model during different stages of the construction process to increase the decision-making capabilities. A case study is used to demonstrate the capabilities of the developed BIM add-in tool for construction progress visualization.

Introduction

Updating the project schedules requires actual progress data collection from the site (Abdelsayed and Navon, 1999). For example, the comparison between the actual and planned progress shows the project deviations, whereas the automated progress monitoring enables an equitable measure of the project performance and each activity actual dates can be defined more precisely (Turkan *et al.*, 2012). One of the most important tasks of construction management is to track the progress and take corrective actions required on time. Software packages such as Microsoft Project and Oracle Primavera are widely used in the construction industry for this purpose. Planning software is based on activities defined in different work breakdown structures with planned and actual dates for each activity. In addition to the dates, many other parameters can be loaded to the activities, such as resources or quantities for reporting purposes. It is possible to receive a planned versus actual data from the software and also report activities that are in the critical path of the project. All these reports created by using the software are limited with the activities defined that do not include a visual representation of the project.

Updating the schedules with actual progress at the site and creating reports requires the necessary skills in using the related software. Moreover, progress is monitored based on activities. Consequently, it is not possible to monitor each stage in the project or each status of the activities in a large-scale project due to the excessive number of activities. However, in some cases, it is necessary to monitor the critical building elements at this level of detail to make proactive decisions. Reinhardt et al. (2004) developed an approach to collect data for the project management tasks by employing navigational models as well as identified that the interaction between data at different levels of detail is one of the needs for progress monitoring.

4D scheduling is another method that combines the schedule with the BIM model elements to visually represent the progress at the construction site. Visualization of the progress increases the decision-making capabilities of project managers through the latest data collected from the progress performance (Golparvar-fard *et al.*, 2009). Furthermore, 4D scheduling has been utilized for the planning and constructability review as well as for the improvement of the coordination and collaboration between the projects' stakeholders (Mahalingam et al., 2010). Software packages, such as Autodesk Navisworks Manage, Synchro Pro Software, and Vico Office have functionalities for linking the model elements automatically with the work schedule through a common parameter (Figure 1, and Figure 2). Although 4D simulations are commonly used in the construction industry for the last decade and provide valuable information to decision-makers, a limitation is that they are based on schedules, which have a limited number of manageable activities. Since

the number of activities is limited, the granularity of the progress data is low. As a result, the representation of all statuses and stages of a large scale project is often not possible due to a large increase in the number of activities in the schedule.

The majority of studies that updated the BIM model based on the progress of building elements performed this update automatically by matching the activity ID and the 3D element ID. Kim et al. (2013) proposed a methodology for automatic updating of the 4D model by using image processing to monitor construction progress. Tuttas et al. (2014) presented two approaches for automatic monitoring of the construction site, firstly generation of as-built data, and secondly comparison between planned and the as-built data. Getuli et al. (2016) described a workflow using apps and mobile devices for information exchange in construction. However, this approach only allowed visualization of the installation activities and required properly structured schedule information. In contrast, we present an approach for progress monitoring of the various status of building elements without the need for integration with the schedule information.

Several strategies for automatic collection of the construction progress data using advanced technologies have been explored by the researchers (Turkan et al., 2012; Shih and Wang, 2004; Golparvar-fard et al., 2015; Son and Kim, 2010). These studies used remote-sensing technologies (e.g., laser scanning) and demonstrated that visual information from the site could be collected as a point cloud data and compared directly with a building information model of the project. For example, Park et al. (2017) developed a real-time web and database-supported visualization method for presenting the latest information in 4D BIM models. Also, Chen and Luo (2014) proposed to integrate the construction quality management system and 4D BIM application for improving the current processes.

However, the previously developed methods for automatic collection of the construction progress data can only be used for verifying the construction progress percentage or checking whether the element is installed, and they do not provide information about other stages of the elements (e.g., tested or inspected). Moreover, the tracking methods of the construction progress that are used in the industry - even with emerging technologies- are based on the activities defined in the work schedules of the project which includes planned or installed status only.

