THE LONG AND FOSTER HEADQUARTERS BUILDING: A BUILDING INFORMATION MODELING CASE STUDY

by

Megan Wortman
Robert Leicht
Nevena Zikic
John I. Messner

Technical Report No.57

April 2008

Abstract

In this technical report, findings are reported from a case study investigating the use of Building Information Modeling and 4D modeling for constructability and schedule review. The use of Building Information Modeling and 4D Modeling is becoming more prevalent in the Construction Industry due to the spatial aspect and computable features that are offered. This report offers a case study example for the use of these tools on the Long and Fosters Headquarters Project during the early construction of the project.

This technical report is a CIC (Computer Integrated Construction) commissioned case study research project. The research project began September 1, 2006 and ended on May 5, 2007.

Contents

List of Figures

1. Introduction

This report explores the use of Building Information Modeling (BIM) and 4D Modeling to facilitate constructability and schedule review as a case study utilizing the Long and Foster Headquarters Project in Chantilly, VA, USA.

1.1 Background

The use of Building Information Modeling and 4D Modeling is becoming more prevalent in the Construction Industry due to the spatial aspect and computable features that are offered. The spatial aspect of these modeling applications provides an advantage over the use of 2D CAD drawings and CPM schedules (Fischer and Koo, 2000). The computable nature of these applications offers a way to quantify the building information provided within in the model. These models not only represent virtual images of a building, but they also include a database to store building information. These images offer an easier way to visualize the building and the construction process used for the building. The complexity and tediousness of linking the 2D drawings with the project schedules to visualize a project has led to the advancement of these intelligent modeling applications (Fischer and Koo, 2000).

1.2 Research

This study focuses on the use of Building Information Modeling (BIM) and 4D Modeling for the Long and Foster Headquarters Project. The report concentrates on the development of a BIM and 4D model; it also provides benefits and challenges encountered in creating and using these models. The Long and Foster research project was conducted by a group of students under the supervision of Professor John Messner. The research group developed the models using the 2D CAD drawings and project schedule that were furnished by James G. Davis Construction Company. The research group met weekly in the Immersive Construction Lab to discuss the development and progress of these models.

1.3 Research method

The research comprised three stages. First was the development of the building information model by the modeling team. Second, the BIM file was used to create a 4D model of the project schedule. The third stage was the culmination of the research with a visit to the Immersive Construction Lab at Penn State to review the models by the project team. At this meeting the responses of the project team were obtained using a questionnaire.

1.4 Research reporting

The remainder of this report comprises five sections. In the next section, an overview of the project is presented. The process for developing the BIM file is presented. Subsequently, the

process and the findings are presented in sections 3, 4, 5, and 6.   In the final section, conclusions from the research and directions for future research are presented.

2. Project Overview

The Long and Foster Building Project presented in this report is the new headquarters building for the Long and Foster Companies. This five-story office building will be built on a 39 acre-site located in Chantilly, Virginia. The building was designed by Architect Beery Rio of SOMA Architects. The building is being constructed by James G. Davis Construction as the Construction Manager on this project. Davis's construction duration for this project is 18 months, and the estimated cost for the project is $52 million. The ground breaking for this project occurred on 26 October 2006, and is scheduled to be completed in the summer of 2008 (Long and Foster Breaks...2006).

2.1 BIM Development

The development of the BIM was performed by a team of undergraduate modelers in the Architectural Engineering program at Penn State. The development was separated into different systems with each modeler responsible for a single building system. The models were developed using a single central model file that the modelers could access, but they developed their system models in separate files and merged the content back to the central file after each modeling session. The team met weekly in the Immersive Construction (ICon) Lab to coordinate the modeling effort, discuss challenges, and to raise questions about the software or the design content.

2.2 4D Model Development

The 4D model was developed in a similar manner to that of the BIM; with the exception that one modeler was responsible for the 4D model. The BIM file had to be modified to match the construction sequences in the schedule. The modified model file was exported to a file usable in a 4D software program. The 4D software was then used to link the model file with the existing schedule furnished by Davis Construction.

2.3 Final Meeting

The culmination of the project was the review of the BIM file and the 4D model by the project team in the ICon Lab. The meeting was held as a schedule review meeting, with additional points raised by team members pertaining to visualization aspects of the building geometry about which they had concerns.

2.4 Questionnaire

Feedback from the final meeting was obtained for determining the value of the models for project communication and planning. The questionnaire was a modified version of a questionnaire developed for obtaining information about 4D modeling by Tan (2005). The questionnaire, which can be found in Appendix 1, includes three open ended questions to

gain general information about the respondent, then poses 7 statements about the use of the models and offers a 5 point Likert scale ranging from Strongly Disagree to Strongly Agree for responses. The questionnaire ends with a few open ended questions to gain more in depth feedback about what aspects of the models they found to be of value. The goal was to gain feedback about the value added to the schedule review process and the clarity of communication amongst the project team.

3. Building Information Modeling

In the following three sub-sections the role of BIM in this project is presented, starting with a background of BIM use in the AEC Industry.

3.1 Defining BIM

Penn State's CIC Research Group defines building information modeling as the "process of designing, analyzing, integrating, and documenting a building's lifecycle by developing an intelligent virtual prototype of the building using a database of information." Through BIM authoring software, building information is input and stored in a database through a modeling interface. The information and model are then used to create various analyses, such as quantifying building components (Bazjanac, 203). The analyses may be inherent to the authoring software or may require a separate analysis tool. The model can also be used as a tool to share information throughout the design, construction, and operation of the building (BIM FAQ, 2007). The importance is in the information which accompanies the geometry and the ability for analyses gained through this information.

BIM is now growing in use for design reviews and construction reviews in the building industry. One reason BIM is becoming more popular in this industry is because it attempts to provide interoperable features (Kiviniemi et al, 2005). The interoperability of BIM data, often facilitated using IFC data files, allows different programs to share and exchange a building's information using the same format (Revit Interoperability, 2007). With this interoperable feature, various trades can share a building's information.

BIM is incorporated into a variety of software programs. Some of the common authoring software include Autodesk Revit, Graphisoft ArchiCAD, Bentley Architecture, and Nemetschek Allplan which is popular in Europe.(3) These programs are used for authoring BIM files, as communication tools, and offer some analysis tools, such as quantity takeoffs.

