A FRAMEWORK FOR DELIVERY OF INTEGRATED BUILDING INFORMATION MODELING

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ABSTRACT

This research investigates a building information model (BIM) implementation based on generic project needs and presents a modeling process map. It provides examples from a specific case study on how 3D, cost and scheduling models are created and linked, and illustrates the workflow process for employing integrated modeling. Provided is documentation of the modeling practices both within and across the modeling teams.

The paper serves three primary purposes: scientific, which formalizes the process for creating and analyzing projects based on interconnected 3D, cost and schedule information; practical, which illustrates how building owners, construction companies, and building modeling firms can implement the technology; educational, which describes how designers and constructors can work in teams to create integrated models.

KEY WORDS

Building information modeling, virtual construction, modeling process, BIM management

INTRODUCTION

Currently in the AEC industry there is a wide range of methods for creating interconnected building information models, including 3D-fabrication (Eastman at al 2005), 3D-time (Haymaker and Fischer 2001), and cost-schedule (Tanyer and Aouada 2005). However, there is no systematic approach for implementing modeling that combines three distinctive types of information: 3D, cost and scheduling. This paper will offer a framework and a process map for creating integrated building information models (BIM).

Previous research projects have demonstrated the need for separate interconnected models to represent a building project (Kiviniemi at al 2005). This study builds on previous work on 4D modeling implementation (Haymaker and Fischer 2001) and proposes an approach to integrate cost data into the 4D model. Technical considerations on IFC data sharing (Leonard and Stephens 2005) are not in the scope of this research since all information exchanges were done in the native software formats. Collaboration is described in the context model information sharing between the three teams: 3D, cost, and scheduling.

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The research is based on the processes used by the modelers for the California Academy of Sciences (CAS) in San Francisco. The 400,000 square foot Renzo Piano building will be reconstructed on its current site in Golden Gate Park. The design retains a few of the more culturally significant structures and the concept focuses on creating a world class museum experience integrated with efficient and functional research, collections and administration spaces.

The building information modeling was initiated by Webcor Builders who is the general contractor on the project in order to:

- improve owner communication
- verify construction drawings consistency
- check building constructability
- avoid clashes between the structure and the mechanical system
- visualize a very complex concrete placement work flow
- establish standard modeling knowledgebase for use on future projects

The 3D and cost modeling was completed by Graphisoft's Construction Services team with their commercially available Constructor and Estimator software. The sequence modeling was done using Primavera's P3 scheduling suite. The data collection and analysis is based on field research and work with the modeling teams. It is additionally supported by open interviews of the leading team members.

Presented is a high-level implementation framework which will help academics and building modeling teams with the creation and the integration of building models. The discussion in this study is generic and the basic principles described can be applied using other available modeling solutions.

BACKGROUND ON CREATING AN INTEGRATED 3D-COST-SEQUENCING BUILDING MODEL FOR THE CAS PROJECT

The integrated BIM was created by linking objects in the 3D model to estimating "recipes", which hold information about how the object is build. Recipes consist of "methods", which represent separate work activities required to build the object. Furthermore, methods are made of "resources", which comprise each activity. Information on building materials, equipment and labor resides at the resources level. The resources are linked to tasks in the sequencing model to create the integrated BIM (Figure 1). The process section will provide more details on how the modelers used different applications in each phase.

Modeling in the CAS case started after the building was designed by the design architect and after the executive architect has completed 50% of the construction documentation (CD). Those drawings were provided in a DWG and PDF formats to the construction modeling team to create a 3D object model. The recipes, methods and resources were created by Graphisoft's modeling team and the general contractor in order to represent work structures typical for the local area and specific to the project. Schedule documentation for the sequencing model was provided by Webcor in PDF format.

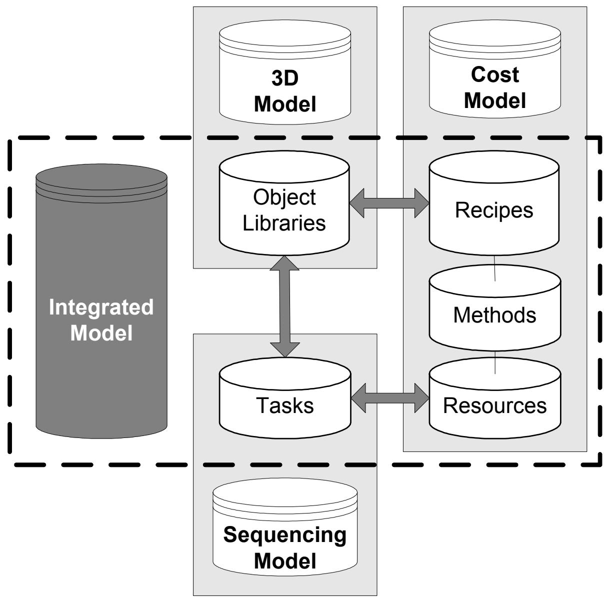

Figure 1: High-level Project Information Model Map

The model was further developed with information from the construction documents at 85% completion and 95% completion. At the time of this research the modeling team was working on the update at 95% CD development and this phase was not considered for this study.