The goal of this paper is to define an element based tracking method for the visualization of the actual progress of each element (i.e., the lowest level of detail in the model, for different custom status). The four main statuses of mechanical and electrical services during the construction phase, (i.e., planned, installed, tested and inspected) are represented for

each element in the building information model to demonstrate the potential use of the approach. These statuses were chosen since they are the ones that are challenging to track efficiently for electrical and mechanical components (Love et al., 2019). The other component statuses that can be potentially used for this purpose include "ordered", "shipped", "received", "critical", "waiting for inspection", or "on hold". Color coding is defined for each status and visualized in the 3D model based on the status of each element.
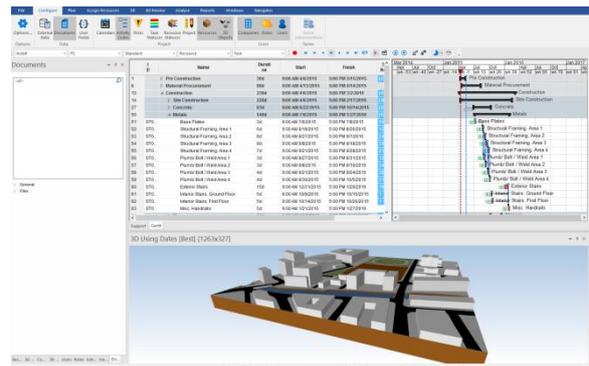
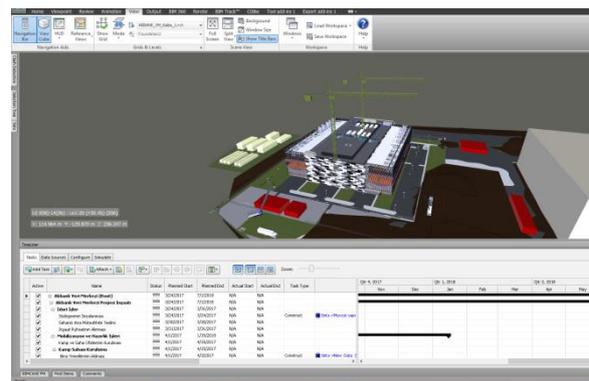

Figure 1: Sample view of Synchro software

Figure 2: Sample view of Autodesk Navisworks software

The BIM software, Autodesk Navisworks Manage (2018), was used for development of the new add-in. This software package was selected for two main reasons: (1) it is compatible with different software packages, and (2) it does not allow users to make any model revisions. The former provides access to all data collected from a wide range of file formats, whereas the latter prevents any unintentional model changes.

The developed add-in is user-friendly, simple to use and can be easily facilitated for different buildings construction progress visualization with the flexibility to define new status definitions. The BIM model of data center facility, which includes structural, architectural, mechanical and electrical elements, is used as a case study for the demonstration of the developed BIM add-in technology. A detailed description of the methodology including

demonstrations from the case study is presented, and the findings and conclusions are provided.

Description of case study building

The case study is a data center building that is under construction in Turkey and aimed to be completed in 2019. The facility is constructed on 75,486 m² and includes 52,000 m² of data center space, 3,000 m² of conference space, 10,500 m² of underground carparks, and 34,000 m² of landscaping. Four floors of the data center building are selected as the case study to demonstrate the application of the developed add-in.

The main reason for selecting a data center building as a case study is its' unique requirement for monitoring of the construction progress. The data centers are value-added services that offer resources for processing and storing data on a large scale for organizations of any size. They have complex mechanical and electrical systems to operate 24 hours and seven days a week and are equipped with fire protection systems. Moreover, the data centers' electrical and mechanical services are tested by the international standards, whereas installation sequences need to follow the completion of commissioning. Also, the site inspections following the testing are the predecessor for following installations and need to be monitored and recorded. While the visual representation of the completed installation, testing, and inspections present very valuable information for the data center construction, it also improves the construction planning.

