A Feasibility Study of IFC-Based BIM 4D Simulation Using Commercial Systems to Support Construction Planning in the U.S.

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Building information modeling (BIM) 4D simulation's support in construction planning is important given the current trend in decreasing number of experienced construction planners. However, the adoption rate of BIM 4D simulation is relatively low comparing to other BIM uses. An improved BIM interoperability can help achieve more benefits of BIM use. Industry foundation classes (IFC) is an ISO registered data standard for building and construction industry data. It plays key roles in BIM interoperability. In this paper, the authors investigated the feasibility of using IFC-based BIM in creating 4D simulations with three different commercial platforms (Navisworks, Synchro, and Navigator). Experiments were conducted in creating 4D simulations of a simple bridge model and a complex duplex apartment model. It was found that: (1) the 4D simulations were successfully created in all three platforms therefore the feasibility was tested; (2) the IFC-based interoperability in this 4D simulation could be best achieved by using separate architecture, engineering, and construction (AEC) objects during importation; and (3) the round trip from 4D simulations back to IFC models was still missing. Future research is recommended to investigate innovative methods that improve 4D simulation using integral IFC models and enable round trip interoperability with IFC models.

Key Words: 4D simulation, Industry foundation classes (IFC), Building information modeling (BIM), Interoperability, Construction planning.

Introduction

The lack of software interoperability has baffled the AEC industry for several decades. It was reported by the National Institute of Standards and Technology (NIST) that the incurred cost due to the lack of interoperability in the facilities industry was estimated to be 15.8 billion USD per year in the US (Gallaher et al., 2004). Ten years later, a survey of contractors in the McGraw-Hill Construction report (McGraw-Hill Construction, 2014) showed that almost half (46%) of the contractors with heavy software use experience considered the needs in interoperability improvement to be of high/very high importance. The lack of software interoperability mainly reveals itself in the form of missing information and information inconsistency, when models are exported from one software and imported into another. In the extreme case, models cannot be transferred between two software at all and the new model must be recreated from scratch.

BIM is intended to be interoperable since its first introduction. BIM is defined to be "a data rich digital representation cataloging the physical and functional characteristics of design and construction" (GSA, 2007), and "serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward" (NIBS, 2007). BIM research and applications have surged in recent years, which support many practical tasks in the AEC industry such as structural analysis, cost estimation, and construction planning (Kreider et al., 2010). In spite of the great intent of BIM to be fully interoperable, a seamless BIM interoperability is far from reality (Poirier et al., 2014). As BIM software are provided by various commercial companies, they usually use proprietary data representations that are unique and tend to be compatible only with software created by the same company (Redmond et al., 2012). While the various BIM applications developed by commercial companies greatly facilitated the adoption of BIM, the inherent proprietaries, however, to a certain extent hindered the interoperability of BIM. For example, the McGraw-Hill Construction report (2014) reported a negative value/difficulty ratio for energy and structural analysis using BIM, which means that it is actually easier to recreate the BIM for energy and structural analysis rather than reusing existing BIM that has been created in a different BIM authoring platform (McGraw-Hill Construction, 2014). In view of this interoperability problem, twelve companies came together in 1994 and proposed an open standard to facilitate information exchange in the AEC industry (Kiviniemi, 2006). This, a few years later, became the widely known IFC schema. The IFC schema defines a standard data exchange format in the construction and facility management industries. It was registered as ISO 16739 (ISO, 2013). With the wide adoption of IFC, almost all commercial BIM platforms claim to be compatible with IFC. Therefore, BIM 4D modeling should be achievable using IFC-based BIMs. To test this feasibility, the authors initiated the investigation on the use of IFC-based BIMs in 4D simulation to support construction planning in the US.

