4D construction simulation model of MASP

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Abstract. Building Information Modeling (BIM) is an effective tool students can use to learn how building components work together to secure necessary structural stability in the course of construction. In Summer 2014, students enrolled in the BIM class at Texas A&M University created a 4-dimensional construction simulation model of the Museu de Arte de São Paulo (MASP) to understand how the entire building is sustained by two huge concrete beams connected with four external columns. For this class project, students analyzed the building system while creating a 3-dimensional model of the museum. They also came up with a construction sequence that would best maintain structural integrity of the building in the course of construction, and then produced a short animation video explaining the MASP construction process. This paper presents how the MASP project helped students learn a unique building system and its construction sequence.

Keywords: BIM, 4D Construction Simulation, MASP

1   BIM for Construction

According to the Smart Market Report on BIM released by McGraw Hill in 2009 [1], there is consensus in the construction industry, especially among contractors, that Building Information Modeling (BIM) helps to improve collective understanding of the design intent, which results in reduced conflicts and change orders during construction. McGraw Hill reported that BIM is most utilized by contractors for clash detection, spatial coordination, client engagement, shop fabrication, quantity takeoff, and 4D scheduling. Using BIM, general contractors can easily figure out the spatial relationship between building components, detect clashes between them, fix those clashes in advance, and then bring all sub-contractors in the same page for their roles and responsibilities in the course of construction. Four-dimensional visual representation of the construction sequence, which can be produced by assigning the start-date and end-date of each and every work package to associated building components, enables them to discuss constructability issues in advance, prevent reworks, keep their jobsite safe, and come up with plans for pre-fabricated modules [1, 2]. From academic investigations and tests, Riley [3], Akinci et al. [4], Guo [5], and Kang et al. [6] reported the advantages of 4-dimensional visual representation of the construction sequence in time-space conflict analysis and construction planning.

2   BIM Class for Construction

As BIM has been widely used in the construction industry, many contractors expect higher education institutions to teach students how to use BIM especially for construction management. [7] Many contractors are searching for students who understand how to create a building information model, how to detect clashes between building components, how to assist a project manager to remove those clashes during pre-coordination meetings, and if possible, how to produce a 4-dimensional construction simulation model that can be used for construability analysis or modularized construction planning. Understanding the competency that the construction industry is looking for, BIM has recently become one of the most popular topics among students in higher academic institutions. [8]

To provide what the construction industry and students are seeking, the Department of Construction Science at Texas A&M University offers a BIM class, which is basically designed to train students how to create a building information model, how to use BIM for clash detection and material takeoff, how to use BIM for presenting the construction sequence visually and analyzing constructability issues in advance, and eventually how to use BIM to enhance communication among project team members. In order to cover these activities that industry professionals do using BM, the BIM class teaches students 3 computer applications:

- BIM application for creating an object-based parametric 3-dimensional model of a building (BIM authoring application)
- BIM application for creating a federated 4-dimensional model which can be used for clash detection and presenting the construction sequence (BIM manipulating application)
- Computer application for creating a video clip.

Teaching these computer applications in one semester would be challenging for any instructor unless students are highly motivated. To get students motivated and trained effectively for the BIM skills that the construction industry is looking for, the BIM class at Texas A&M University uses the Goal Oriented Active Learning (GOAL) pedagogy, which is in essence about setting up the goal for students and help them actively pick up necessary knowledge while trying to accomplish the goal.