Methodology

Autodesk Revit (2018) was used as BIM authoring software since it is one of the most commonly used BIM authoring tools according to the surveys conducted by the National Building Specification (NBS) for last three consecutive years (NBS, 2016; NBS, 2017; NBS, 2018). Additionally, the same software supplier provides other tools fully compatible with their BIM authoring software. The main goal of our approach is to develop a custom add-in for an element based status tracking method that allows for updating multiple statuses at once. The used Autodesk Navisworks Manage 2018 comes with application programming interface (API) and software development kit (SDK). The add-in is developed in MS Visual Studio 2015 for Autodesk Navisworks Manage 2018. Moreover, Autodesk Navisworks Manage is used for visualizing, clash detection and 4D work schedule integration.

Each model element has specific parameters loaded from BIM authoring software, and their values are represented in the Properties tab after selecting the individual elements. These properties are grouped in different tabs based on the BIM authoring software use. It is possible to include progress data of each

building element (e.g., statuses) by adding custom parameters and values. However, it is not possible to select multiple elements and add custom parameters to these elements at the same time. Consequently, since there are high numbers of elements in the project, updating the statuses of elements is a tedious process when performed by hand.

The add-in is created using windows for the application template of MS Visual Studio with .net framework 4.5.2. Firstly, in the software, a connection is created between .net and .comapi for writing new parameters and their values to the elements (Figure 3). Next, the defined property category data is added to each selected model element and a control operation is defined to prevent any duplicated information (Figure 4).

```
'COMAPI .net connect
    Dim nwState As Autodesk.Navisworks.Api.Interop.ComApi.InwOpState10
    nwState = Autodesk.Navisworks.Api.ComApi.ComApiBridge.State

    'create new Property Category Vector
    Dim newPvec As Autodesk.Navisworks.Api.Interop.ComApi.InwOaPropertyVec
    newPvec = nwState.ObjectFactory(Autodesk.Navisworks.Api.Interop.ComApi.nwEObjectType.eObjectType_nwOaPropertyVec)

    'propertycategory vector
    For Each row As DataRow In dtProperty.Rows
        'create new property
        Dim newP As Autodesk.Navisworks.Api.Interop.ComApi.InwOaProperty
        newP = nwState.ObjectFactory(Autodesk.Navisworks.Api.Interop.ComApi.nwEObjectType.eObjectType_nwOaProperty)

        'set name, username and value of the new property
        newP.name = row.Item("Property_Name")
        newP.UserName = row.Item("Property_Name")
        newP.value = row.Item("Property_Value")
        'add the new property to the new Property Category
        newPvec.Properties().Add(newP)

    Next
```

Figure 3: Code for connection between .net and .comapi

```
Dim oItem As Autodesk.Navisworks.Api.ModelItem
    Dim oDOC As Autodesk.Navisworks.Api.Document
    oDOC = Autodesk.Navisworks.Api.Application.ActiveDocument

    'add property category to each item selected
    For Each oItem In oDOC.CurrentSelection.SelectedItems
        'select path of the item
        Dim oItemPath As Autodesk.Navisworks.Api.Interop.ComApi.InwOaPath
        oItemPath = Autodesk.Navisworks.Api.ComApi.ComApiBridge.ToInwOaPath(oItem)
        'select Property Category from path
        Dim PropCat As Autodesk.Navisworks.Api.Interop.ComApi.InwGUIPropertyNode2
        PropCat = nwState.GetGUIPropertyNode(oItemPath, True)

        If CheckBox1.Checked = True Then
            Dim PropCatAtt As Autodesk.Navisworks.Api.Interop.ComApi.InwGUIAttribute2
            Dim checkAtt As Boolean = False
            For Each PropCatAtt In PropCat.GUIAttributes()
                If PropCatAtt.ClassUserName = TextBox1.Text() Then
                    checkAtt = True
                    MsgBox("You Selected Existing Tab " & TextBox1.Text() & " to remain." & vbCrLf & "Please give a
unique TAB NAME to prevent duplicate data." & vbCrLf & vbCrLf & "Sample:  " & TextBox1.Text() & "_1",
MsgBoxStyle.OkOnly, "BIMCAVE")
                    TextBox1.Text = TextBox1.Text() & "_1"
                    Exit Sub
                End If
            Next
            'if the PropertyCategory does not exist add it
            If Not checkAtt Then
                PropCat.SetUserDefined(0, TextBox1.Text, TextBox1.Text, newPvec)
            End If
        End If

        If CheckBox2.Checked = True Then
            Dim PropCatAtt As Autodesk.Navisworks.Api.Interop.ComApi.InwGUIAttribute2
            Dim Index As Integer = 1
            For Each PropCatAtt In PropCat.GUIAttributes()
                If Not PropCatAtt.UserDefined Then Continue For
                If Not PropCatAtt.ClassUserName = TextBox1.Text() Then
                    Index += 1
                    Continue For
                End If
                PropCat.RemoveUserDefined(Index)
                Exit For
            Next
            PropCat.SetUserDefined(0, TextBox1.Text, TextBox1.Text, newPvec)

        End If

    Next
    MsgBox("PROPERTIES LOADED UNDER NEW TAB :" & vbCrLf & TextBox1.Text, MsgBoxStyle.OkOnly, "BIMCAVE")
```