BIM 4D simulation was introduced to help with the construction planning process. BIM 4D simulation links construction activities and schedules to 3D building objects to simulate the construction progression over time (Eastman et al., 2011). It can be used at various stages of construction to analyze the design's constructability (Aldafaay et al., 2017) and to conduct construction planning and monitoring tasks, with intuitive information display and high information transparency (Hartmann et al., 2008; Tulke & Hanff, 2007). Four-D simulation was introduced prior to the introduction of BIM, but BIM 4D simulation gains from the integration of multidimensional construction data from BIM, especially the 3D models of building objects; because BIMs are object-oriented (Collier & Fischer, 1995). BIM 4D modeling enables a vivid display of detailed and accurate work plans that include information that support multiple construction management tasks, ranging from managing temporary structure, quantity take-offs, to managing site logistics (Dang & Tarar, 2012). Such information supports three main functions through the simulation - planning, visualization, and analysis (Kriphal & Grilo, 2012). Implementing 4D modeling allows planners to detect potential problems prior to the actual construction phase, which can lead to a reduction in the amount of rework and clashes. Because of the conceivable benefits in using 4D simulation for construction planning, many research efforts were conducted in the past two decades on developing, exploring, and/or analyzing 4D simulations. For example, Adjei-Kumi & Retik (1997) proposed a 4D visualization framework of construction processes at activity and component levels using a library of 3D graphical images of building components, facilities, and related activites. Kam et al. (2003) explored and analyzed a product model and fourth dimension (PM4D) approach in managing the design and construction of a university building project in Finland, in which they concluded the use of PM4D could bring "higher efficiency, better design and construction quality, and more informative decision supports" comparing to the scenario where PM4D was not used. Fu et al. (2006) developed an IFC viewer that served as a holistic interface for nD modeling. Zhang et al. (2002) and Hu et al. (2008) developed a 4D site management model+ (4DSMM+) as a tool for visualizing critical path method that allowed 4D management at both the coarse level and the fine detailed level of a construction job site. Sampaio & Santos (2012) implemented an interactive 4D simulation prototype that is integrated with virtual reality (VR) technology. Although many research and development efforts were utilizing IFC models to support 4D simulations, none of these existing research reviewed, however, focused on testing the feasibility of using IFC models to create 4D simulations in commercial systems for construction projects in the US.

The adoption rate of 4D simulation by construction practitioners was relatively low comparing to several other BIM uses (Kreider et al., 2010). One of the main reason of this relatively low adoption rate is the high cost associated with creating such simulations, which is incurred by: (1) the need of much detailed information required in the simulation, which vary based on end users' needs and expectations, and (2) the lack of interoperability between different software that may provide input resources to such simulation. As a result, the BIM 4D technology is adopted only by a small portion of AEC companies (Mahalingam et al., 2010). The lack of interoperability between different software is mainly due to the use of proprietary data format by different software. The notion that using IFC-based BIMs can facilitate BIM interoperability is widely accepted. Therefore, if IFC-based BIMs are used, some challenges in creating successful BIM 4D simulation can be overcome through improved interoperability. A better interoperability of BIM would also simplify BIM-based workflows, which reduces the intensity of training needs of the users on BIM tools including BIM 4D simulation tools, among others.

In this paper, the authors investigate the feasibility of using IFC-based BIMs in creating BIM 4D simulations to support construction planning in the US. Three different BIM software that are widely used in the US were experimented with in creating BIM 4D simulations of a simple bridge model that was consisted of one bridge deck and four bridge piers and a complex duplex apartment model (East, 2013). The research method, experimental details, results and discussions are described in the following sections of the paper.

Method

The study on IFC-based BIM 4D simulation is conducted using a straightforward 3-step method (Figure 1): (1) AEC objects preparation – this step prepares the AEC objects in IFC format, to be used in later BIM 4D simulations. The

AEC object referred here is a broad concept including not only objects of building elements and infrastructure elements but any objects in an architecture, engineering, and construction project; (2) Simulation creation – this step prepares the 4D simulation in a commercial BIM platform based on the IFC objects prepared in the previous step. In this step, the IFC-based AEC objects are imported into the target 4D simulation platform. If a direct IFC importation is not available in the selected 4D simulation platform, indirect importation through conversion into intermediate data format will be explored. Schedule information will be created and linked. If the importation of AEC objects into the target 4D simulation platform is successful (i.e., direct or indirect), then arbitrary schedule information will be created in the simulation platform and linked to the imported AEC objects. If the direct importation is not successful and no indirect importation method is found, then the IFC-based 4D simulation using the selected platform will be considered infeasible. The linked AEC objects and schedule information will be processed to create the 4D simulation for displaying the construction progression with time; (3) Results analysis – this step analyzes the simulation results aimed to test the feasibility of using IFC-based BIM in 4D simulation creation and identifying research gaps.