To set up the goal, the BIM class uses the semi-realistic construction project sponsored by construction firms. The goal of the BIM class is to develop the construction execution plan of the sponsor's project and produce a video presenting their execution plan. Before each semester gets started, the instructor explorers on-going construction projects, analyzes student's workloads associated with those projects, interviews the representatives of the construction firms to see if they are interested in sponsoring the class project. Once the project gets selected, the instructor collects 2-dimensional drawings of the project, determines the scope of the class project, and arranges the students' field trip to the jobsite if possible. To get students excited and motivated about the class project, the instructor also arranges the sponsor's visit to the BIM class, so that students have chances to meet the sponsor's representatives. Once the BIM class starts, students are introduced to the nature of the

class project, for which the sponsor's representatives visit the BIM class and help students understand what is depicted in the 2-dimensional drawings provided for the class project. At the end of the semester, once students have finished working on the class project and submitted their video to the instructor, the sponsor's representatives are invited one more time to evaluate those videos using the rubric provided by the instructor. The instructor is basically asking the sponsor's representatives to see if the video is explaining the construction execution plan effectively and logically using the 3-dimensional model and 4-dimensional construction simulation model.

To help students get engaged in active learning, the instructor uses various online resources including YouTube videos. Instead of explaining nuts of bolts of the BIM applications, the instructor explains the concept of creating the object-based building information model using parameters, and shows students the entire process of creating a building information model using a simple example. The instructor then asks students to create a 3-dimensional model of their dream house without considering any dimensional issues. While working on the first assignment, students are encouraged to use as many online resources as possible if they want to know a specific function of the BIM applications. Also students are encouraged what they have discovered with other students through social networking services including Facebook. The instructor invites some students to show the 3-dimensional model they have created to their peer students in class, which often encourages other students to get motivated and do more and better for the class project.

Coupled with the class project, the Goal Oriented Active Learning pedagogy provides students with a unique opportunity to pick up new knowledge with their own pace. Personalized learning method is about providing students with learning environments to meet the needs of individual learners. David Miliband [9], Minister of State for School Standards for the United Kingdom (U.K.), stated that "personalized learning is the way in which our best schools tailor education to ensure that every pupil achieves the highest standard possible". Education leaders invited to the SIIA-ASCD-CCSSO Symposium on [Re]Design for Personalized Learning in 2010 jointly identified the following essential elements for personalized learning [10]:
1. Flexible, Anytime/Everywhere Learning
2. Redefine Teacher Role and Expand "Teacher"
3. Project-Based, Authentic Learning
4. Student Driven Learning Path
5. Mastery/Competency-Based Progression/Pace

The Goal Oriented Active Learning environment helps students learn how to use BIM applications at their comfortable speed while working on the class project. There are a huge amount of resources available on the Internet, and students are encouraged to take best advantage of them and pick up new knowledge at their comfortable speed. The instructor's role is to set up the goal for students and monitor their progress in order to provide them with a competency-based progression model.

While working on the class project, students create a 3-dimensional building information model of the architectural components as well as mechanical, electrical, and plumbing (MEP) components. They also learn how to detect clashes between architectural components and MEP components of the building using BIM

applications. Students identify the work packages representing unit activities on the jobsite, determine how much time they need to allocate to execute these work packages, establish the sequential relationship between them, and develop a network diagram of these work packages, which helps students figure out the start-date and end-date of each and every work package they have in the network. Students then split the building information model into unit building components that can be matched with work packages they have identified. A 4-dimiensional construction simulation model is created by assigning the start-date and end-date of these work packages to associated building components. Several BIM applications facilitate the production of the 4-dimensional construction simulation model, and enable users to time travel through the network of work packages. Students then develop a storyboard and script to get the idea as to how they want to present their construction project in the video using their 4-dimensional construction simulation model. Students also create animation clips supporting their storyboard, and produce a short video clip by stitching their animation clips together and adding narration using their script. The ultimate goal of this class project is to produce a video clip presenting the logical sequence of the construction process using BIM. To help students follow this challenging process, the entire class project is split into 10 smaller tasks as shown in the following list.