Figure 4: Code for adding the property category data

The user can select multiple elements at the same time based on the status of each element (i.e., planned, installed, tested and inspected). Elements can be selected manually from the model or by using find items in-built functionality of the Navisworks. Element selections can be saved for future references and used through search or selection sets. While the selection sets are used to store the selected elements, they do not refresh the selection. Instead, the search sets refresh the selected elements based on the defined criteria in each run. On the other hand, the individual element selection enabled to change the

status of each element based on the progress at the site.

A custom tab name, parameter name and parameter value can be defined using the Add-in for the selected elements. The workflow for loading custom parameters is aimed to be simple and user-friendly with three basic steps: (1) selecting elements, (2) specifying the parameter values, and (3) loading to the elements, as the user form illustrated in Figure 5. It is also possible by the software in-built functionalities to filter elements based on the custom parameters loaded as well as change the visual properties, such as making transparent or change color temporary. Appearance profiler built-in functionality of the Autodesk Navisworks software is used for changing the elements' visual properties based on the defined values of their parameter. In the case study, the following set up was used: transparent for the planned elements, green for the installed elements, blue for the tested elements, and red for the inspected elements.
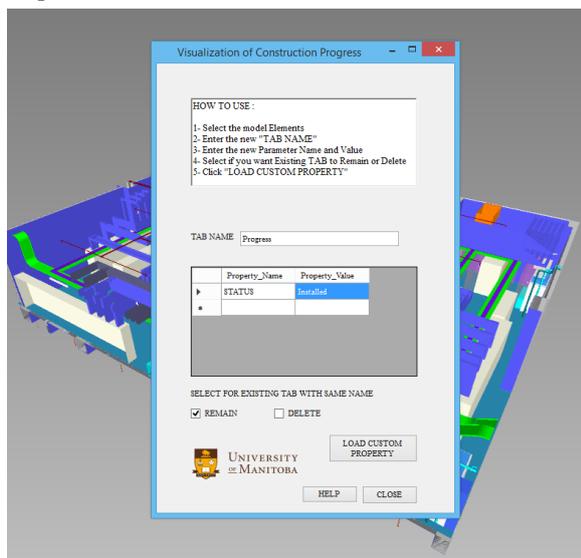

Figure 5: Add-in user form view

Structural and architectural model elements are selected manually from the model and progress status of the elements were entered to the model. Search sets used for loading the actual status to the elements are created for electrical and mechanical elements based on their installation, testing and inspection sequences. A sample room with a total area of 538 m2 was selected for visualizing the results of our approach using the developed add-in and in-built functionalities of Navisworks. In addition to structural and architectural elements, the sample room has 2,080 elements including cable trays, bus bar system, electrical equipment, sprinkler and ductwork for the ventilation. The status of each

element is loaded using the add-in for compliance with construction progress for six consecutive months.

