



4.0 TECHNICAL ANALYSIS #1

4D Modeling as a Comparison Tool

4.1 Problem Statement

Even though 4D Modeling is becoming more prevalent in the building industry primarily within the construction aspect, there are still many obstacles for properly using and understanding the 4D Modeling tool. Because 4D Modeling is a fairly new idea used in the construction industry, many are still learning the basics about what can be done with 4D Modeling. As more of the industry becomes familiar with the idea of 4D Modeling, the next step will be how to properly use the tool. Many believe that 4D Models can only be used to show a construction sequence; however, there are many other uses for 4D Modeling. One area that proves to be useful for the BWMC- Women's Center and Inpatient Tower is using 4D Modeling as a comparison tool between two systems. By developing a process that provides a clear description on how to compare systems using 4D Modeling, many project teams will be able to compare alternative systems during the value engineering process.

4.2 Goal

The goal for developing a 4D Modeling process is to show the benefits of using a 4D Model as a comparison tool when looking at alternative systems. The analysis will first look at developing a 3D model of the Women's Center and Inpatient Tower. The 3D Model will be used to compare the other two analysis areas within my thesis project. The process for developing and using a 4D Model as a comparison tool will first be documented and then will be reviewed through my other two analysis areas. The 4D model will be used to review both the structural alternative and façade alternative that were chosen for the two other topics. In order to show the differences in sequencing and durations, the sequencing for the two systems will be illustrated on a single model. By showing the sequencing on a single model, the system that finishes first can easily be determined. If the 4D Model would have been developed and used on the Patient Tower, it would have made the comparison between systems' durations much easier. The use of the 4D Model on the project may have also led to different decisions on the structural system and façade system.

4.3 Analysis Steps

1. The first step to this analysis is to develop a 3D Model.
2. Create a CPM schedule in Microsoft Project.
3. Link 3D Model and CPM schedule in Navisworks Timeliner
4. Simulate the construction sequencing for the two systems using a single model.
5. Review the simulation process and develop conclusions.
6. Repeat steps 2-5 for the second analysis area.



7. In order to develop a clear and concise process for using 4D Modeling as comparison tool, various areas on 4D Modeling where processes have been developed need to be researched. The research will focus on how to develop an effective description of the process used.
8. Document the process of creating and utilizing a 4D Model as a comparison tool.
9. Document the lessons learned with using a 4D Model.
10. Receive feedback on the process and case studies and make any changes necessary.
11. Finalize the analysis area.

4.4 Resources and Tools

1. Architectural Engineering Faculty (Professor Messner, Craig Dubler, Rob Leicht)
2. Revit Architecture
3. Revit Structures
4. Navisworks Timeliner
5. Microsoft Project

4.5 Introduction to 4D Modeling

The term 4D modeling can be defined as the process of attaching the fourth dimension of time to a 3D model. A 4D model is created by linking a construction schedule to a 3D model using a 4D simulation program. The 4D simulation software that was used for the Women's Center and Inpatient Tower Project was NavisWorks with Timeliner.

4.6 4D Modeling Process

For the Women's Center and Inpatient Tower Project, a 3D model was first created in Revit Architecture. Figure 13 shows an image of the 3D Model created in Revit Architecture.

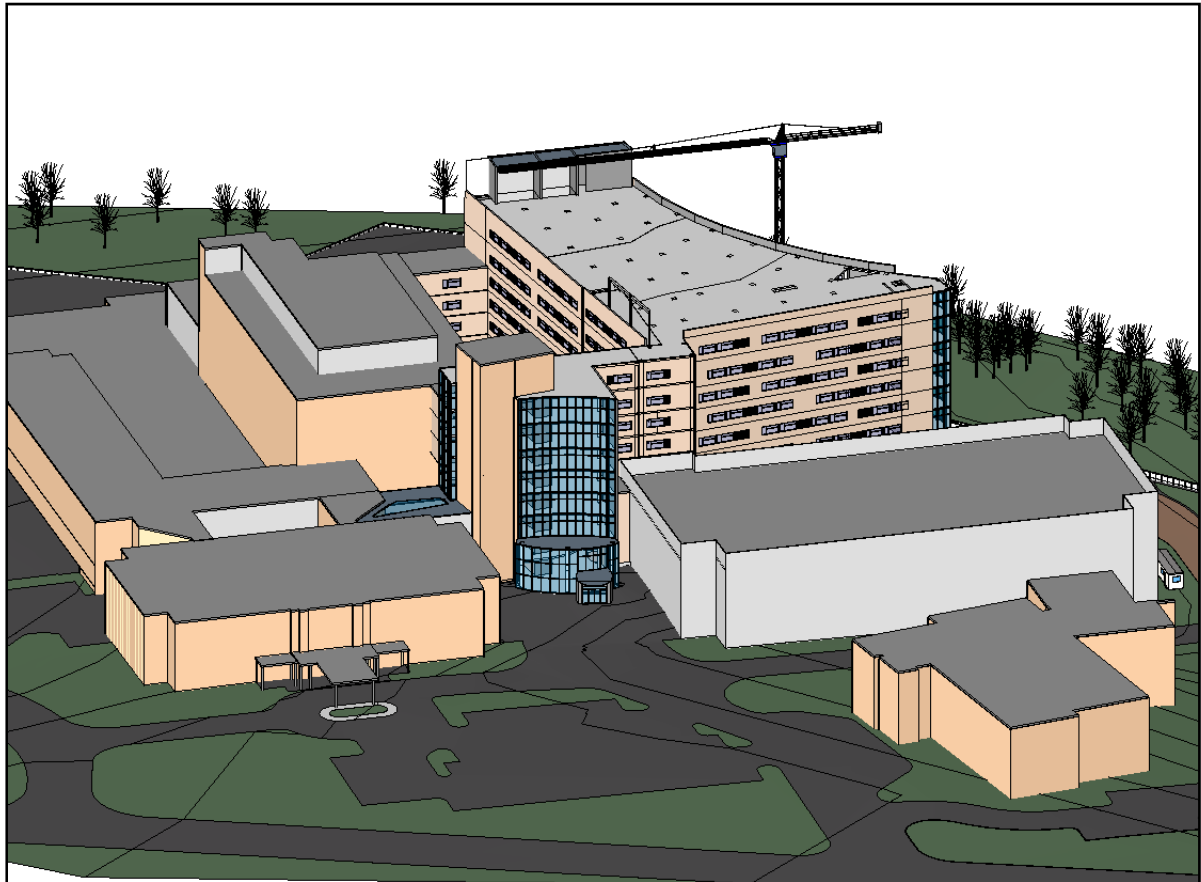
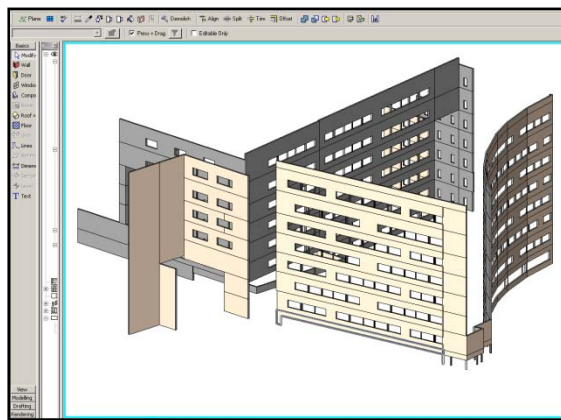


Figure 13: 3D Model of BWMC- Women's Center and Inpatient Tower created in Revit Architecture