- Project 1 - Learn how to use a BIM application and create a building information model of their dream house.
- Project 2 - Create an architectural and structural model of the sponsor's project.
- Project 3 - Create a mechanical, electrical, and plumbing (MEP) model of the sponsor's project.
- Project 4 - Learn how to detect clashes and exercise this function using their own model.
- Project 5 - Identify work packages, develop a network diagram of these work packages, and figure out the start-date and end-date of each work package.
- Project 6 - Assign the start-date and end-date of these work packages to associated building components, and create a 4-dimiensional construction model.
- Project 7 - Produce a poster presenting the work scope, logistic issues, construction sequence, and risk management issues of the project.
- Project 8 - Develop a storyboard and script presenting the execution plan for the sponsor's construction project.
- Project 9 - Produce a draft short video presenting the construction execution plan.
- Project 10 - Produce a final video presenting the construction execution plan.

3   BIM Class Project: Museu de Arte de São Paulo (MASP)

In Summer 2014, the instructor of the BIM class at Texas A&M University decided to go with an unusual class project. In previous semesters, commercial buildings are

usually chosen for the class project because mechanical, electrical, and plumbing (MEP) components of those buildings are often collided with architectural and structural components, and those collisions are the good educational resources the instructor can use to teach students how to detect clashes and make proactive decisions to fix those problems during pre-construction coordination meetings. What was selected for Summer 2014 was the Museum of Art in Sao Paulo instead.

There are several reasons why the instructor selected the Museum project, which was already completed in 1968, over regular commercial building projects. First of all, the structural configuration of the building got the instructor's attention. Unlike other commercial buildings, the MASP building is sustained by two huge concrete beams connected with four external columns, in order to leave the first floor open for the public. Lima stated that: "*before construction of the museum, the site had been occupied by a small, sloping belvedere-park called Trianon Terrace, which included a Neoclassical composition of pergolas sitting on a large semi-buried ballroom built in 1916 and demolished in 1951. A constraint to building on this site was a city ordinance mandating continued public access to it and its street-level views*" [11]. The MASP building designed by the Italian-Brazilian architect Lina Bo Bardi met this requirement by putting a semi-buried podium below the ground level, a plaza on the ground level, and an elevated exhibition hall on top of the plaza. To provide an open space at the plaza level, the entire exhibition hall is sustained by the 2 huge external concrete beams connected to 4 external columns. Coming up with a construction execution plan for a sustained exhibition hall would be a good challenge for construction science students.

The second reason that made the instructor to choose the MASP project was that the MASP building was relatively simple in terms of creating a 3-dimensional model. Since the summer BIM class runs only for 5 weeks, as opposed to 15 weeks in the regular semesters, the instructor was looking for a bit simple but still challenging project. The MASP building met the instructor's expectation.

Once the MASP project was decided for the summer class project, the instructor started collecting 2-dimensional drawings. The instructor's colleague who originally introduced this project helped to locate architects who designed the MASP building and collect 2-dimensional drawings from them. Since many drawings were not available, students were also suggested to use any pictures available over the Internet.

Students were give 1 week to create a 3-dimensional model of the MASP building. To help students better understand the building, a College of Architecture professor, who is familiar to the MASP, visited the BIM class and presented the history of the building, the configuration of the building, and the use of the building up to now. Although there was not enough drawings and information about the building, students managed to create a 3-dimensional model of the MASP building as shown in the Figure 1.
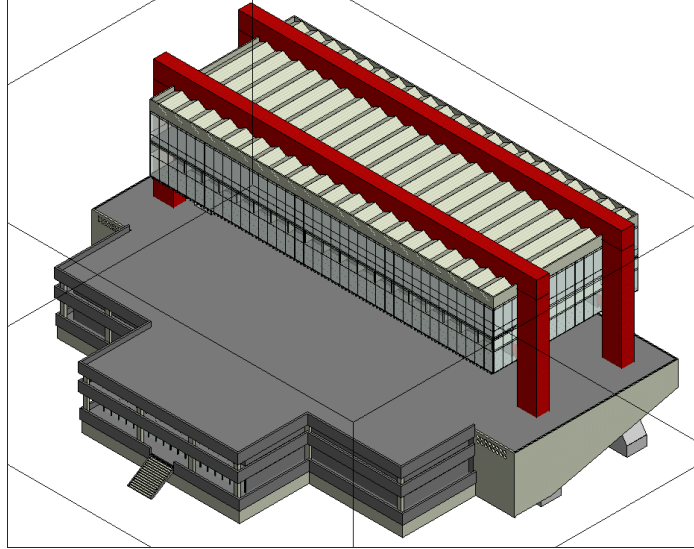
Fig. 1. Three-dimensional building information model of the MASP created by a student who took the BIM class in Summer 2014