Results

The work schedule used for this project has 1,855 activities including the contractual, design, and construction activities. The construction phase only includes the installation activities, whereas the hand-written daily reports monitor the status of tested or inspected elements. It is a common practice to define the installation activities of the work schedules based on floor, system or zone. Consequently, the monitoring for individual elements is not possible with the existing work schedule breakdown. Besides, the project has 131,952 model elements that need to be monitored. As a result, a large number of building elements prevents the creation of the individual activities for each element, and the installation progress monitoring is limited with the activities defined in the work schedule. Table 1 presents a summary of the status change of the model elements for six months. Furthermore, Figure 6 presents the visualization of the monthly status change of model elements. The model elements that are monitored using this approach can also be more specific. For example, the hanger and support of the piping systems can also be monitored. This level of detailed information provides the decision-makers with a higher level of understanding of the progress at the site.

Table 1: Status change of model elements for six months

Model Elements	Months					
	1	2	3	4	5	6
Structural System	Installed	Installed	Installed	Installed	Installed	Installed
Cable Trays	Planned	Installed	Tested	Inspected	Inspected	Inspected
1,000A Busbar	Planned	Planned	Installed	Installed	Tested	Inspected
3,000A Busbar	Planned	Planned	Installed	Installed	Tested	Inspected
4,000A Busbar	Planned	Planned	Planned	Installed	Installed	Inspected
5,000A Busbar	Planned	Planned	Planned	Installed	Installed	Inspected
Sprinkler system	Planned	Planned	Planned	Planned	Installed	Tested
HVAC system	Planned	Planned	Planned	Planned	Planned	Tested
Main Equipment	Planned	Planned	Planned	Planned	Planned	Installed

During the construction phase, the progress data is collected using 2D drawings, daily reports, site photographs (e.g., laser scanning). In 4D process, all this data for individual elements collected from the site is not effectively used. The progress is only represented if it is related to a dedicated activity in the schedule. Therefore, the data available for individual elements are not used for visualizing the construction progress. Instead, only the progress based on the activity definitions can be visualized. The results of the proposed approach show that it is possible to visualize the construction progress data based on each element.

(a)

(b)

(c)

(d)

(e)

(f)