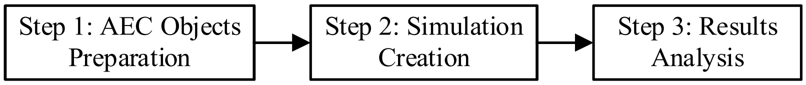


Figure 1: Research method.

Example Illustration

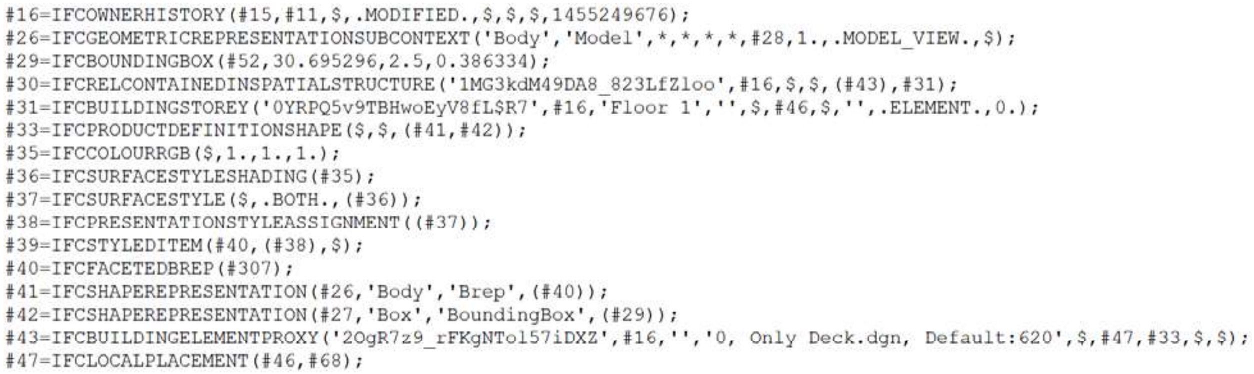
Three BIM 4D modeling platforms were tested in the experiments, including Navisworks, Synchro, and Navigator. Two models were used in the experiments – a simple bridge model and a more complex duplex apartment model. This section illustrates the experimental process with the simple bridge model using Navisworks.

Step 1: AEC Objects Preparation

A BIM authoring tool was randomly selected and used to create five AEC objects as part of a simple bridge model, namely, four piers and one deck. These AEC objects were exported into IFC format. Figure 2 shows partial raw IFC data of the bridge deck IFC exports. Figure 3 shows a labeled-graph visualization of the partial raw IFC data in Figure 2, to illustrate the linkages between the data entities. As the data in Figures 2 & 3 show, "IfcBuildingElementProxy" (#43) was the main entity to represent the bridge deck object. From Figures 2 & 3 we can see that it is linked with an "IfcBuildingStorey" (#31), meaning that this AEC object (i.e., the bridge deck) belongs to the building storey. This may sound irrational because bridge deck belongs to a bridge not a building. This is due to the fact that BIM was designed for buildings (not infrastructure) in the first place and we have to use the same set of entity definitions in IFC to represent a bridge. How to refine/extend the IFC standard to better represent bridges and other types of infrastructure projects is an active research area but is out of scope in this paper. Among the three linked entities to "IfcBuildingElementProxy" (#43), the "IfcProductDefinitionShape" (#33) is the main entity to represent the geometric shape of the bridge deck. It has two main representations – the "IfcBoundingBox" (#29) representation, and the "IfcFacetedBRep" (#40) representation. The bounding box representation is the use of a box to contain the object to approximately represent its location and dimensions. The faceted boundary representation, on the other hand, is a detailed representation of the object's geometric shape. Surface rendering properties of the object are represented through the linked "IfcSurfaceStyle" (#37). For example, the color of the object is represented through the "IfcColourRGB" (#35) that was linked with the "IfcSurfaceStyle" (#37) through the "IfcSurfaceStyleShading" (#36). The instance of "IfcColourRGB" (#35) in Figure 2 shows that the color component values for red, green, and blue are all 1, which encodes a white color.