3.2 BIM for the Long and Foster Project

The BIM authoring software that was used for the Long and Foster Project was Autodesk Revit. For this project, both Revit Building 9.1 and Revit Structures 4.0 were used. Revit software was designed to be used for BIM (Revit Architecture, 2007). This program offers many features such as parametric modeling and multi-user interface with a single file. The parametric objects used in Revit have relationships with each other. For example, if a window were inserted into a wall, the wall information would change to reflect the presence of the window. Due to the parametric component of Revit, a change that is made in one view creates a change in all of the views (Revit Interoperability, 2007). For example, a wall that is created on a plan view will be visible in an elevation view, and in a section view. Figure 1(a)

shows a wall being drawn on a floor plan. Figure 1(b) shows an elevation view of the wall that was drawn on the floor plan.
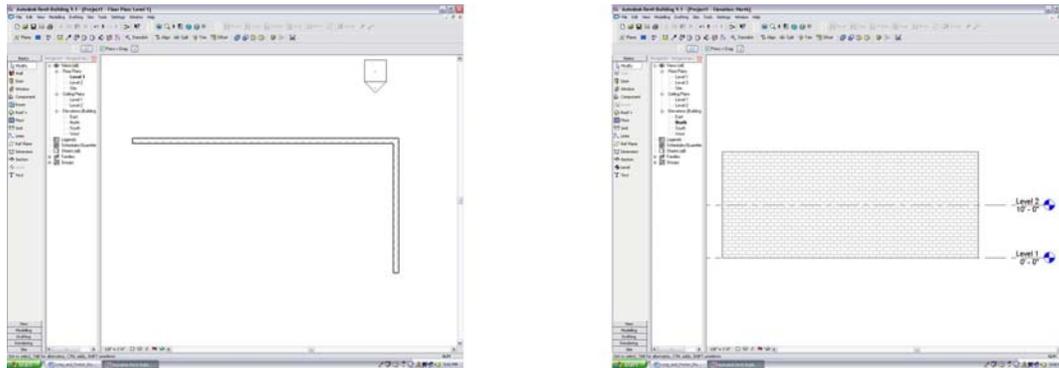

Figure 1a. Wall in Floor Plan; 1b. Wall in Elevation View

Another feature is the multi-user interface of a single file. This multi-use allows a project to be split into project areas allowing different people to simultaneously work on their portion of the model. These model components are saved in a single file, where they are combined into one building model (Revit Interoperability, 2007). Due to the features that Revit offers, it has become one of the more popular BIM applications used in the US building industry.

For the Long and Foster Project, 3D geometry was created from the 2D CAD drawings that were provided by BeeryRio of SOMA Architects. The 2D CAD drawings were converted into a 3D model using Revit Building 9.1 and Revit Structures 4.0. Figure 2 shows the process for developing a 3D model.
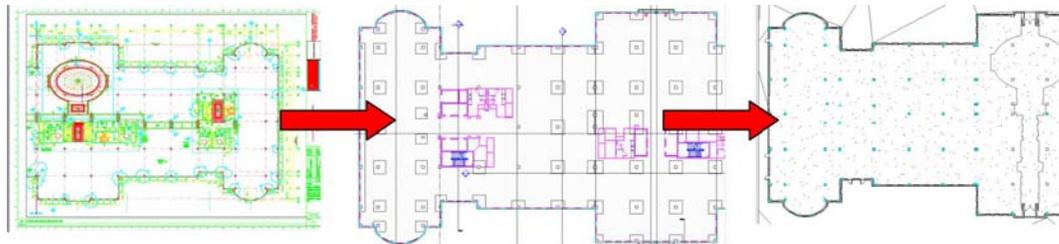
Figure 2a: Imported 2D CAD drawings; 2b: Architectural objects developed over the 2D CAD drawing; 2c: The 2D CAD drawing was removed.

The model was divided into three main systems. The structural system was developed in Revit Structures. The concrete structural objects were defined by floor and each floor was divided into six sections. The slabs and columns were organized into these six sequences to match the sequences in the project schedule.

Revit Building 9.1 was used to create the building façade elements. The façade was also organized by floor and by facade installation sequence. The walls were divided into four

sequences to match the project schedule. The most critical system for this model was the roof system. Due to the complexity of this system, this area was the Davis personnel's primary concern for the model; therefore, much time was dedicated to accurately develop this system. Figure 3 is an image of the 3D model taken from Revit Building 9.1.
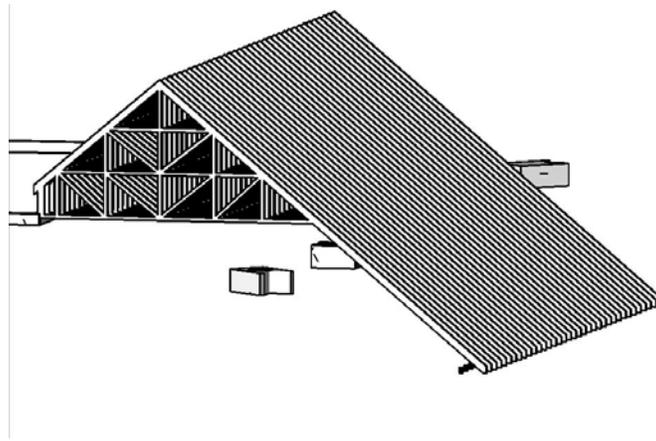

Figure 3: Perspective of Roof Trusses

3.3 Benefits of using BIM

Through the development of the model, the research team was able to recognize some of the benefits associated with using BIM. One of the main benefits observed was the creation of a central model. The central model allowed many users to work on different aspects of a model concurrently. The central model made it very easy to divide the model into different components or systems.

Another benefit found was the ability to easily import and develop the model from the 2D CAD drawings. For this project, the 2D CAD drawings were used as a basis for the 3D model. This saved a lot of time in building the model because the 2D drawing elements could be directly used to create the model, rather than laying out the whole design anew within the model.

A third benefit for using BIM is the model uses actual construction components by combining a variety of layers. One example of this is the wall systems that are provided in the software program's families. The walls created represent an actual wall with insulation, studs, and a finished façade as one example of an assembly. With 2D CAD, these layers would need to be developed separately, but with BIM, they are packaged into one system. A second example of this would be a window system; the windows are made up of many layers such as the glass box, mullions, window sill, that come as a single object but carry all of the information and properties of all of the components.