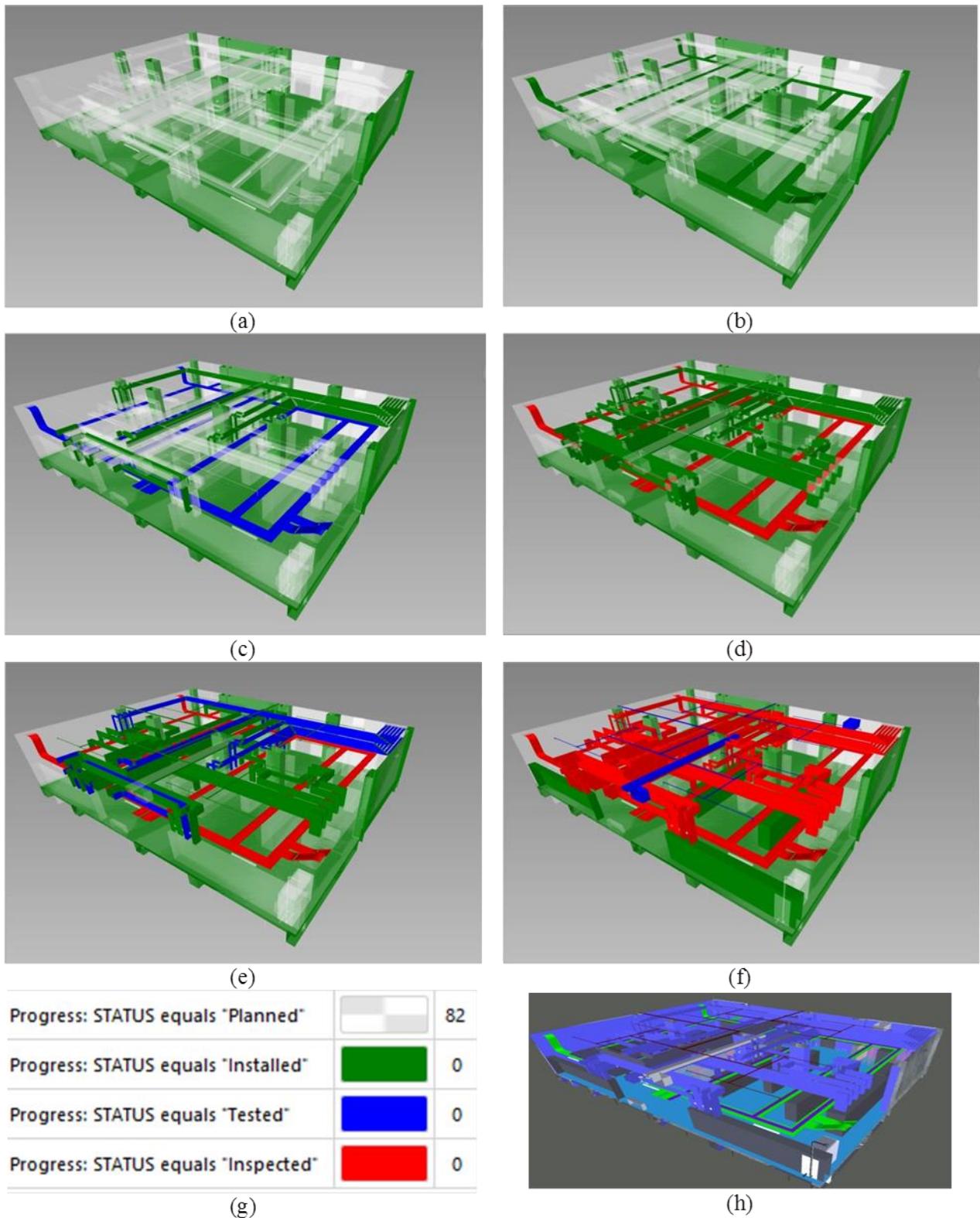| Progress: STATUS equals "Planned"		82
Progress: STATUS equals "Installed"		0
Progress: STATUS equals "Tested"		0
Progress: STATUS equals "Inspected"		0

(g)

(h)

Figure 6: Visualization of 6 months progress: (a) first month progress; (b) second month progress; (c) third month progress; (d) fourth month progress; (e) fifth month progress; (f) sixth month progress; (g) color coding for status; (h) 3D model of the case study room

The visualization of the case study results shows different status of the elements in a 3D environment.

The two main advantages of the developed approach are: (1) it allows selection of individual model

elements and loading data to these elements, and (2) it supports the selection of the model's elements from different systems and monitoring progress status of each element. In our case study, we defined two additional status 'tested' and 'inspected.' On the other hand, the use of the 4D scheduling method would require the creation of the additional 263,904 activities next to the existing installation activities.

Conclusions

In the common practice, visualization of the 4D process is limited with the activities defined within the construction schedules, and it is not possible to define the activity of each element status. This paper proposes a new add-in method for visualization of the status progress of the building elements (e.g., inspected, tested) within the BIM models. The add-in is developed in Navisworks, and it enables project monitoring based on the individual elements. The effectiveness of the developed method is tested using the complex data-center building as a case study. A sample room with a large number of elements is selected to present the monthly construction progress visualization over the six months. The results show that it is possible to successfully monitor construction progress based on the individual elements in the model. This approach increases the planning ability of decision makers and allows easier foreseeing of the potential problems.

One of the limitations of our approach is the requirement of Navisworks software. However, Navisworks is a widely used tool in the construction industry, and it comes with other Autodesk products. Another limitation of the proposed approach is that the construction progress is monitored based on the elements that do not have any relation with the construction schedules (e.g., actual dates). While the main goal of this paper is to propose the new method for visualization of the construction progress based on the model elements, separate parameters within the developed add-in can be used to load actual dates for the elements.

