3 - Designing the Design Model (With a Focus on 4D Modeling)

3.1 - Introduction

According to a National Institute of Standards and Technology study, "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry – 2008", the estimated cost of inadequate interoperability among computer-aided design, engineering and software systems is $15.8 billion per year in the U.S. Capital Facilities Industry. In order to combat this loss due to inadequate interoperability, many AEC and Facilities organizations have begun efforts to improve the interoperability of software systems and the facility construction process.

One effort by the buildingSMART alliance is focused on the industry wide adoption of Building Information Modeling (BIM). This effort is aimed at open interoperability and full facility lifecycle implementation of building information models in order to obtain lowest overall cost, optimum sustainability, energy conservation and environmental stewardship. As a part of the buildingSMART alliance effort, the Computer Integrated Construction (CIC) Research Group at Penn State is currently working on The BIM Execution Planning (BIMex) research project. The goal of this research is to develop a BIM Execution Planning Guide to aide in the creation a BIM execution plan in the early stages of a project, which is intended for facility owners, designers, contractors, subcontractors and manufacturers. A BIM Execution Plan would help project participants reach decisions on BIM implementation for the different stages of a project.

The research of this thesis analysis falls under the goal of the BIMex research project, and specifically under the task of developing a process for BIM planning on a project. If the goal of a project team is to use multiple BIM uses at multiple stages of a project, it is important for that team to plan a process that is customized for that project. The planned process should include BIM supported tasks with the exchange information needed between the tasks. The BIMex research team selected process mapping as a way to visually create and convey BIM work processes. Process mapping can help to establish a logical sequence of tasks, identify the process inputs, identify the process outputs, and identify the team participants (agents) responsible for the tasks.

One goal of this research is to utilize process mapping in order to distinguish the difference between creating a design stage building information model and a for construction building information model. Designers typically build a model for design intent purposes only; and the content, level of detail and grouping of a design stage model does not typically meet the needs for that model to be used for construction BIM uses. This problem is caused by the fact that the designers typically lack the downstream information from contractors and manufactures required to build a model for construction.

BIM uses in construction include 3D coordination, 3D construction system design, unit price estimating (5D), 4D planning and site utilization planning. This research will focus on the use of 4D planning for construction. 4D planning is defined as a 3D building model linked to a construction schedule in order to visually simulate the progression of construction over time. Process maps were created to convey the process of developing a 4D model. The Model Progression Requirements Document was also developed for this analysis in order to identify the necessary model content, level of detail, and grouping requirements of a model used for different BIM uses at different stages of a project.

The Detroit Integrated Transportation Campus (DITC) project created a building information model for 3D design coordination during the design phase. This model includes the architectural components (exterior walls, roofing, windows, doors, interior walls, ceilings, flooring, etc.) and structural components. The model was only used during design for coordination, and within the design-bid-build delivery, the project has no plan of handing the model to the contractor for use in construction. A "what-if" scenario was taken for this research to analyze the process of using the DITC model during design to create a 4D Milestone Model, and also using the model for construction as a 4D Detailed CPM model. Two process maps for developing a 4D milestone model and a 4D detailed CPM model were compared to highlight the difference in tasks, inputs, outputs and agents for each process. Also, the Model Progression Requirements Document was used to compare the differences of the model content, level of detail and grouping requirements between the 3D Design Coordination Model, 4D milestone model and 4D detailed CPM model.

3.2 - Process Mapping

The BIMex research team selected process mapping as a way for project teams to visually create and convey BIM work processes for a company or a project. Process maps can be used on a company level to establish typical work flows for specific BIM uses that a company utilizes, and set a company-wide standard. Process maps can also be utilized on a project level to establish the work flows for project specific BIM uses.

There is not a standard type of process modeling for the Construction Industry. For precedence the BIMex Research Team looked at different process modeling types that have been created in the Construction Industry. The BIMex team reviewed the Integrated Business Process Model (IBPM) developed by Victor Sanvido et al. (1990) at Penn State, which utilizes IDEF0 modeling methodology, to convey the process required to provide a facility. The team also reviewed the Generic Design and Construction Process Protocol, developed by a research team at the University of Salford, which breaks down the design and construction process using no particular modeling methodology. The BIMex team selected to use Business Process Modeling Notation (BPMN) for the creation of process maps, specifically utilizing TIBCO, a process modeling software. The goal of the BIMex Research Project is to create generic process maps for multiple BIM uses, which will be utilized by project teams as templates to create project specific process maps.

Chitwan Saluja, a member of the Computer Integrated Construction (CIC) Research Group and BIMex Team at Penn State, created a procedure to develop process maps for BIM task execution. The procedure along with a format that divides the process maps into four swim-lanes (External Info, Enterprise Info, Process, and BIM Info Ex.), will allow teams to map project specific BIM tasks. The six step procedure is as follows:

Step 1: Hierarchically decompose the task into a set of activities.

Step 2: Define the dependency with other activities.

Step 3: Break up every activity within the task (repeat a-c)

a: RESOURCE: Identify the resource to be used

b: RESULT: Define intermediate and final results in the form of BIM models, and information exchange required for the activity.

c: AGENT: the agent performing the activity.

Step 4: Check if the results have been met – e.g.: decision making criteria, entry – exit criteria.

Step 5: The feedback to be provided to other agents concerned (e.g.: the client for his approval of the estimation, the designer, etc.)

Step 6: Document, review and redesign this process for further use.

As part of the BIMex Research Project and for this research, a process map for developing a 4D model was created utilizing the process and format developed by Chitwan Saluja. This process map, titled "Develop 4D Model", is available in Appendix B and was created as a generic process map for an ideal project delivery such as Integrated Project Delivery. The process map is based on ideal project delivery to promote such delivery; however, it can easily be edited to represent other deliveries such as Design-Bid-Build. The process map was created as a generic map so that it can be used at any stage of a project, and for different levels of 4D modeling. In order to create a generic process map no specific agents were identified, tasks were kept generic, and specific outputs were not identified.

The DITC model was only used during design for coordination, and within the design-bid-build delivery, the project has no plan of handing the model to the contractor for use in construction. A "what-if" scenario was taken for this research to analyze the process of using the DITC model during design to create a 4D Milestone Model, and also using the model for construction as a 4D Detailed CPM Model. In order to visually represent the process of creating each 4D model, process maps were created for developing a 4D Milestone Model during design, and developing a 4D Detailed CPM Model for construction. These process maps are titled "Develop 4D Milestone Model" and "Develop 4D Detailed CPM Model", and are available in Appendix B. In order to create each of these project specific process maps; specific agents were identified for tasks, tasks were changed to represent each model's development, and specific outputs were identified. Editing the generic map to represent these specific processes was a simple task, which helps to validate the process of using generic process maps to create project specific maps.

3.3 - Model Progression Requirements

This research also focuses developing a tool to define the progression requirements of a model. If a project intends to utilize multiple BIM uses on a project; either multiple models must be created for those uses, or ideally, one project model must be capable of being utilized for all project BIM uses. Because models for different uses and different stages of a project require different information, level of detail and grouping requirements, the model must be edited for each BIM use. Defining the different requirements for the progression of a BIM model was identified as an industry wide problem by the BIMex Team and the BIMex advisory board, comprised of industry BIM experts.

In order to help define the progression requirements of a model for different BIM uses on a project, the American Institute of Architects (AIA) published the AIA Document E202-2008: BIM Protocol Exhibit. AIA Document E202-2008 utilizes a spreadsheet to define the Level of Detail (LOD) and Model Element Author (MEA) for the different model elements of a project Building Information Model, and is available in Appendix C. The table prompts the user to identify each project phase; and the LOD and MEA required for each model element at the end of each phase. Document E202-2008 organizes the different model elements in the table by CSI UniFormat™. The document also indentifies different levels of detail (increasing in detail at 100, 200, 300, 400 and 500) for multiple BIM uses. These uses include Design and Coordination, 4D Scheduling, Cost Estimating, Program Compliance, Sustainable Materials and Environmental. Table 3.1 below represents the defined levels of detail for 4D Scheduling.

	Level 100	Level 200	Level 300	Level 400	Level 500
4D Scheduling	Total project construction duration Phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Fabrication and assembly detail including construction means and methods	

Table 3.1, Level of Detail for 4D Scheduling, AIA E202-208: BIM Protocol Exhibit

After review of AIA Document E202-2008 with John Messner Ph.D., BIMex Project Advisor, it was determined that the document was missing some key features for a model progression document. The problems with AIA Document E202-2008 are as follows:

- Although the CSI UniFormat™ is effective at dividing the work packages of a construction project, it is not as effective at defining the model elements required for many different BIM uses.
- Project phases do not successfully divide the requirements of a BIM model for different uses. Different uses during the same project stage may require different model requirements.

- The generic levels of detail (100-500) can not entirely define the detail requirements of model elements for different BIM uses, and there is no space for element grouping requirements.

In order to cover the deficiencies of AIA Document E202-2008, the Model Progression Requirements (MPR) Document was developed for this research. The document is a spreadsheet, similar to AIA Document E202-2008, which project participants complete to define the progression requirements for a Building Information Model throughout a project's lifecycle. A blank MPR document is available in Appendix C. The differences from the AIA Document are as follows:

- The Model Elements are organized using CSI UniFormat™, along with added categories that include elements missed by AIA Document E202-2008 and CSI UniFormat™. These added categories include Construction Systems and Equipment, Temporary Safety and Security, Temporary Facilities and Weather Protection, Construction Activity Space, Facility Space, and Project Information. Also, all categories are not sub-divided beyond the first level of CSI UniFormat™ as they are in AIA Document E202-2008; therefore the user can define sub categories as needed.

- The model progression stages are not divided by project stage; however, they are divided by BIM use.

- Grouping was added as a definition field for model elements of a particular BIM use. Level of Detail is important to define; however, it is also important to define grouping requirements as they will be different for different BIM uses.

- Model Element Author is not included in the MPR, as a Model Element Author would be defined by work package and is not necessary for a model progression document.

- The Level of Detail and Grouping for each element and BIM use is defined with the users own terms. This allows the user to define these characteristics in detail, and with their own project specific terms.

In order to complete the Model Progression Requirements a user would follow the steps outlined below:

1. Define the intended BIM uses for a project across the top of the BIM Use columns of the spreadsheet. These uses should be listed in chronological order so the progression of the model uses run from left to right.

2. Identify the necessary Model Content down the left side of the spread sheet.

3. Work through each BIM Use defining the Level of Detail and Grouping requirements for each Model element.

The activity "Establish Model Progression Requirements" within the process map for "Develop 4D Model" is a reference to using the MPR Document. A sub-process map was created for this activity, and walks a user through the steps of completing the document. This process map, “Establish Model Progression Requirements”, is available in Appendix C.

In order to substantiate the usability of the MPR, the document was applied to the DITC project’s use of Design Coordination, and the “what-if” scenario of utilizing the model for a 4D Milestone Model and a 4D Detailed CPM Schedule. The three uses Identified for the DITC in the MPR Document were Design Coordination, 4D Milestone Model, and 4D Detailed CPM Model. The requirements for Design Coordination were filled out in retrospect, referencing the model that had been produced for the design of the project, and the requirements for both 4D models were completed also. The completed Model Progression Requirements for the DITC project is available in Appendix C, titled “Model Progression Requirements – Detroit Integrated Transportation Campus”.

When reviewing the completed MPR for the DITC the differences between Model Content for each BIM use is obvious. The Level of Detail remained the same across all BIM uses, as neither 4D model required more LOD than was defined in the design model. However, the Grouping of Model Content changed drastically for each BIM use. The reason behind this is that the design model was not created in mind of utilizing it for a 4D model, and the grouping requirements for a 4D Milestone Model and a 4D Detailed CPM Model differ due to differences in the breakdown of construction activities. When a Grouping requirement stated to group elements, it inferred the elements were too small, and needed to be grouped with other elements. Conversely, when a Grouping requirement stated to divide elements, the elements were too large, and needed to be divided into different groups. The added Model Content categories became very valuable for the use of the MPR. Especially the Construction Activity Space category, as not all model content included in the schedule activities were modeled in design; therefore, allowing those activities to be modeled as simple construction spaces rather than detailed model elements. The Project Information category also became valuable in order to define the level of schedule needed for each 4D model. This category is not only valuable to the 4D modeling BIM use; for example, it could be used to define material properties for Engineering Analysis, estimate levels for Cost Analysis (5D), O&M manuals for a Record Model, etc.

3.4 - 4D Modeling

Currently in the AEC industry, the use of 4D modeling on projects is still sparse. However, as the industry is adopting the use of Building Information Modeling, 4D Modeling is becoming more prevalent on projects. Unfortunately, many industry members do not realize the potential of 4D modeling to be used throughout both the design and construction of a project. Most projects that utilize 4D modeling, have one project 4D model for visualizing the entire construction of project. This 4D model is also typically created at one level of schedule, whether it is a milestone schedule or a CPM schedule. This lack of “whole project” 4D modeling can be related to the slow acceptance of BIM and the lack of defined levels of scheduling within the construction industry.

It is very difficult to find defined levels of scheduling within the construction industry. After speaking with construction industry professionals and reviewing different literature on construction, only one source was able to produce a substantial definition for different levels of scheduling. Kevin Coyne, of Exponent, directed me towards the book "Construction Scheduling: Preparation, Liability, and Claims – Second Edition". The book defined five different levels of scheduling as follows:

Level No. 1: Executive level Master Summary Control Schedule – Consists of a bar chart of a time-scaled network of 15 to 50 activities. This level of detail and be useful for periodic management briefings and reporting.

Level No. 2: Detailed Integrated Schedule – Detailed master integrated schedule covering all phases of the project and in network format. This is the schedule that is used to plan implement and control the overall project.

Level No. 3: Contract Schedules – Schedules prepared by contracted parties for each contract involved in the overall project. Major contracts are usually in networking format. Some exceptions may be made for small contracts, which may use bar charts.

Level No. 4: Two- or Three-Week Look-Ahead Schedules – Schedules that are prepared each week and in advance of the next two or three weeks of planned efforts. These may be prepared for each of the major construction trades and may be in bar cart form or in simple network abstracts. These schedules should include the identification of all required resources (equipment and manpower by craft/trade) on a daily basis.

Level No.5: Daily Work Schedules – These schedules should be prepared at least one day in advance and with the participation of field superintendants, area supervisors, craft supervisors, foreman, and so on. The objective is to plan, schedule, and coordinate on a daily basis the required labor, construction equipment, and materials needed for each work task. In addition, they need to communicate work task versus cost accounting information essential for capturing and documenting actual field costs. This includes not only base contract work, but also changes, problems, and areas of potential disputes. Such schedules can also aid in capturing manpower data and measuring labor productivity. Because of the extent of construction brokering being used today, these schedules are not common on construction projects.

These different levels define the different types of schedules that can be used to communicate different levels of scheduling on a project; however, they do not define the level of schedule detail for a project. According to the book, level of schedule detail should be determined by including as many activities as seem necessary to effectively plan, schedule, and control the overall project. These different levels of schedule can also be applied to 4D modeling to illustrate the many different 4D models that could be utilized on a project. The effort to have different levels of schedules and 4D models on a project would not only help plan, schedule, and control the overall project, but could visually communicate the schedules to project participants. In order to tie the defined levels of schedule to the DITC Model Progression Requirements, the level of schedule was noted in the Project Information category under Model Content. The 4D Milestone Model was associated with an Executive Level no. 1 Master Summary Control Schedule, and the 4D Detailed CPM Model was associated with a Level no. 2 Detailed Integrated Schedule.

3.5 - Summary & Conclusions

A generic process map was created for developing a 4D Model for this research and the BIMex Research Project, just as other BIM use process maps will be created for the BIMex Research Project. These generic process maps will accompany the BIM Execution Planning Guide, utilized as template process maps for project teams to create project specific processes. Editing the generic "Develop 4D Model" process map to represent the specific processes, "Develop 4D Milestone Model" and "Develop 4D Detailed CPM Model", was a simple procedure, which helps to validate the idea of using generic process maps to create project specific maps.

The AIA Document E202-2008: BIM Protocol Exhibit is a good tool for defining the progression of a model throughout a project; however, it is missing key elements in order to cover a wide-range of BIM uses and model content; and the document doesn't allow for the necessary description to properly define Level of Detail for model content. In order to cover the deficiencies of AIA Document E202-2008, the Model Progression Requirements Document was developed. To substantiate the usability of the MPR, the document was applied to the Design Coordination of DITC model, and the "what-if" scenario of utilizing the model for a 4D Milestone Model and a 4D Detailed CPM Schedule. The MPR for the DITC conveyed the progression of the model throughout the three uses, and defined the model content requirements with a detailed, project specific method.

The DITC has yet to begin construction, and the project has no plan of passing the model to contractor to be utilized for construction. This process would fall under the inadequate interoperability in the U.S. capital facilities industry, as defined by the National Institute of Standards and Technology study. Therefore, the model should be passed on, with a "no-liability" clause, for the contractor to use as they please. As it is a Design-Bid-Build delivery, the contractor selected may have no BIM experience; however, no matter the experience level, the contractor should attempt to use the model in construction.

As an effort to implement the industry wide adoption of Building Information Modeling (BIM), through open interoperability and full facility project lifecycle, the AEC industry should utilize process mapping and model progression documentation to develop BIM Execution Plans on both a company and project level. Process maps and model progression documents could be created on a company level to better define company specific BIM processes, while also created on a project level to define project specific BIM processes. Ideally, BIM participants on a project would combine their company process maps and model progression documents to create project specific documents.

The lack of "whole project" 4D modeling can be related to the slow acceptance of BIM and the lack of defined levels of scheduling within the construction industry. By defining levels of scheduling and relating those levels to the creation of multiple 4D models, the construction industry would not only benefit from improved planning, scheduling and project control; but could also benefit from improved communication on projects.