3.4 Challenges of using BIM

When developing the 3D model, some limitations with using BIM were also discovered. One of the main limitations with using BIM was the limitations of the current geometric modeling functions in the authoring software. These geometric modeling functions are not currently as sophisticated as the functions found in solid modeling software; therefore, some aspects of modeling proved to be difficult. One area that was difficult to model for this project was the rounded roof section, which will be addressed in more detail later on in the report.

Another limitation found with using BIM was the level of difficulty associated with creating a new family. The objects in the authoring software are individual items which belong to families of objects with similar traits. The Autodesk Revit software packages offers a variety of families and objects to facilitate the modeling process, however, the offerings are not limitless, and projects sometimes require objects and families not readily offered.

The process for creating a family was found to be both tedious and time consuming. One of the biggest concerns for this project was creating a family for the roof trusses.   The coordination of the roof construction was a major concern for the project personnel and the roof trusses played a central role. Figure 3 shows an image of the roof trusses that were created for this project.

The creation of a new object within an existing family can usually be accomplished through some minor editing of an existing object's properties to suit a new application. For example, several new wall types were developed for this project to match the wall types specified in the project documents. The walls were created by modifying the layers associated with existing wall types which closely resembled the wall type specified. However, if there is no pre-existing family or similar object to be edited, the family needs to be created. The value of the BIM software capabilities is based on the ability to analyze the information associated with the geometry, which is reliant on these objects. When a new object is created, these properties are essential to its success. It was found, through several attempts, that proper creation of a family requires a thorough understanding of the function of the objects, the geometry, and the essential properties associated with the object and its relationships with other building components.

4. Modeling in 4D

In this section, the process used for developing the 4D model is presented, along with the findings from implementing the model on the Long and Foster Headquarters Project.

4.1 Defining 4D Modeling

The term 4D modeling can be defined as the process of attaching the fourth dimension of time to a 3D model (Gopinath and Messner, 2004). A 4D model is created by linking a construction schedule to the 3D model. This process of linking a schedule to a 3D model occurs in a 4D simulation program (Fischer and Koo, 2000). Figure 4 illustrates the process of linking a 4D Model. Some of the common linking software used for 4D simulation includes Navisworks with Timeliner, Commonpoint Project 4D, and Bentley Navigator (Fischer, 2007). While the process of linking the files is relatively simple, the process of preparing the model for linking is more involved.
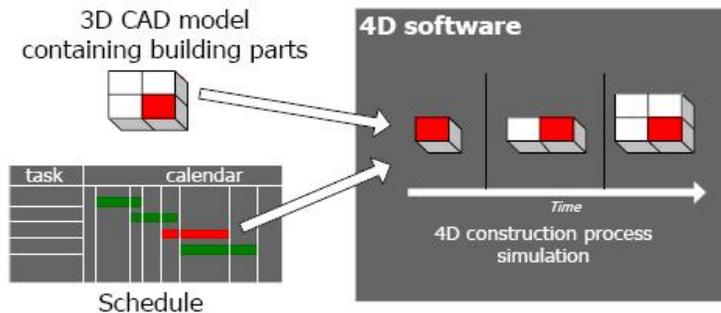

Figure 4: Process for developing a 4D model by combining the 3D geometry with the project schedule.

4.2 Modeling in 4D for the Long and Foster Project

The 4D simulation software that was used for the Long and Foster Project was NavisWorks with Timeliner. NavisWorks is a design review program for 3D models (Jetstream v.5, 2007). This model viewing program allows users to combine 3D models, review the combined 3D model, and also view the model in real-time (Jetstream, 2007). For this project, NavisWorks Jetstream version 5 with Timeliner was used. The Timeliner module was used to develop a 4D simulation of the Long and Foster Model.

For the Long and Foster Building, a 4D model was created using the 3D model and the construction schedule from the project. The construction schedule was linked from a Microsoft Project file. The 3D model and construction schedule were imported into the 4D simulation program, then the 3D model was linked to the activities in the schedule. To make the linking process quicker and easier, model components were created and imported separately into NavisWorks based on the sequence of construction activities. By bringing in

pieces of the model instead of the entire model, it was simpler to isolate each imported model component and link it to the correlating schedule activity.

Elevation views were primarily used to group the model components, with a focus on the facade. These views show the exterior sides of a building and through a trial and error process the use of the elevation views proved to be the easiest way to incorporate only the necessary model components. Initially, systems with extra objects or missing geometry were imported into the linking software. By creating the model components in elevation views, the problem with importing additional or missing pieces of a model was alleviated.

For each of the sequences which needed to be linked in Navisworks, a view was created in the Autodesk Revit file, allowing it to be easily exported again in case of changes to the geometry. In each of the elevation views, the visibility settings were changed and the views were cropped to show only the necessary elements within the model. Figure 5 shows an example for a set of columns. Image 5a illustrates a cropped elevation view of the column group, while 5b shows a visibility settings window for the group of columns. As the views were created, they were exported into a NavisWorks cache file, so that they could be directly imported into the linked NavisWorks file. Although this process of creating views and importing them separately into NavisWorks was time consuming, it proved to be the easiest way to import the 3D model pieces into the linking software. Figure 6 shows the process used for creating a 4D model in Navisworks and Figure 7 is an image taken from the 4D model simulation in Navisworks Timeliner.
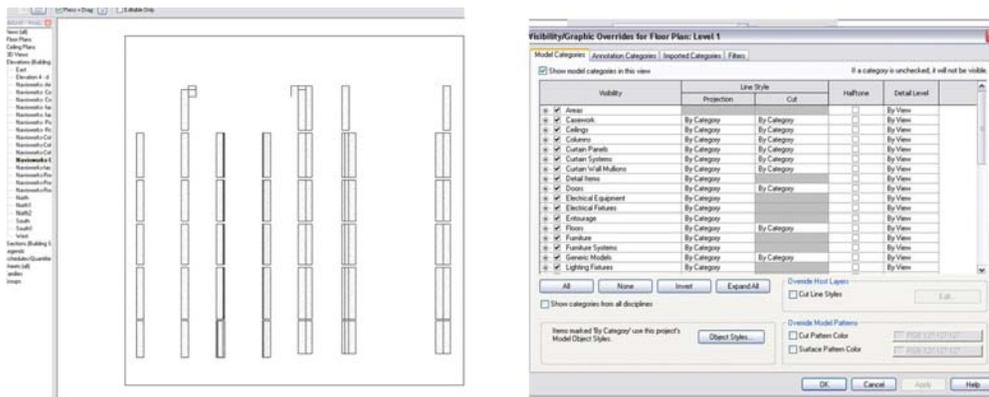