The future work will include the expansion of the proposed method to allow instant data integration with handheld devices, which can be used for the updating of the element parameter values. Furthermore, further integration will be developed - using the unique ID of model elements and work breakdown structure codes of schedules- between construction schedule software and proposed method for updating the actual schedule data from the add-in. Future work will include adding additional parameters such as the actual dates, related entity names, and reference document links to the individual elements. This approach will enhance the visualizations of the construction progress and create a valuable database for the project handover and facility management.

References

Abdelsayed, M. and Navon, R. (1999.) An Information Sharing, Internet-Based, System for Project Control. *Civil Engineering and Environmental Systems*, 16(3), pp.211–233.

Chen, L. and Luo, H. (2014.) A BIM-based construction quality management model and its applications. *Automation in Construction*, 46, pp.64–73.

Getuli, V., Ventura, S.M., Capone, P. & Ciribini, A.L.C. (2016.) A BIM-based Construction Supply Chain Framework for Monitoring Progress and Coordination of Site Activities. *Procedia Engineering*, 164, pp.542–549.

Golparvar-fard, M., Pena-mora, F., Arboleda, C.A. & Lee, S. (2009.) Visualization of Construction Progress Monitoring with 4D Simulation Model Overlaid on Time-Lapsed Photographs. *Journal of Computing in Civil Engineering*, 23, pp.391–404.

Golparvar-fard, M., Pena-mora, F., & Sevarese, S. (2015.) Automated Progress Monitoring Using Unordered Daily Construction Photographs and IFC-Based Building Information Models. *Journal of Computing in Civil Engineering* 29(1), pp.1–19.

Love, P. E. D., Zhou, J., & Matthews, J. (2019.) Project controls for electrical, instrumentation and control systems: Enabling role of digital system information modeling. *Automation in Construction*, 103, pp.202–212.

Kim, C., Kim, B. & Kim, H. (2013.) 4D CAD model updating using image processing-based construction progress monitoring. *Automation in Construction*, 35, pp. 44–52.

Mahalingam, A., Kashyap, R., & Mahajan, C. (2010.) An evaluation of the applicability of 4D CAD on construction projects. *Automation in Construction*, 19(2), pp. 148–159.

NBS (2016.) NBS National BIM Report 2016. Available at: https://www.thenbs.com/knowledge/national-bim-report-2016.

NBS (2017.) NBS National BIM Report 2017. Available at: https://www.thenbs.com/knowledge/nbs-national-bim-report-2017.

NBS (2018.) NBS National BIM Report 2018. Available at:

https://www.thenbs.com/knowledge/the-national-bim-report-2018.

Park, J., Cai, H., Dunston, P.S., & Ghasemkhani, H. (2017.) Database-Supported and Web-Based Visualization for Daily 4D BIM. *Journal of Construction Engineering and Management*, 143(10), pp.1–12.

Reinhardt, J., Akinci, B. & Jr, J. H. G. (2004.) Navigational Models for Computer Supported Project Management Tasks on Construction Sites. *Journal of Computing in Civil Engineering*, 18, pp.281–290.

Shih, N. and Wang, P. (2004.) Point-Cloud-Based Comparison between Construction Schedule and As-Built Progress : Long-Range Three-Dimensional Laser Scanner's Approach. *Journal of Architectural Engineering*, 10, pp.98–102.

Son, H. and Kim, C. (2010.) 3D structural component recognition and modeling method using color and 3D data for construction progress monitoring. *Automation in Construction*, 19(7), pp.844–854.

Turkan, Y., Bosche, F., Haas, C. & Haas, R. (2012.) Automated progress tracking using 4D schedule and 3D sensing technologies. *Automation in Construction*, 22, pp.414–421.

Tuttas, S., Braun, A., Borrmann, A. & Stilla, U. (2014.) Proceedings of the *Comparision of photogrammetric point clouds with BIM building elements for construction progress monitoring. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Zurich, Switzerland, pp. 341–345.