Step 2: Simulation Creation

The prepared IFC objects from Step 1 were directly imported into Navisworks (Figure 4). An arbitrary construction schedule was prepared using the timeliner option in Navisworks. Construction schedule can also be imported from files generated by MS Project, Excel, Primevera, etc. Sets of piers (1,2,3,4) and deck were selected using the selection tree in the graphical user interface (GUI) of Navisworks; and these AEC objects were linked to activities in the arbitrary schedule (Figure 5). Once the activities from the construction schedule were successfully linked to the AEC objects in navisworks, the 4D simulation can be automatically generated. The simulation can be used to plan, control, coordinate construction activites, visualize and analyze the conflicts, and conduct clash detection (Figure 6).



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#16=IFCOWNERHISTORY(#15,#11,$,.MODIFIED.,$,$,$,1455249676);
#26=IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Body','Model',*,*,*,*,#28,1.,.MODEL_VIEW.,$);
#29=IFCBOUNDINGBOX(#52,30.695296,2.5,0.386334);
#30=IFCRELCONTAINEDINSPATIALSTRUCTURE('1MG3kdM49DA8_823LfZloo',#16,$,$,(#43),#31);
#31=IFCBUILDINGSTOREY('0YRPQ5v9TBHwoEyV8fL$R7',#16,'Floor 1','',$,#46,$,'',.ELEMENT.,0.);
#33=IFCPRODUCTDEFINITIONSHAPE($,$,(#41,#42));
#35=IFCCOLOURRGB($,1.,1.,1.);
#36=IFCSURFACESTYLESHADING(#35);
#37=IFCSURFACESTYLE($,.BOTH.,(#36));
#38=IFCPRESENTATIONSTYLEASSIGNMENT((#37));
#39=IFCSTYLEDITEM(#40,(#38),$);
#40=IFCFACETEDBREP(#307);
#41=IFCSHAPEREPRESENTATION(#26,'Body','Brep',(#40));
#42=IFCSHAPEREPRESENTATION(#27,'Box','BoundingBox',(#29));
#43=IFCBUILDINGELEMENTPROXY('2OgR7z9_rFKgNTol57iDXZ',#16,'','0, Only Deck.dgn, Default:620',$,#47,#33,$,$);
#47=IFCLOCALPLACEMENT(#46,#68);
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Figure 2: Partial raw IFC data of a bridge deck in the simple bridge model.

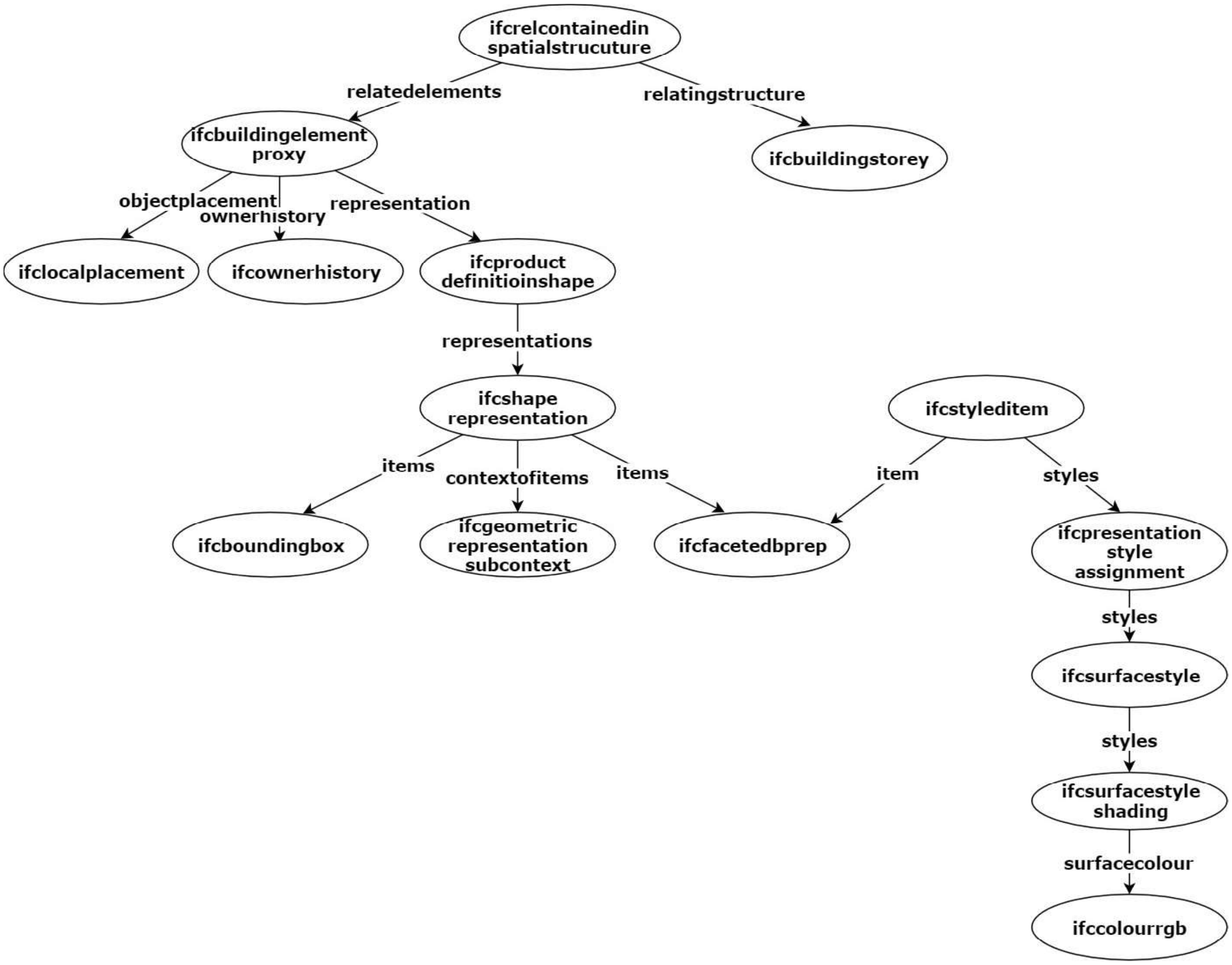


Figure 3: A labeled-graph visualization of the partial raw IFC data of the bridge deck.

Step 3: Results Analysis

Example views at selected timestamps of the generated 4D simulation in Navisworks were shown in Figure 6. Because the IFC-based AEC objects were directly imported into the Navisworks platform and there was no major obstacle in linking schedule activities with the IFC objects, the use of IFC model in creating 4D simulation was deemed to be feasible. Also, the visual display of dimensional information of the AEC objects and the start-finish time information of each object was accurate.