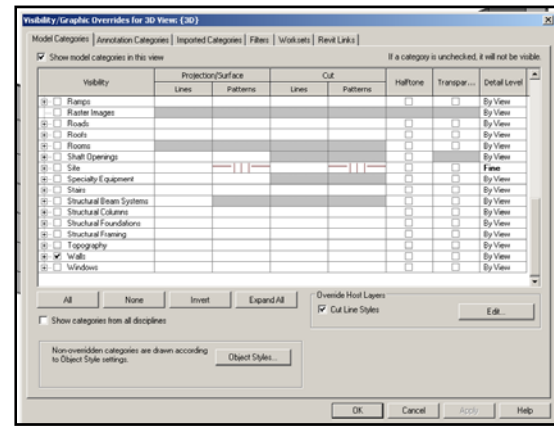
Once a 3D model was developed, a construction schedule for each analysis area was created in Microsoft Project. The 3D model was broken up based on the two analysis topics that are being compared. For the structural system comparison, only the structure of the Patient Tower and site plan were used in the 4D Model. With the façade system comparison, the entire model was imported into the 4D Model, but only the façade system was used for the actual 4D Model. The model components for each of the analysis areas were imported into Navisworks. The construction schedule for each analysis was also imported into Navisworks Timeliner. The construction schedules for the two analyses were created using Microsoft Project. The schedule for each analysis area will include both of the systems being compared so that only a single schedule needs to be imported and linked in the 4D Model. Once the schedule and 3D model for the analysis were imported into Navisworks, they were linked together. To make the linking process quicker and easier, model components were created in Revit Architecture first and then imported separately into NavisWorks. By bringing in pieces of the model instead of the entire model, it was easy to isolate each imported model component and link it to the schedule. The model components were created in Revit Architecture by using the visibility settings in the 3D View. In the 3D View, the visibility settings were changed and the views were cropped to show only the necessary elements within the model component. Figure 14 shows an example of a wall component. The first



image illustrates a cropped 3D view of the GFRC wall group. The second image shows a visibility settings box for the GFRC walls. As the views were created, they were saved as a NavisWorks file so that they could be directly imported into NavisWorks. Although this process of creating views and importing them separately into NavisWorks was tedious and time consuming, it appeared to be the easiest way to link the 3D model to the schedule. Figure 15 shows the process used for creating a 4D model in Navisworks.



Cropped 3D View
(ex. GFRC Walls)



Visibility Settings Box

Figure 14: 3D View and Visibility Setting Box for GFRC Exterior Wall

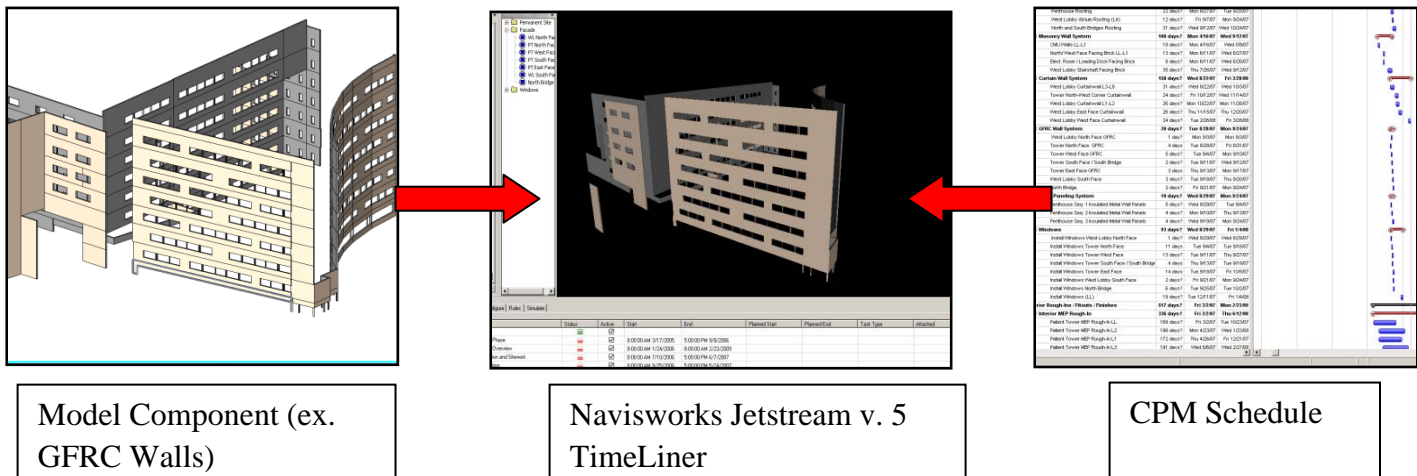


Figure 15: Process for creating 4D Model in Navisworks



In order to show a clear comparison of the two systems for each analysis, only the model components that are being compared within the analysis area are being illustrated in the 4D Model. For example, with the structural system analysis, the only area that is being redesigned is the area above the mechanical room; therefore, this is the only area that is being sequenced in the 4D Model. For the façade comparison, only the façade area where the comparison is being made will be sequenced in the 4D Model. The rest of the model will be used as a background for this area. The goal of this analysis was to include both systems on one 4D Model; however, that proved to be very difficult and confusing for the façade analysis. For the structural analysis, both systems are shown on one 4D Model; therefore, different colors were used to show when each system finishes. The color coding will make it easier to see which system finishes first and which finishes last. In order to use different colors for the two alternatives, two different task types need to be used for the two systems. The purpose of the task type is to show the various processes occurring with the same model components. For example, one task type can be used as a temporary task. This temporary task can be created to show the process of a model component being created and then being taken down later in the construction process. With this analysis, the task types allow the two systems to be linked to the same model pieces. The task types are used to show the difference in durations between two systems on the same model components. For example, with structural analysis, the precast concrete planks were given one task type and the composite slab was given another task type. The rest of the model that is not being sequenced in the 4D Model was given the permanent task type. Each task type used different colors for the start and finish to illustrate the differences in durations. Both systems were then attached to the same model components. Figure 16 shows an example of the linked schedule and the task type associated with the schedule tasks. Figure 17 shows the colors assigned to each task type.

Name	Status	Active	Start	End	Planned Start	Planned End	Task Type
Erect Penthouse (Seq 2) Structural Steel		<input checked="" type="checkbox"/>	8:00:00 AM 8/23/2007	5:00:00 PM 8/31/2007	5:00:00 PM 8/31/2007	5:00:00 PM 8/31/2007	
Erect Penthouse (Seq 3) Structural Steel		<input checked="" type="checkbox"/>	8:00:00 AM 8/31/2007	5:00:00 PM 9/12/2007	5:00:00 PM 9/12/2007	5:00:00 PM 9/12/2007	
Precast Hollowcore Planks/ Concrete Topping		<input checked="" type="checkbox"/>	8:00:00 AM 6/15/2007	5:00:00 PM 8/29/2007	5:00:00 PM 8/29/2007	5:00:00 PM 8/29/2007	
Set Precast Planks/ Concrete Topping L3		<input checked="" type="checkbox"/>	8:00:00 AM 6/15/2007	5:00:00 PM 6/18/2007	5:00:00 PM 6/18/2007	5:00:00 PM 6/18/2007	Temporary
Set Precast Planks/ Concrete Topping L4		<input checked="" type="checkbox"/>	8:00:00 AM 6/22/2007	5:00:00 PM 6/25/2007	5:00:00 PM 6/25/2007	5:00:00 PM 6/25/2007	Temporary
Set Precast Planks/ Concrete Topping L5		<input checked="" type="checkbox"/>	8:00:00 AM 7/28/2007	5:00:00 PM 7/30/2007	5:00:00 PM 7/30/2007	5:00:00 PM 7/30/2007	Temporary
Set Precast Planks/ Concrete Topping L6		<input checked="" type="checkbox"/>	8:00:00 AM 8/4/2007	5:00:00 PM 8/6/2007	5:00:00 PM 8/6/2007	5:00:00 PM 8/6/2007	Temporary
Set Precast Planks/ Concrete Topping L7		<input checked="" type="checkbox"/>	8:00:00 AM 8/11/2007	5:00:00 PM 8/13/2007	5:00:00 PM 8/13/2007	5:00:00 PM 8/13/2007	Temporary
Set Precast Planks/ Concrete Topping L8		<input checked="" type="checkbox"/>	8:00:00 AM 8/18/2007	5:00:00 PM 8/20/2007	5:00:00 PM 8/20/2007	5:00:00 PM 8/20/2007	Temporary
Set Precast Planks/ Concrete Topping L9		<input checked="" type="checkbox"/>	8:00:00 AM 8/25/2007	5:00:00 PM 8/29/2007	5:00:00 PM 8/29/2007	5:00:00 PM 8/29/2007	Temporary

Figure 16: Image of Tasks and Task Types in Navisworks Timeliner



Task Types					
Name	Start Appearance	End Appearance	Early Appearance	Late Appearance	Simulation Start Appearance
<input type="checkbox"/> Construct	Green	Yellow	None	None	White
<input type="checkbox"/> Demolish	None	None	Yellow	Model Appearance	Green
<input type="checkbox"/> Temporary	Red	Model Appearance	None	None	White
<input type="checkbox"/> Permanent	Model Appearance	Model Appearance	Model Appearance	Model Appearance	Model Appearance

Appearance Definitions		
Name	Transparency %	Color
<input type="checkbox"/> White	0	
<input type="checkbox"/> Grey	0	
<input type="checkbox"/> Red	0	
<input type="checkbox"/> Red (90% Transparent)	90	
<input type="checkbox"/> Green	0	
<input type="checkbox"/> Green (90% Transparent)	90	
<input type="checkbox"/> Yellow	0	
<input type="checkbox"/> Yellow (90% Transparent)	90	
<input type="checkbox"/> Purple	0	
<input type="checkbox"/> Purple (90% Transparent)	90	

Figure 17: Image of Colors Assigned to the Task Types in Navisworks Timeliner

For the precast concrete planks, the color used to illustrate the start of construction is red. Because the precast planks finish after the composite slab, the color used for the end of construction is the model appearance. The color used to illustrate the beginning of the composite slab is green and the end of the composite slab is yellow. For the façade analysis, the two systems could not be compared only using one 4D Model. The reason for this is because the sequencing of the EIFS and GFRC would often overlap; therefore, only one color would highlight the walls. It was difficult to show that two systems were being constructed at the same time on the same façade. The sequencing for the two systems was also different. The EIFS would go up by face on two walls at the same time using scaffolding. The GFRC would go by face on one wall at a time using the tower crane. The difference in sequencing adds to the complexity of comparing the two systems using one model. Through trial and error, I found that the easiest way to visually illustrate the difference in durations was to use two separate models for the two façade systems. Because two different models were used to compare the GFRC and EIFS systems, the start color used for both the GFRC façade and the EIFS façade is green. When each system is finished, it will turn to the model appearance. Figure 18 illustrates the two structural systems' sequencing and durations being compared on a single 4D Model. The structural 4D Model in Figure 18 shows the completion of the composite slabs on Levels 3-6 (yellow), the construction of the composite slab on Level 7 (green), and the construction of the precast planks beginning on Level 3 (red). The first model created for the façade comparison is shown in Figure 19. As illustrated in the image, it is difficult to see when the two systems would overlap. The façade model shows the construction of the GFRC and EIFS on the north and south faces. Even though both systems are being constructed, only one of the colors is displayed. The red indicates that the EIFS is being constructed. The color green, which is not shown, should be displayed to show the GFRC being constructed on the same sides as the EIFS. Figure 20 shows the final models used to compare the two façade systems. The two models proved to be the easiest way to compare two different



durations. In Figure 20, the two façade systems' sequencing and durations are being compared on two different 4D Models. The facade 4D Model in Figure 20 shows the completion of the GFRC Panels on most of the building facades, the construction of the GFRC Panels on the east façade, and the construction of the EIFS on most sides of the building. Please see Appendix B for more images of the 4D Models.

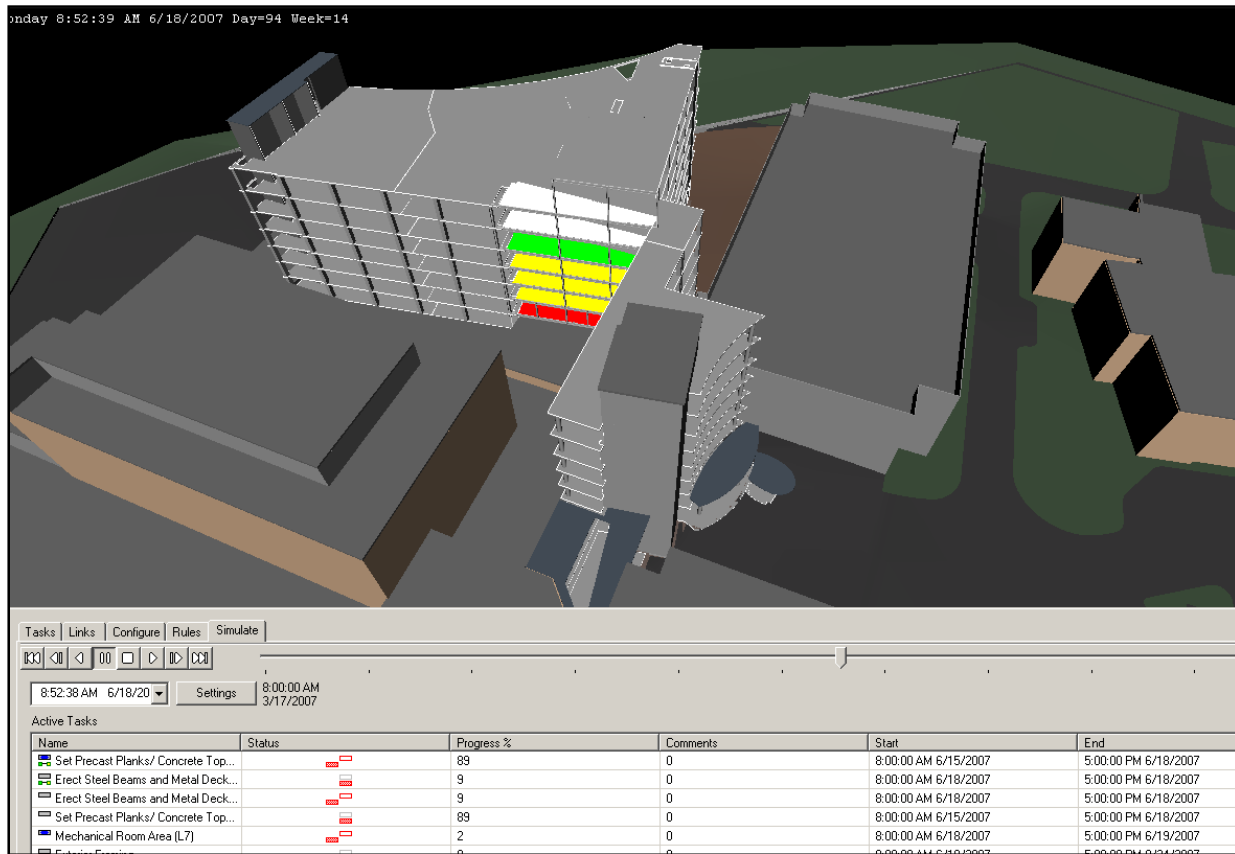


Figure 18: Image of Structural 4D Comparison Model Simulated in Navisworks

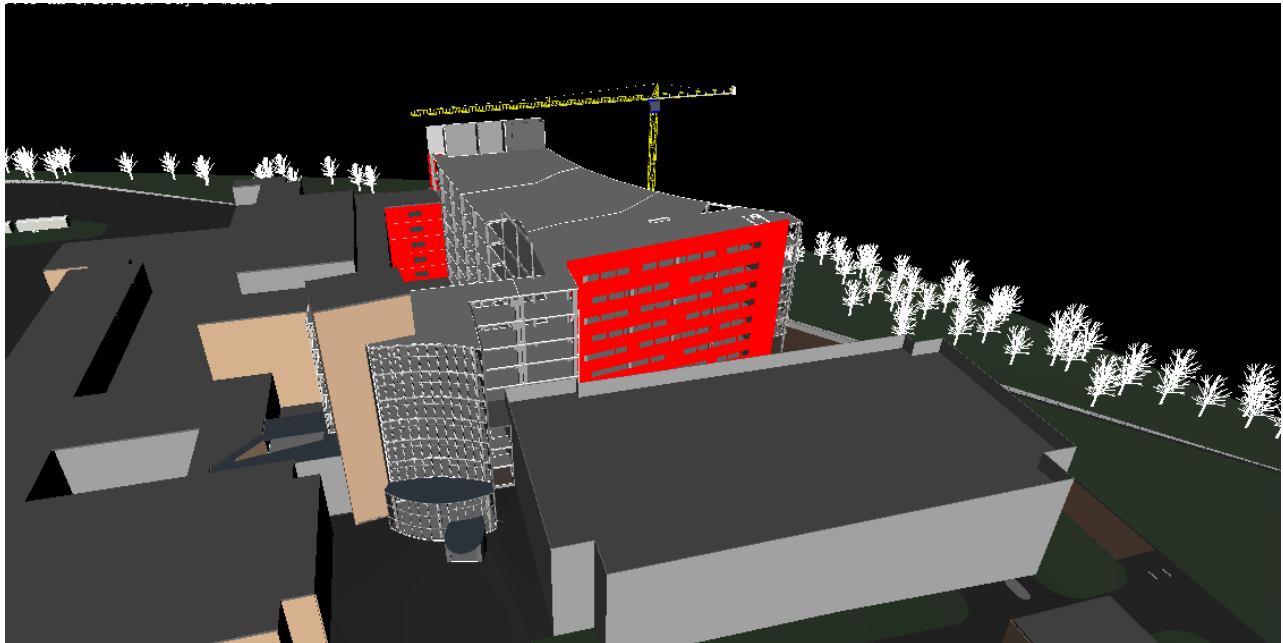
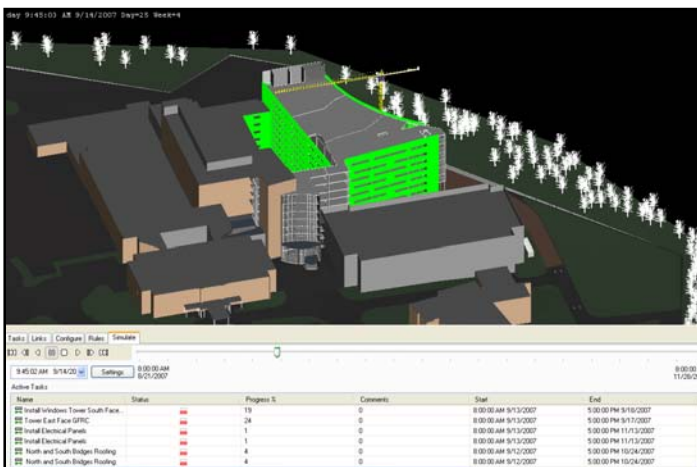
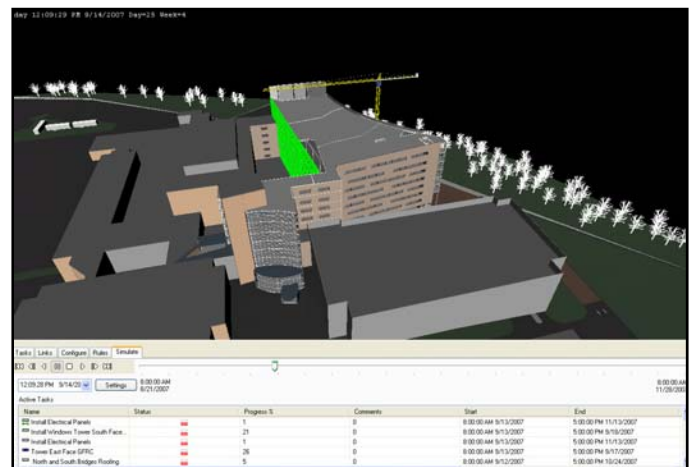


Figure 19: Image of 1st Facade 4D Comparison Model Simulated in Navisworks



EIFS Sequencing



GFRC Sequencing

Figure 20: Image of Structural 4D Comparison Model Simulated in Navisworks



4.7 Lessons Learned

Through the development of the 4D model, I was able to document some of the lessons learned from creating a 4D comparison model. The following list explains the lessons learned with this analysis:

- The 3D model was difficult and tedious to break up in Navisworks. I found that the best solution is to create the model components in the 3D Revit Model first and then import the components into Navisworks.
- The schedule was somewhat difficult to edit once it was imported into Navisworks. Sometimes the schedule could be edited in the Timeliner and other times the schedule was locked and could not be edited. I found that the schedule needs to be unlinked in the tasks tab within the timeliner tool. In order to unlink a new link, the new link needs to be right-clicked on and unlinked needs to be selected. Once the link is “unlinked”, the schedule can be edited.
- The schedules could be edited in Navisworks by unlinking the schedule link. By being able to edit the schedule in Navisworks, there is no time wasted with deleting the link, revising the schedule in Microsoft Project, and relinking the schedule back into Navisworks.
- During the simulation, only some of the walls and windows would highlight to show that they were being constructed. I checked to make sure that all walls and windows were linked to the schedules. I found no problems with the components linking to the schedule so I am unsure why only some of the components are highlighted when being constructed. This problem may be affected by the size of the model that was imported to Navisworks.
- The use of different task types allowed for different colors to be used for each alternative system. The different colors made it very easy to visualize the differences in durations. As discussed above, the use of the different tasks and colors did not help in situations where two systems began at the same time.
- It is difficult to show the construction of two tasks using the same model components at the same time. When the two systems are going up at the same time in the same area, only one of the colors for one of the tasks will show up. Because the second color does not show up, it is unclear that the system is being constructed at the same time as the other system. For example, with the façade analysis, the GFRC system and the EIFS system were going up at the same time on the west side of the building. Because they both started at the same time, only the color for the EIFS system showed up. It was unclear to tell whether the GFRC was going up at the same time; however, once the GFRC was finished on the west side, the walls would turn yellow. The yellow indicated that the GFRC was finished on the walls. The model was very confusing because you didn't see the GFRC starting, but you could see it finish. Because it was difficult to illustrate when the two systems started on one wall, two separate models were used to show the façade systems comparison.



- As found with the façade system comparison, the process for comparing two systems described above does not always work. The process worked well with the structural system comparison because one system started before the other system so you could clearly identify where each structural system was in the simulation. With the façade system, this comparison was difficult because one façade did not go up before the other. Many times, the two systems would start at the same time on the same side or one system would start first and then the second would start on the same wall. During these instances, the second façade system did not appear to be going up on the same wall even though it was. The only way it was apparent that the second façade was going up was when the color changed to indicate the wall was done being constructed. Also, the walls were constructed by face for both the EIFS and GFRC, which made it challenging to show how far along the walls were in the simulation until the entire face would change color. If the two systems are not being sequenced the same, it is hard to illustrate the difference in durations.
- By using different task types and colors, the simulation of the two systems could occur in the same area using the same model components. Once again, the tasks did not help with areas where two façade systems were beginning at the same time.
- The selection sets option in Navisworks made it very easy to combine model components into one item. This item could then easily be linked to the corresponding scheduling task.

4.8 Conclusion and Recommendations

The use of 4D Modeling in the construction industry has become extremely popular over the past few years. For my research, I decided to look into 4D Modeling because I believe that the use of this tool will save money, time, and will also make the visualization process of a construction schedule much easier. I specifically chose to look at 4D Modeling as a comparison tool because my thesis project is based on comparing alternative systems. By creating a process for using a 4D Model as a comparison tool, I could review this process with my two analysis areas that deal with comparing two systems. With the other two analysis areas, I have found that the alternative solutions proposed in my thesis project have proved to be shorter in schedule durations. I believe that if 4D Modeling was used to compare these systems on the Patient Tower project, the project team would have reconsidered the proposed alternative systems. This tool would have been very valuable especially during the value engineering process. The models I have created do not show a lot of detail, but if the models had more detail, the project team could have visualized the actual construction steps with the 4D Model. For example, there are currently some issues with the construction of the EIFS system on the project. The process for constructing the EIFS system is proving to be very labor intensive and tedious. If a model was created in



great detail to illustrate the time consuming installation, the project team may have re-evaluated the decision to use EIFS as a value engineering solution.

Although, the use of 4D Modeling as a comparison tool did not work for all situations as seen with the façade comparison, the 4D Model was effective in showing the differences in durations for the two systems in the structural model. For the façade comparison, two separate models were used to illustrate the durations for the EIFS and GFRC. I believe it would have been able to compare the façade systems using one 4D Model if there was an option that allowed the model component to change colors as the systems are being placed on the building. For example, with the façade model, it was impossible to show the GFRC beginning on a face where the EIFS was still being constructed. The only way the beginning of the GFRC system would appear is if the EIFS was already complete on that specific face. By having an option that allowed the colors to change as systems were still begin simulated on the same side, the beginning of the GFRC could appear even as the EIFS is still being constructed. As the technology advances, there will be ways to better compare durations for the different systems. Within the next few years, I believe this new technology will continue to grow within the construction industry. Even though the 4D Modeling has some flaws, it is still an effective tool to compare various systems. The use of 4D Modeling will not only reduce time and cost on a project but will also aid in a better understanding of the construction sequences and durations.