Figure 5a: Cropped elevation view of columns; 5b: Visibility settings window
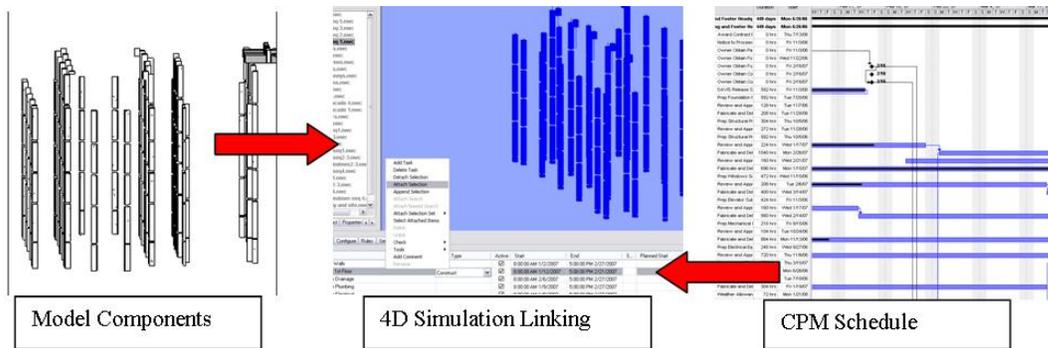
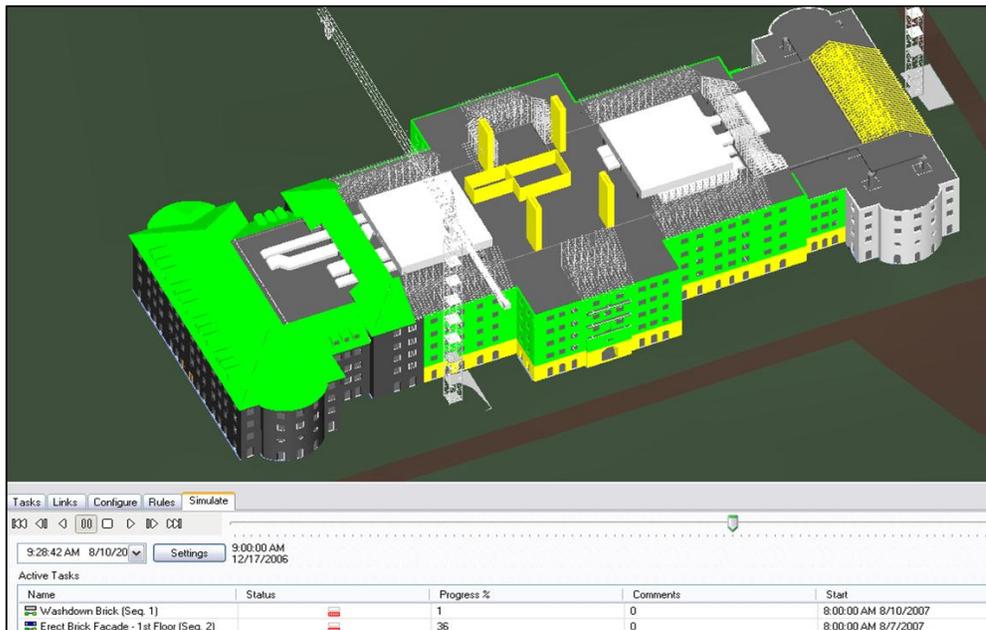*Figure 6a: Model components; 6b: 4D simulation linking; 6c: CPM schedule*

Figure 7: Image from 4D simulation in NavisWorks Timeliner

4.3 Benefits of Using 4D Modeling

Through the development of the 4D model, it was possible to document the benefits associated with using 4D modeling software. A benefit found with using the NavisWorks 4D modeling software was that the coordinate systems in the 4D model matched up with the coordinate system used in the BIM program. This is one of the interoperable features presented earlier in the report. The consistent coordinate systems allowed model components to be imported separately into the 4D program and still align in 3D.

4.4 Challenges of Using 4D Modeling

When developing the 4D model, some limitations were also encountered.   One of the main limitations discovered with using Autodesk Revit was the need to regroup and rename the

model pieces in the BIM software before importing them into the 4D linking software. The 3D model needed to be re-grouped so that the correct geometry could easily be linked to the correlating schedule activities in the 4D model. For example, the columns needed to be grouped by sequence in the 3D model so that they matched up with the schedule sequencing in the 4D model. This process of regrouping each model component was slow and did not add direct value.

A second limitation found with using 4D modeling was that the 3D model elements were not arranged by the floor they were aligned with in the BIM. Because the elements were scattered within each sequence of model components, it was very difficult to find a specific element in the 4D software program to link for a specific sequence. An example from this project was the ductwork for the model. In the 3D model some of the ductwork was linked to the roof and some of the ductwork was linked to the topography. When these components were added to the selection tree, from which the linking is performed in the 4D software, the ductwork elements that were attached to the roof and topography were spread throughout all of the elements within each floor. Because the ductwork elements were among two different components, it was time consuming to find and link all ductwork to the schedule activities.

A third challenge was the process of deleting and re-importing model pieces. When importing 3D model components into the 4D program, some of the elements were either added or omitted from the sequences. These added or omitted pieces created iterative process of trial and error to determine if the 4D model contained all of the necessary geometry, as well as in increased likelihood for missing necessary components. The process involved changing the views in the 3D model so that only the necessary elements within the model component would be imported into the 4D model. An example of this was the wall component for the 3D model; the walls were imported into the 4D program by sections based on the schedule sequence. When these wall sections were imported, many times there was either a wall added or missing from the desired sequence. When this occurred, the views for the wall components needed to be adjusted in the 3D model and then re-imported into the 4D model. This process provided a challenge with creating a 4D model.

5. Final Review Meeting Results

On March 2, 2007, a meeting was held to present the 3D and 4D models to the project team. The meeting was attended by employees from Davis Construction, the owners for the Long and Foster Building, the lead architect from BeeryRio of SOMA Architects, and members from the CIC research group. Professor John Messner led this presentation with the help of Robert Leicht and Nevena Zikic.