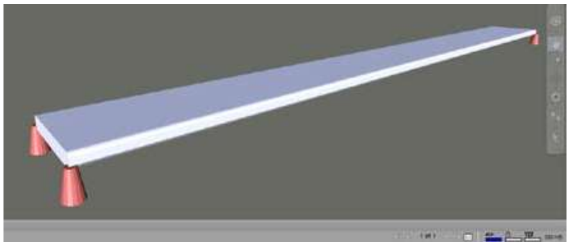
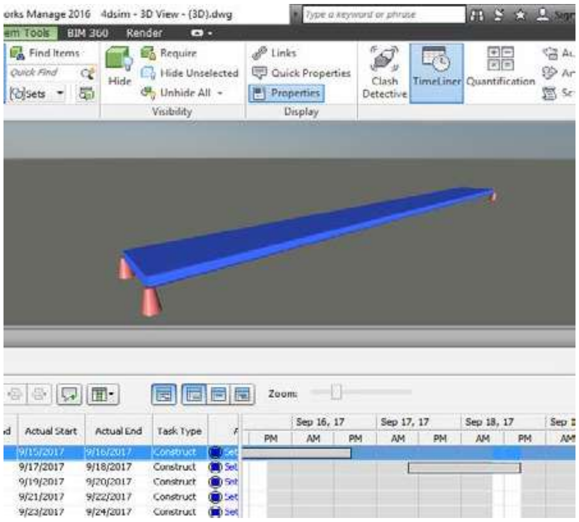


Figure 4: A simple bridge model imported into Navisworks.



Actual Start	Actual End	Task Type
9/15/2017	9/16/2017	Construct
9/17/2017	9/18/2017	Construct
9/19/2017	9/20/2017	Construct
9/21/2017	9/22/2017	Construct
9/23/2017	9/24/2017	Construct

Figure 5: A simple bridge model in Navisworks with schedule activities linked to objects.

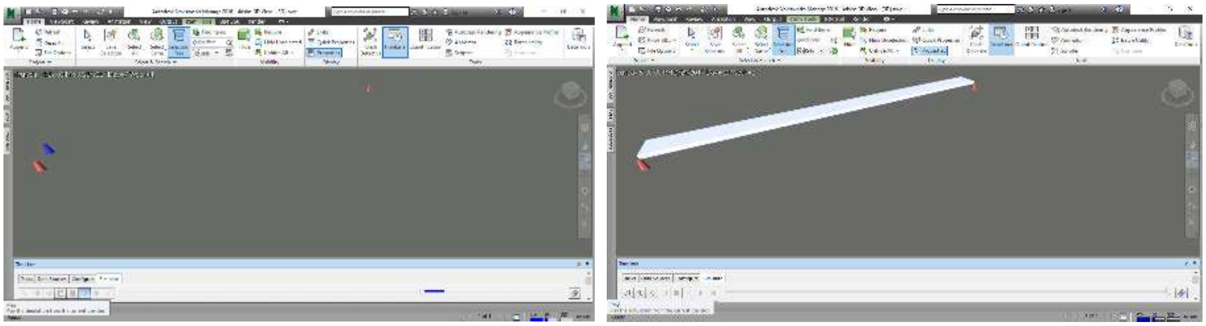


Figure 6: Four-D simulation of a simple bridge model in Navisworks.

Results and Discussion

The results in using the bridge IFC model and duplex apartment IFC model for 4D simulations in different commercial platforms are presented in Table 1. Simulations were successfully created from IFC-based BIMs in all the three commercial platforms. Each allowed direct importation of IFC files. Other functions such as clash detection, real-time mark-ups and rendering were also provided. For visualization, Synchro and Navisworks had additional rendering options. Both Navisworks and Navigator had design review functions which could enable reviewing 3D model components and schedule activities with real time access and shared views across stakeholders. Synchro allowed getting the cross-section views of the model on the run. It was straightforward to link the AEC objects to the construction activities from schedule in all the three commercial platforms. The time spent in creating the 4D simulations in all three commercial platforms are shown in Table 1. It shows that in Navisworks it took the least time to create the 4D simulations. The main reason of this difference in time was the platforms' differences in GUIs, where the GUI of Navisworks was easier to navigate than Synchro and Navigator. However, this could be due to the subjective GUI preferences of the authors. In addition, the time reduction in the duplex apartment model compared to the bridge model (in spite of increased model complexity) was because of the more familarity with the simulation platforms after using them once. The experiments were conducted using a laptop with a random access memory (RAM) of 8.0 gigabytes (GB) and an Intel Inside Core i5 processor with 2.4 gigahertz (GHZ). With an increase in the central processing unit (CPU) speed and/or RAM, the time taken for processing and rendering could be further reduced.