Students then moved on to the next step, and come up with a logical sequence of construction, for which they divided the entire project into about 50 action items, determined how much time they wanted to allocate for each action item, identified the relationship between action items, and then developed a network among those action items. Figure 2 shows the action items identified by a student who took the BIM class in Summer 2014.

With the use of construction schedule application, students identified the action items on the critical path and figured out the start-date and end-date of each action item. By assigning the start-date and end-date information to associated building components in the 3-dimensioanl model, students were able to create a 4-dimensional model that represents the sequence of construction. Figure 3 shows the 4-dimensional model presenting the construction sequence of the MASP.

Once the 4-dimensional model is produced, students now have a good understanding as to how they want to build the building. Before putting students into the process of creating animations and video, the instructor asked students to produce a poster that presents their construction execution plan. This activity was designed basically to allow student to develop some idea as to how they want to present their construction execution plan to the class project sponsor. Figure 4 shows one of the posters produced for the class project.
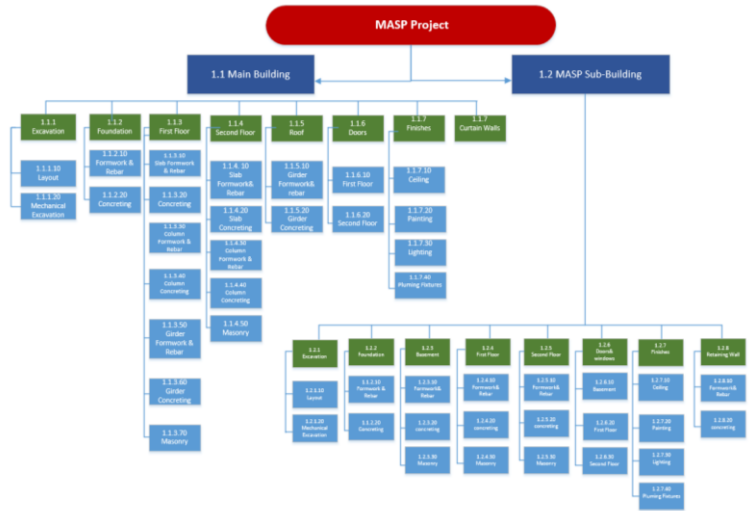
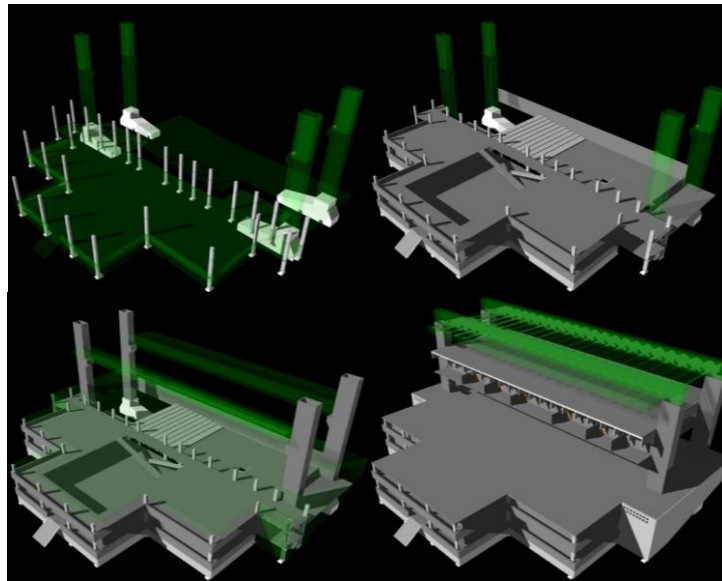**Fig. 2.** Action items in terms of building the MASP