5.1 Model Discussion

The presentation of the 3D and 4D models generated many items for further consideration regarding the design and construction of this building. Some of these items were critical and others were minor. One of the geometry issues discussed during the meeting was the rounded roof section that existed on each of the four corners of the building. During the development of the 3D model, the modellers were unable to accurately create one of the rounded roof sections in the model. Figure 8 illustrates the rounded roof section as it was represented in Revit.
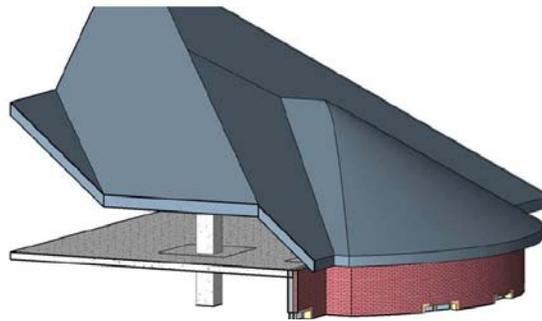

Figure 6: Rounded roof section as modelled in Revit Building 9.1

The modeling problem posed a serious issue about how this rounded roof section would be able to be constructed as specified by the architect's design. This concern led the architect and construction team to re-evaluate the roof design. After the meeting, the CIC research team continued to work on a way to accurately represent this roof design in 3D. Figure 9 illustrates the roof section that was developed in Google SketchUp by members of the CIC Research Group.

An issue that arose from the 4D model was the column and slab sequencing on the fourth and fifth floors. During the development of the 4D model, it was discovered that the slabs were being placed on the fifth floor before the supporting columns were placed on the floor below this slab. Figure 10 shows the sequences where the slabs on the fifth floor are sequenced before the columns on the fourth floor. This sequencing issue identified a need to revise the sequence in the construction schedule. While having an impact on the schedule accuracy, this scheduling issue did not have an impact on the project completion date. The sequencing of these slabs and columns on the 4th and 5th floor did not correspond to the other slab and

column sequences. Davis Construction was able to eliminate this problem through some simple revisions to the project schedule.
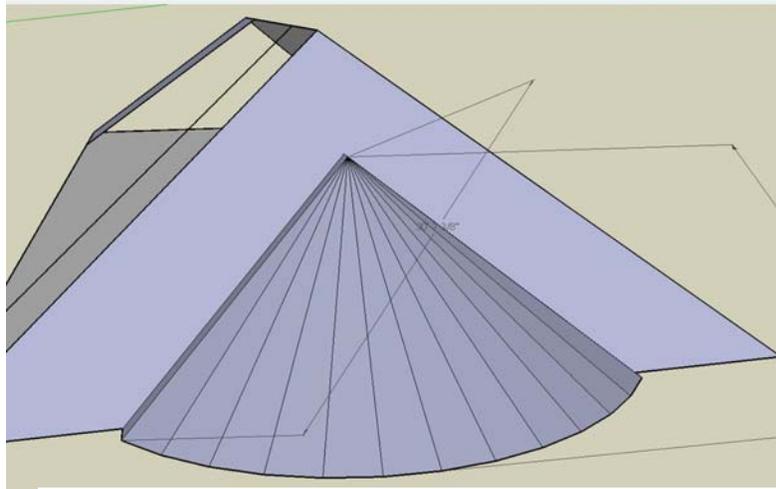

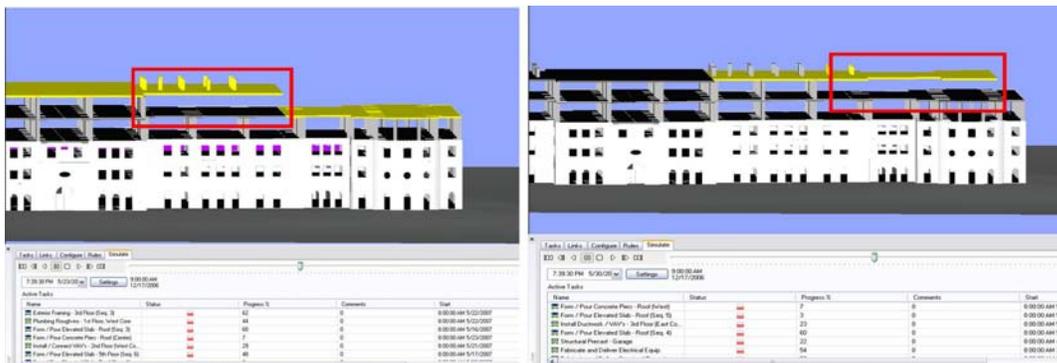*Figure 9: Rounded roof section developed in Google SketchUp*

Figure 10: 4D Simulation with missing columns

One of the other issues that arose at the meeting was the openings for the roof ductwork on both the east and west sides of the building, as seen in Figure 11(b). The main concern with these openings was whether or not they would be visible from the ground level. During the meeting, this issue was reviewed utilizing the 3D model in Revit. In Revit, a camera snapshot was taking of this roof opening from the ground level. Based on this camera snapshot, it was concluded that the roof openings would not likely be seen from the ground level. Figure 11(a) presents a camera-shot view of these openings from the ground level.
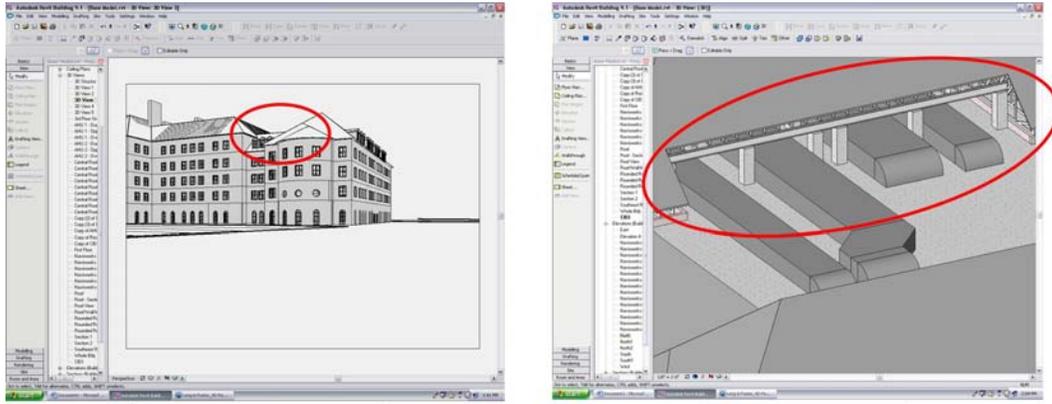
Figure 71a: Camera view from ground; 11b: Close up view of ductwork and roof