SELECTION CRITERIA

The first step toward a successful BIM implementation is to define the success factors and success measures (Kunz and Fischer 2005) to be used for the project. Critical success factors should be linked to prime benefits for the modeling client Webcor. The BIM users and their objectives have to be clearly defined and aligned. The detailed breakdown of those criteria should determine what building models are needed. A separate decision has to be made on whether those models should interact with each other what the appropriate links should be.

MODEL DATA

The sample model selection matrix presented in Table 1 illustrates how the project objectives could be matched with individual building models. Depending on specific objectives different models could be chosen at different levels of detail. Critical considerations for both the model data and level of detail selection will be the users (building owner, consultants, subcontractors, etc.) and the project stage.

For example in the CAS project the general contractor was interested if the architectural and structural systems will collide with the extensive HVAC system in the building. Only geometric model data from the Architectural, Structural and the MEP domains were used for this purpose.

Table 1: Building Model Selection Matrix

PROJECT OBJECTIVES	**MODEL DATA**					
	Geometry			**Schedule**	**Cost**	**Other**
	Architecture	Structure	MEP			
Improve Project Communication						
Verify Constructability						
Visualize Workflow						
Detect Clashes						
Simulate Energy Performance						
Fabricate Material						
Establish Knowledgebase						
Deliver Facility Management						

The models were hosted in NavisWorks without bringing any additional data from the Cost or Scheduling models. This provided quick, flexible and scalable solution for the client. As the level of detail increased those individual models were updated and tested for additional clashes.

LEVEL OF DETAIL

Level of detail (LoD) is usually added within each individual model space. The LoD across domain models does not have to be the same in order for them to be linked. A high LoD structural model can be linked to a low LoD scheduling model or vise versa. The link however has to be at the lower LoD and elements in the model with the higher LoD have to be grouped.

Low LoD is loosely defined on the building systems level in the 3D and Cost models and master tasks in the Sequencing model. Medium LoD includes separation within the building systems and tasks (e.g. concrete placement for a group of columns as a single task) and more detailed breakdown at the resources level of the Cost model. High LoD will incorporate information about each object in all three models. A very high level of detail would represent a fabrication model (e.g. structural steel). This paper is focused on the low and medium LoD.

In the CAS case for the initial integrated BIM the schedule provided was at a medium and the geometry was at low LoD. The schedule LoD was reduced by combining tasks that relate to similar geometric elements. The LoD in the Cost model occurs at the resources level and it is increased by defining more specific resources for a given method. The resources in the Cost model provide the link between the geometry and the schedule.

The findings in this paper support and advance previous research (Kiviniemi at al 2005) that the object definitions between the different model domains vary significantly. A single object in one model domain could represent several objects in another. The key to creating functional and scalable integrated BIM becomes the bidirectional link between the models.

THE MODELING PROCESS

The project went through two cycles of modeling: original modeling (v.1) at 50% CD completion and revision 1 (v.2) at 85% CD completion. There were three modeling teams: 3D, Cost, and Schedule. A Modeling Manager at Graphisoft was responsible for work assignment and coordination between the teams. The Cost and the Scheduling models required fewer resources and they were completed by an expert in the respective domain who was occasionally assisted by an additional modeler.

THE MODELING TEAMS

Detailed modeling work time data for each team was not available for the CAS project and was not collected by Graphisoft. A number of interviews were conducted with the team leaders to estimate the relative weight (Figure 2) of each phase as measured by the number of modelers and the working days they engaged on a task. Planning and creation of the initial 3D building model required by far the most concentrated effort. Subsequent phases involved about 50% less time to complete revisions for v.2 of the model which was built with medium LoD.

Further research is needed on the amount of time necessary to complete building models since this directly relates to determining their cost. Nevertheless the limited data provided here could help firms with their resource planning for BIM.

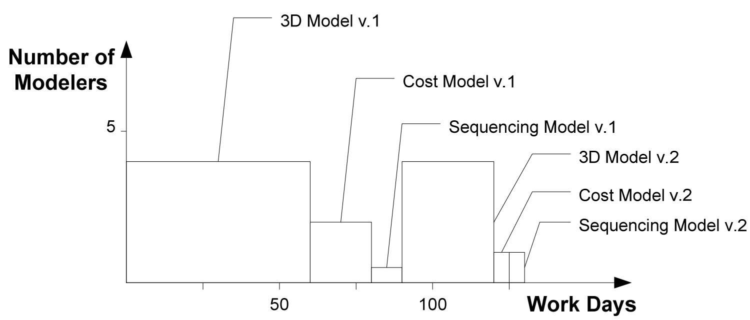

Figure 2: Task Weights

MODELING PHASES

The process flow (Figure 3) was tracked between all modeling participants. Identified are three main phases: Planning, 3D Model Development, Integration. They combine activities from all domains: 3D, cost, and sequencing.

PLANNING

Modeling Manager: Develop a content plan

The Modeling Manager is the "owner" of the modeling process. He is responsible for assigning team leaders for each project stage and for managing the client relationship. The

Manager holds weekly calls/meetings with the client and the cost and sequencing modelers. He identifies which models are required and who the individual "model owners" are. A modeling template file is created with standard layers and notations. The Modeling Manager defines the responsibilities of each team member and also creates a schedule for the 3D modeling.

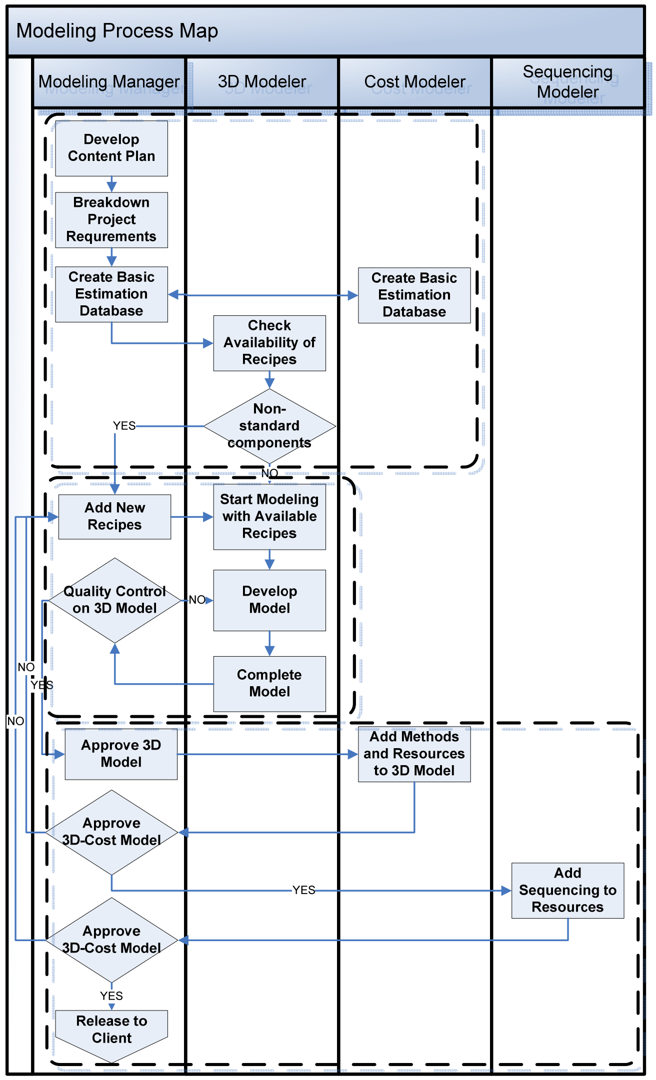

Figure 3: Process Map for 3D-Cost-Sequencing Modeling

Modeling Manager: Breakdown project requirements

In this phase the Modeling Manager breaks down the project for the three modeling groups. The main model components are identified and a library of standard 3D objects is generated. Major repetitive non-standard objects which will be used throughout the modeling are created using Graphisoft's GDL tools. In the CAS project examples of such non-standard components are the seats in the planetarium and the skylights on the roof of the building (Figure 4). They are created by the Manager and provided to the 3D Modeling team.

The Manager developed modeling guides for specific building parts. Those include step-by-step procedures with advice on how to use the template file, the standard elements and custom made objects.

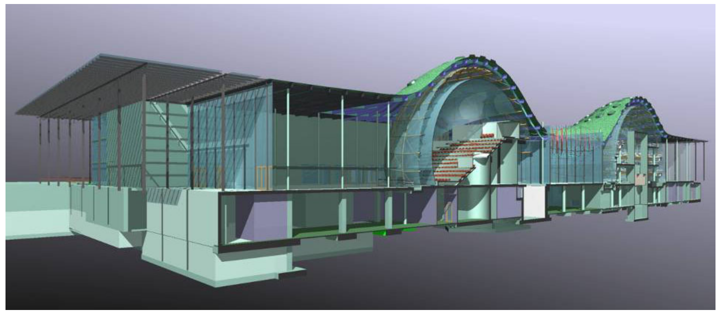

Figure 4: CAS Model Section

Modeling Manager: Create basic estimation database

The manager together with the cost modeling expert creates standard recipes in Graphisoft's Estimator at low LoD. Those are built from the general contractor's estimation database. Those records are in MS Excel format and most entries were transferred into Estimator using MS Access database structures.

The created recipes are imported form the cost modeler to the 3D modeler - Graphisoft Constructor, which is based on ArchiCAD technology. They are available through the standard API however manual synchronization is needed between Estimator and Constructor if any changes are made in either database.

3D Modelers: Check availability of recipes

The 3D Modelers receive and review the construction documents, the content plan and the modeling guidelines. They check the availability of recipes against major building components in the construction documents. They plan their own modeling process and discuss it with the Manager.

3D Modelers: Send request for more standard recipes

If there are too many non-standard components the 3D Modelers send a request for additional Estimator recipes. Those are created by the Manager and a new Estimator database file is provided for synchronization with Constructor.

3D MODEL DEVELOPMENT

3D Modelers: Start 3D modeling

Modeling starts with creation of the main structural elements. Work on different building floors is divided between the modelers.

3D Modelers: Develop first 3D model

Modelers upload an aggregated 3D model to an FTP server every day for review by the Manager. The Manager reviews it daily and sends them requests for changes with snapshots of items which should be modeled differently. Those for example include discrepancies between the information in the CDs and the 3D model, inappropriate modeling of elements or bad use of Estimator recipes. Every two days the 3D Modelers and the Manager have a discussion on the proposed requests.

In the meantime the Manager models additional non-standard components and complex geometries that require GDL programming. The geometry of the roof (Figure 4) for example was almost entirely developed by the Manger and incorporated in the 3D model file.

Modeling Manager: Approve 3D model

After the 3D model reaches the desired level of detail and all objects are linked to recipes in the initial cost database it is approved and send to the cost modeler.

INTEGRATION

Cost Modeler: Add Methods and Resources to 3D Model

The cost modeler adds methods and resources to the recipe database which increases the LoD of the Cost Model from low to medium. Quantity data is directly downloaded from the 3D object data set.

Work breakdown structure is created in Constructor for the labor portion of the resources and the data is prepared for transfer to the sequencing modeler.

Modeling Manager: Approve 3D-cost model

The cost database is again synchronized with the 3D object data to ensure that the desired elements from the two models are linked. The software provides a list of objects from each model which are not associated with items in the other. Those are manually verified by the Model Manager and if necessary appropriate links are created.

However some cost items could not be described explicitly with the 3D modeler. Those for example included the wall paint. For such elements Constructor allows the creation of “Zones” which could be associated with specific model area, set of objects or specific item. Quantity and material properties data can still be added to the Zones and if desired they can be linked directly to the Cost Model.

Sequencing Modeler: Add Sequencing to Resources

The first step in this phase is to create a sequencing file with the appropriate LoD in Primavera’s P3 software using the schedule provided by the general contractor in PDF format. The sequencing modeler then associates each labor resource in the work breakdown tree with a single or a set of items from the 3D model. If there are 3D elements not associated with recipes he requests that the Model Manager adds new recipes. After all 3D objects are assigned to specific tasks the model is ready to be released for review.

Modeling Manager: Approve 3D-Cost-Sequencing Model and Release to Client

The modeling manager verifies that all objects between the models are linked. He exports the aggregated model to a 5D viewer application that is still under development by Graphisoft. The 3D Model file, the Cost Model file and the 5D simulation file are made available over FTP to the general contractor Webcor Builders.

CONCLUSIONS

This research provided initial documentation of an integrated BIM process. Presented was a sample model matrix to align project objectives with modeling requirements. A selection criterion for the level of detail was introduced indicating that links between two models should be introduced at the lower level of detail. Finally this study offered information and mapped the individual processes for building information modeling.

Further research in needed in describing the processes of integrated modeling in a multi-model environment. The BIM tools should be able to handle the diversity of information among models which makes the paradigm of a single information data repository extremely difficult. The links between the models have become even more important and the support of domain specific views will allow designers to share common data.

Future phases in this line of research will describe uses of BIM at different stages of the design and construction process. The most significant client benefits will be specifically identified and described. The notion of using a model matrix and a set of project objectives to determine modeling needs will be further developed through additional case studies.

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