Table 1

Comparison between three commercial 4D simulation platforms

BIM 4D Simulation Platform	Time in Bridge Model (seconds)	Time in Apt. Model (seconds)
Navisworks	241.2	202.5
Synchro	386.4	369.2
Navigator	424.8	248.6

In this study, IFC models of AEC objects that were created in a randomly selected BIM authoring tool and obtained from online sources were used to create 4D simulation in multiple platforms. While the simulation results varied, the simulation creation using IFC models were all successful. Figures 7 & 8 show the 4D simulation results of the bridge model in Navigator and Synchro, respectively. Figure 9 shows the 4D simulation results of the duplex apartment model in Navigator. This shows the feasibility of using IFC models in commercial 4D simulation platforms. The linking of AEC objects and schedule activities in these platforms were mostly smooth. One observed problem in such use of IFC models, however, is that each AEC object needs to be modeled and imported separately, otherwise it would be difficult to break them down and link to different activities from a schedule. Furthermore, 4D simulation platforms typically would not allow users to insert new AEC objects on the run. In addition, they do not provide the ability to overwrite properties of existing models. In other words, 4D simulation platforms are mostly used as a tool to connect existing AEC objects with schedule information and show 4D visualization, rather than editing the AEC objects. While it is possible to save the AEC objects back to IFC or to save the complete 4D simulation project into a proprietary format, how to save the complete 4D simulation project back into IFC, is identified as a main research gap. Although IFC data schema was not designed specifically to support the modeling of time, without such roundtrip data transfer the IFC-based interoperability is difficulty to be regarded complete.

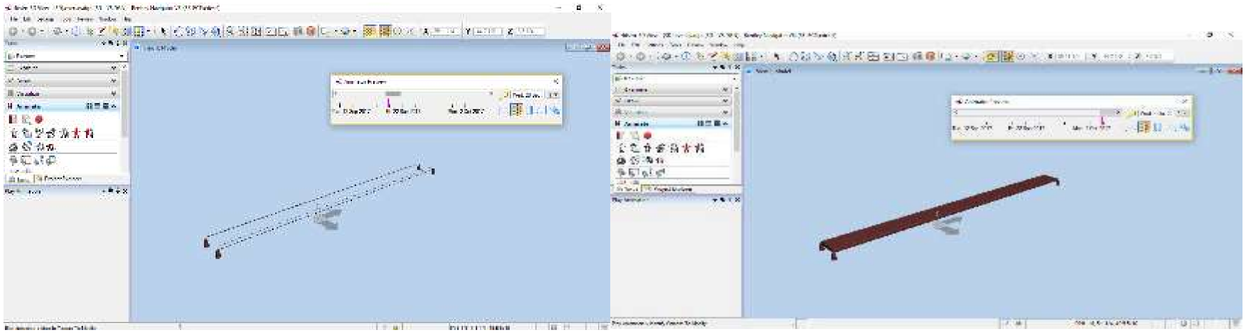


Figure 7: Four-D simulation results of a simple bridge model in Navigator.

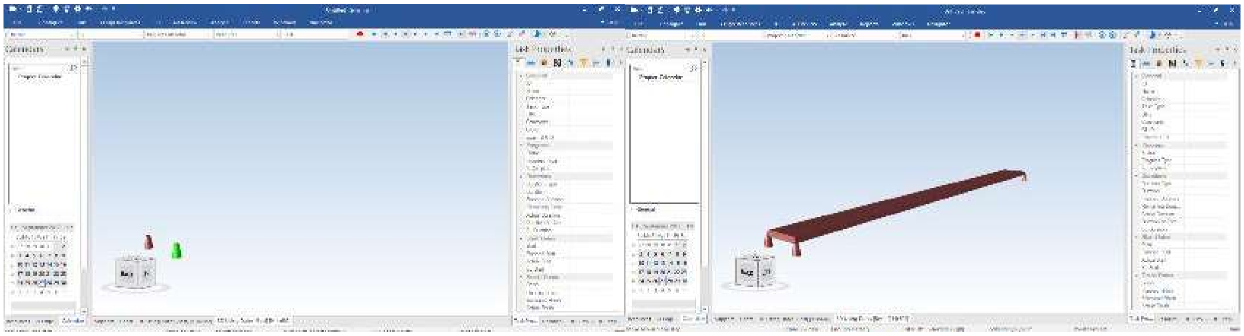


Figure 8: Four-D simulation results of a simple bridge model in Synchro.

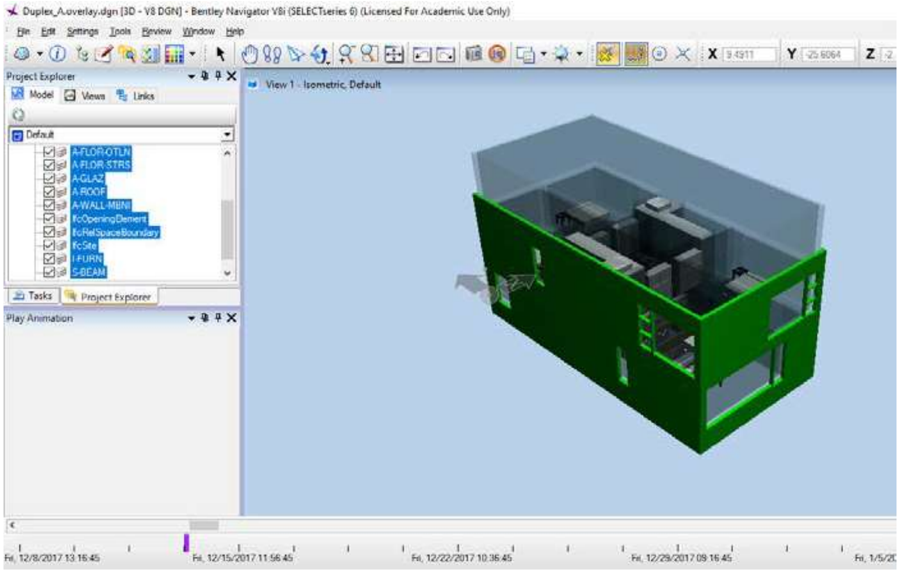


Figure 9: Four-D simulation results of a duplex apartment model in Navigator.

Conclusion

Construction planning is an important but challenging task. BIM 4D modeling provides an intuitive and accurate visualization of the construction progress, which can greatly help with the construction planning process especially for inexperienced planners. In spite of the wide adoption of BIM, the adoption rate of BIM 4D modeling was relatively low comparing to other BIM uses. A better BIM interoperability is expected to faciliate the adoption of BIM including its use in 4D simulation. In this paper, the authors investigated the feasibility of uing industry foundation classesses (IFC)-based BIM in creating 4D simulations by commercial systems to support construction planning in the US. Experiments were conducted in three commercial 4D simulation platforms to test their feasibility, and results were compared in terms of time spent. While simulation results varied in different platforms, the 4D simulations were all successfully created thus indicating the fesibility of using IFC models. The time spent in different software platforms varied due to the differences in graphical user interfaces (GUIs). Furthermore, it was found that: (1) the IFC-based interoperability in this 4D simulation could be best achieved by using separate AEC objects during importation, and (2) the round trip from 4D simulation back to IFC model was still missing. Future research is recommended to investigate innovative methods that improve 4D simulation using integral IFC models and enable round trip interoperability with IFC models.

Limitations and Future Work

Two main limitations of this paper are acknowledged: (1) the AEC objects used in the experiments were relatively simple, which might not reveal issues that could be associated with complex objects such as objects with irregular shapes, color, textures, materials, etc. or objects with complex spatial and topological relations; (2) this preliminary investigation was only conducted on three commercial platforms. In future work, the authors plan to incorporate more complex objects to explore technical issues in using IFC models to create 4D simulation in commercial platforms at a more detailed level, as well as conduct more experiments on more commercial platforms.

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