Another minor issue that was discussed at the meeting was the exposure of the roof trusses. Figure 12a illustrates these exposed trusses. To minimize the potential viewing of the opening and the exposed roof trusses, the members of the CIC Research Group later developed a 3D model that showed that the roof could be shifted down to cover the exposed trusses. Figure 12b below demonstrates the edited roof section that was created. Without the development of these models, some of these concerns may have gone unnoticed or unresolved until later in the project.
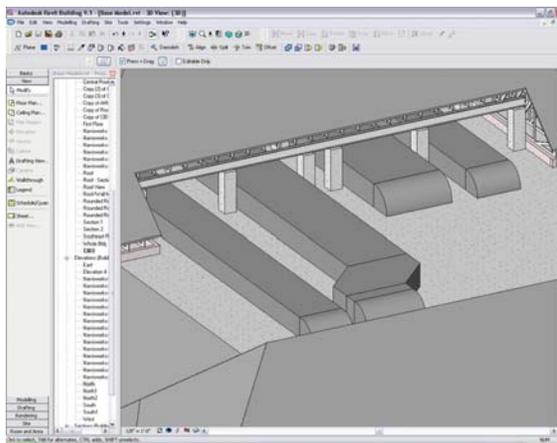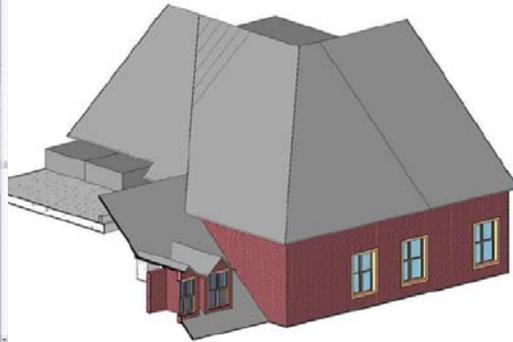

Figure 12a: Roof trusses exposed;   *12b: Revised roofline*

5.2 Summary of Benefits for Long and Foster

From the meeting for the Long and Foster Project, several benefits for using 3D and 4D modeling were identified. One of the biggest advantages found for this project is the visualization of the building geometry. This visualization of the models clearly communicates the design and construction of the building. These models also provide visualization for areas that are difficult to envision, such as the roof geometry coordination. The 3D and 4D models also identify unforeseen errors in the construction drawings and schedule. One issue that was identified on this project was the slab and column sequence, which was discussed earlier in the report.

Another benefit for using these models is that constructability issues can be identified. One issue that was identified for this project was the geometry of the rounded roof sections. As discussed earlier, one of the roof sections could not accurately be modeled, which posed the issue whether or not this roof structure could be constructed. These modeling applications also allow for easy exploration of design alternatives. Design alternatives for the pitch of the roof were explored for the rounded roof section, in an effort to identify potential design changes. The benefits associated with these modeling applications proved to be valuable for the design and construction review of the Long and Foster Building.

5.3 Challenges of BIM and 4D for Long and Foster

Along with the benefits, many limitations were also identified through the discussion and direct feedback from the meeting. One of the main limitations noted for using modeling applications in the building industry is implementing the software among all trades. It was suggested that it would be difficult, at this time, to enforce a standard that requires all trades to employ this software within their company, mainly due to the incurred costs, the learning curve associated with the software, and the challenges of interoperability. Another issue that limits the use of modeling is the extra time or resources that would need to be devoted to developing these models. Many times the designer or construction manager will weigh the benefits of these efforts against the cost and find that the added value offered by the modeling does not outweigh the cost for implementing these programs on simpler projects, and the learning curve is then challenging on the larger or more complex projects. These limitations presented a major barrier for the designer and construction manager to begin using this modeling software.

5.4 Meeting Questionnaire Feedback

During the meeting, the CIC research group received a lot of valuable feedback on the models that were developed. The following paragraphs discuss the results from a questionnaire that was given at the end of the meeting. The survey was completed by the nine individuals from the project team who are involved with the final meeting. The survey focused on the benefits that the developed models provided for the Long and Foster Project.

The figures below illustrate the results for each comment provided in the survey. The results range on a scale from strongly disagreeing with the comment to strongly agreeing with the comment. The first comment in the survey stated that the 4D model helped visualize the construction sequence. In figure 13, the results show that the majority of individuals agreed with this statement.
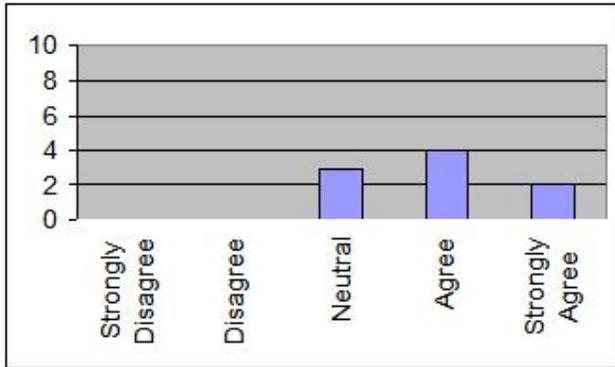

Figure 8: Response - 4D model helped visualize the construction sequence

The second statement made in the survey suggested that the visualization of the 4D model prompted changes in the schedule. Figure 14 illustrates that many of the individuals neither agreed nor disagreed with this statement.
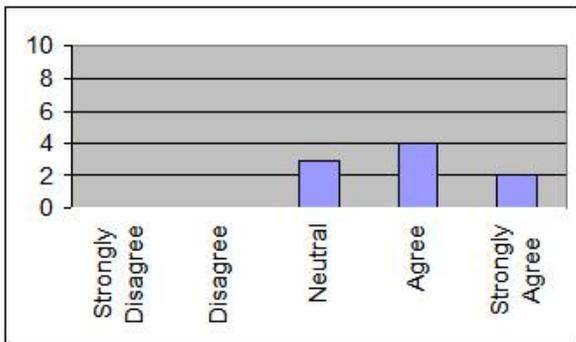