Fig. 3. Four-dimensional construction model presenting the construction sequence of the MASP project

Fig. 4. Poster that presents the construction execution plan of the MASP project

Finally, the instructor asked students to come up with a storyboard and script they wanted to use to produce a video. After getting the script done, students produced several animation clips that support the script. Once multiple animation clips are brought to the video editing application, students aligned those video clips to be synchronized with the narration they recorded in advance using the script. After getting the first draft evaluated by their peers and the instructor in class, students produced the final video. Figure 5 shows the snapshot of the video produced for the class project.
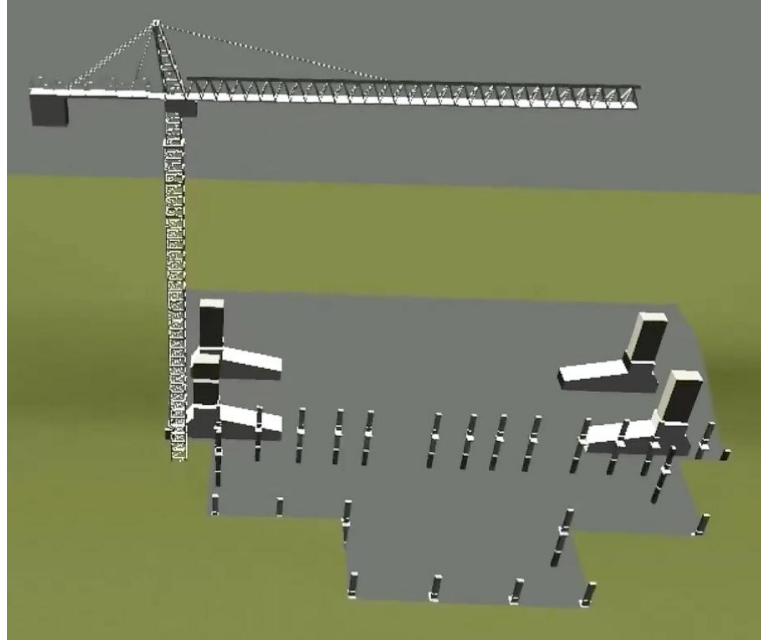
Fig. 5. Snapshot of the video presenting the construction execution plan of the MASP project

4   Conclusion

The MASP project gave students enrolled in the BIM class at Texas A&M University a unique opportunity to study the building system of an elevated exhibit hall, which is sustained by the 2 big concrete beams. While creating a 3-dimensional information model, and 4-dimensional construction model of the MASP building, students learned how the structural integrity could be secured in the course of construction. The video production process gave students a chance to discuss how the construction execution plan can be better delivered through visual representation of a 4-dimensional construction simulation model.

Lack of drawings was one of the critical challenges that students had to deal with for the class project. Unlike other class projects, communication with the architectural firm that designed MASP building was also challenging. Students used then as many resources as they could find off the Websites, however it was challenging even to locate some pictures of the MASP building. Because many dimensions of building components are missing, students had to assume many dimensions, so the 3-dimensional model they created may not reflect the actual building correctly.

Still the configuration of the building with an elevated exhibit hall sustained by the beam is very attractive system, which can challenge students who want to learn how to develop a construction execution plan. Collecting additional information of the building, for example by visiting the building and taking additional pictures of the building or by collecting point clouds of the building using a 3-dimensional laser

scanner, may help the instructor to use the MASP project again for the BIM class project at Texas A&M University.

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