Figure 9: Response - Visualization of 4D model prompted schedule changes

The third question stated that the visualization of the 4D model prompted confidence in construction sequencing. Figure 15 shows that half of the individuals agreed with this suggestion while the other half did not disagree or agree with this statement.
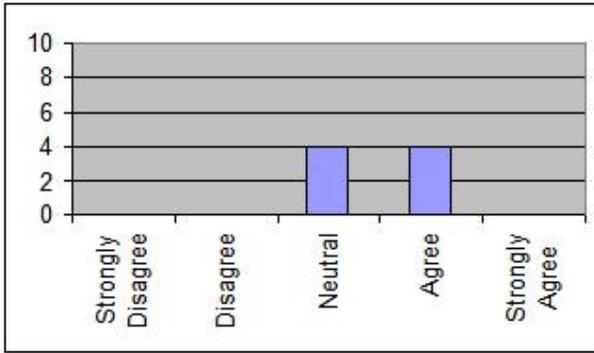
Figure 10: Response - 4D prompted confidence in the schedule

The fourth comment states that the 3D model is a valuable communication tool for the project. Figure 16 illustrates that all of the individuals agreed with this comment.
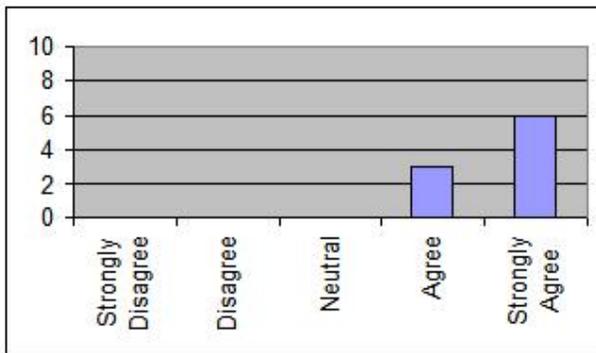

Figure 11: Response - 3D model is a valuable communication tool

The fifth statement suggested that delays in construction process could be avoided if model was incorporated earlier in the construction phase. As shown in Figure 17, all individuals agreed with this statement.
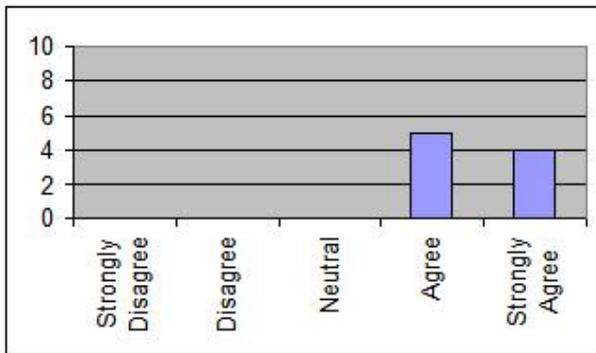

Figure 12: Response - Delays would be avoided by using 4D earlier

The last comment on the questionnaire suggested the addition of construction space occupation for each trade would increase the value of the 4D model. Based on the results in

Figure 18, the majority of the individuals agreed with this suggestion. The feedback provided from this meeting reaffirmed the many benefits for incorporating BIM and 4D Modeling in the building industry.
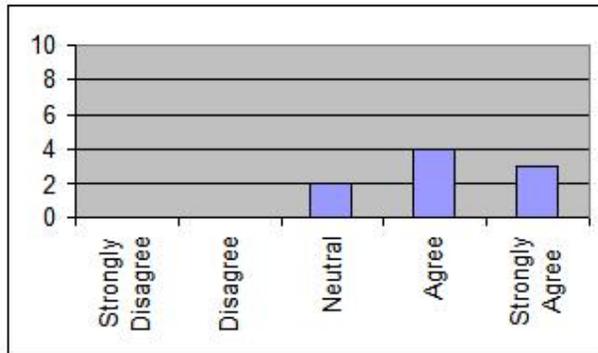

Figure 13: Response - Addition of space occupation would increase the value of the 4D model

5.5 Future Model Development

During the meeting for the Long and Foster Project, we were presented with potential areas that could be further developed in the model. One of the issues addressed at the meeting was an improved site plan. After the meeting, students from the research group revised the site plan by adding roads, trailers, and cranes to the site, as shown in Figure 19. Another model component that could be furthered developed was the structural framing. It was suggested that the connection details for the structural framing would be beneficial. The suggestion was made to also include a cost analysis within the project. The last issue presented in the meeting was to design the façade using the actual brick patterns.
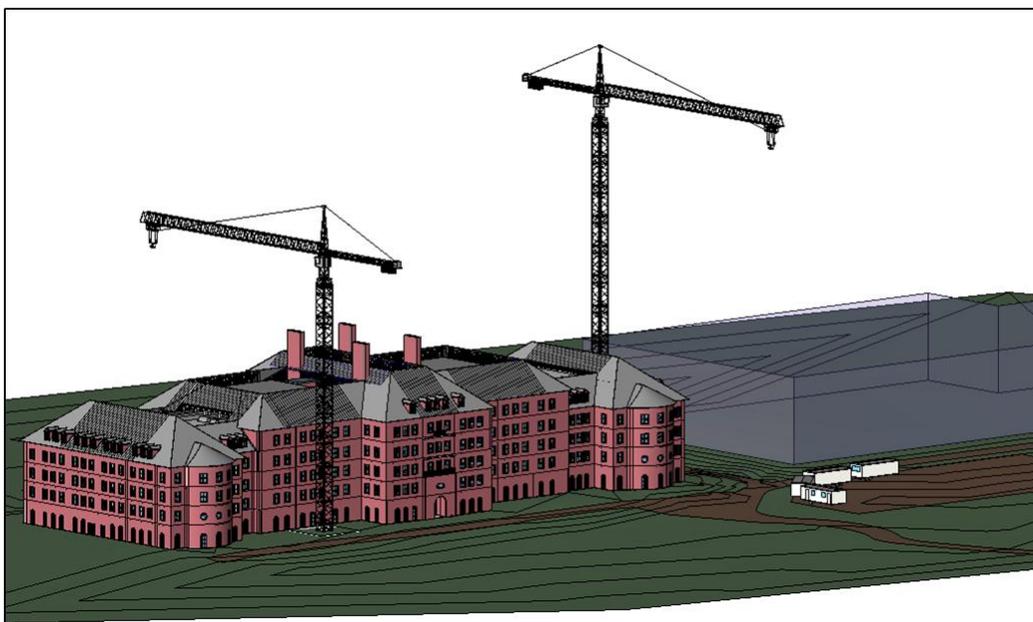

Figure 14: Revised BIM with site plan information added

6. Using BIM and 4D for Education

This report has focused on the use of BIM and 4D Modeling for design and construction reviews in the building industry; however, modeling applications can also be used as an educational tool. By using these applications, students can gain a better understanding about the cost estimating and scheduling for the construction of a building. Through the use of BIM, students can perform quantity takeoffs for the building. Students can then check their calculated takeoff values with the values generated using BIM. A cost analysis of the building can be developed by assigning price values to the materials used in the building. The use of 4D modeling is also a valuable tool for educating students. With 4D Modeling students can evaluate their construction schedules by linking their schedules to a 3D model. By linking the schedules to a 3D model the students are able to visualize the accuracy of their construction schedules. By visualizing the schedule, students are able to recognize the significance of scheduling sequences, durations, and conflicts. Through the use of these applications, students can easily comprehend the concepts associated with cost estimating and scheduling.

7. Conclusions

In this section, the outcomes of the paper are summarized, contributors to the work are recognized, and directions of future work are presented.

7.1 Summary Outcomes

Through this case study, it can be concluded that the use of BIM and 4D Modeling are effective communication and visualization tools for the design and construction of a building. The 3D model was very successful in displaying an accurate representation of the Long and Foster Headquarters. The 4D model was also very valuable in communicating the construction sequence of the building. The biggest challenge found when creating these models was limitations with the software. By working on this project, it was possible to establish more efficient means for creating 3D and 4D models. It can also be concluded that there are many challenges for implementing these applications into the building industry. However, as the modeling technology increases in architecture, engineering, and construction industries, the limitations for implementing BIM will continue to decrease.

8. Acknowledgements

References

Bazjanac, V. (2003). Virtual building environments (VBE) - applying information modeling to buildings, In A. Dikbas, Scherer, R. (eds) *ECPPM 2004 - eWork and eBusiness in Architecture, Engineering and Construction*, Istanbul, Turkey.

BIM FAQ (2007). <u>BIMForum</u>, January 2007, http://bimforum.org.z.seekdotnet.com/index.php?option=com_content&task=view&id=19&Itemid=38#Q2. Accessed: April 17, 2007.

Broekmaat, M. and Bauke Ve Vries. "Implementation Scenarios for 4D CAD in Practice." Department of Architecture, Building and Planning. Eindhoven University of Technology. April 2007. http://www.ddss.nl/downloadPublication.php?ID=215&view

Building Information Modeling (2007). <u>Wikipedia</u>. May 8, 2007. Wikipedia Foundation, Inc. April 2007.http://en.wikipedia.org/wiki/Building_Information_Modeling

Fischer, M., and Koo, B. (2000). "Feasibility Study of 4D CAD in Commercial Construction." <u>Journal of Construction Engineering and Management</u>. July/ August 2000.

Fischer, M. (2007). 4D Modeling: Applications and Benefits, Virtual Builders Roundtable. April 2007, http://www.virtualbuilders.org/VBR_Presentations/Martin_Introduction.pdf

Gopinath, R., and Messner, J. I. (2004). "Applying immersive virtual facility prototyping in AECO." *CONVR 2004: 4th Conference of Construction Applications of Virtual Reality,* Lisbon, Portugal, Sept. 14-15, 79-86.

Jetstream (2007). <u>Wikipedia</u>. April 17, 2007. Wikipedia Foundation, Inc. April 2007. http://en.wikipedia.org/wiki/JetStream_(software)

Jetstream v.5 from NavisWorks (2007). NavisWorks. http://www.navisworks.com/en/jetstream Accessed: April 22, 2007.

Kiviniemi A., Fischer M., and Bazjanc V. (2005). Integration of multiple product models: IFC model servers as a potential solution, in Scherer R.J., Katranuschkov P., and Schapke S.-E. (eds) *22nd Conference on Information Technology in Construction*, Institute for Informatics, Technische Universitat, Dresden, Germany.

Long and Foster Breaks Ground on New Headquarters Building." <u>Long and Foster–The Total Homeownership Experience</u>. October 26, 2006. Long and Foster Real Estate, Inc. April 2007. http://www.longandfoster.com/Press_Release/Press-Release-8.aspx

Revit Architecture (2007). Autodesk, Autodesk, Inc.,
     http://usa.autodesk.com/adsk/servlet/index?id=3781831&siteID=123112; Accessed: April
     19, 2007

Revit Interoperability with CAD (2007). Autodesk,
     http://images.autodesk.com/adsk/files/3968933_Revit_Interoperability_w_CAD.pdf;
     Accessed: April 24, 2007.

Tan, B (2005). A visual process for planning trade flow on construction projects, CIC Technical
     Report, No. 48, The Pennsylvania State University, University Park, PA, USA.

Appendix 1
ICon Lab Survey

This is an anonymous survey and you can skip any question(s) you do not wish to answer. This survey is conducted for the sole purpose of research and all the data collected will be kept strictly Confidential. Please give your comments and provide your responses on a scale of 1-5 (1–strongly disagree and 5–strongly agree). Thank you for your time and cooperation.
Acronyms used in the Questionnaire:
ICon Lab: Immersive Construction Laboratory
4D CAD: (3D CAD + Time as 'schedule')
 General Information:
1. What is your role on the project?

2. How many years of construction experience do you have?
_____ years
 3. What type of building construction experience do you have?

Answer the following questions on a scale of 1-5 (1 –strongly disagree and 5 – strongly agree):

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
4. I have a better understanding of the construction sequence of the building structure after viewing the 4D model.	1	2	3	4	5
5. The ICon Lab would be a good environment for progress meetings.	1	2	3	4	5
6. After seeing the model I feel there should be changes in the schedule.	1	2	3	4	5
7. I have more confidence in the schedule after seeing the model.	1	2	3	4	5
8. The immersive 3-D model is a valuable communication tool on the project.	1	2	3	4	5
9. Using this model early could help avoid delays in construction.	1	2	3	4	5
10. The 4D CAD model with construction space occupation of each trade marked by framework will increase the value of the model.	1	2	3	4	5

11. Did you see something in the model which you had not mentally visualized?
If so, please describe.

12. Did you identify any constructability issues? If yes, please list them.

13. What are the current challenges that you face in the project? Can this technology help you in resolving these challenges? If yes, state how can it be helpful.

14. Can you identify challenges for the adoption of this technology in the industry?

15. What additional items would you like to see included in the models?

16. Other Comments: