PROGRAMMING AND CONCEPTUAL DESIGN USING
BUILDING INFORMATION MODELING

A Thesis
presented to
the Faculty of California Polytechnic State University,
San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Architecture

by
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January 2009

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ABSTRACT

Programming and Conceptual Design Using Building Information Modeling

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This thesis explores the benefits of using Building Information Modeling (BIM) during the programming and conceptual design phase of a project. The research was based on a case study undertaken dealing with the decisions and assumptions made during the design phases of the Center for Science at Cal Poly San Luis Obispo. The project team used a traditional approach to project plan development. The finding of this study was that the project process would have greatly benefited utilizing BIM tools and a collaborative team approach in the programming and conceptual design phase. Because decisions made early in the project have enormous implications to aesthetics and cost, the increase in analysis of design options afforded by the use of BIM tools would have minimized inaccurate, incomplete and unreliable information, and allowed the design team to work in a more efficient, collaborative manner transmitting through all phases of the project.

Keywords: Building Information Modeling, BIM, architectural programming, basic assumption models, Center for Science, conceptual design, cost model, collaborative team, construction industry, integration, project feasibility, project plan development, project procedures, repository of information

ACKNOWLEDGMENTS

First of all, I would like to thank Professor Art Chapman for his unique coaching and enthusiasm. He guided, encouraged and inspired me every step of the way through graduate school and through my thesis. Special thanks to Professor Jim Doerfler for his continued encouragement over the years and letting me try my hand at teaching by guest lecturing in his class; to Bob Kitamura for believing in me and continually coaxing me along; and to Joel Neel, who persistently cajoled me to reach for the light at the end of the tunnel and finish this endeavor.

There are many others to sincerely thank, including those who gave of their time for interviews; Dane Dodd-Hansen, Mark Miller, Joel Neel, Kimon Onuma, Chris Pechacek, Brent Pilgrim, Barbara Queen, Johan Uyttewaal and Rex Wolf, I appreciate your insights.

To my fellow graduate students for their friendship, enthusiasm and encouragement, Jenny Ferguson, Bewketu Kassa, and Eileen Joseph with a special thanks to Jenny for editing my initial work.

Rishon, thanks for sharing your college years with me, Tuesday lunches and my hopes and dreams for graduate school. Alyse, thanks for putting up with my schedule and seeing me through college. Stuart, my best friend, I owe much of my successes to you and your calm approach to life. Thanks for trusting that I could take on one more copious task and get it done.

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CHAPTER 1

Overview

Introduction

Planning, design and construction are moving toward a major change propelled by new tools in building information modeling (BIM).¹ BIM is rapidly changing how the construction industry does business and how people work with each other. It has already begun to be used by architecture and engineering firms to prepare plans for construction, and its use is expanding to more project phases. With one of the major benefits being integrated project delivery, the goal of this thesis is to determine the benefits anticipated in initiating BIM at the programming and conceptual design phase,* and to allow owners, users, architects, engineers, consultants and contractors to better understand the impacts of early decisions on a project through schematic design, design development, construction documents, construction, occupancy and deconstruction.[†]

Just as web-based project management software has improved efficiency and accountability in the construction phase, and is now widely accepted and used in the industry; web-based building information modeling can transform the programming and design phase as is done using Onuma Planning System (OPS) software developed by Onuma, Inc.² Prior to the use of web-based project management, architects, engineers, construction managers, contractors,

*Conceptual Design Phase - Cal Poly requires its program architects to go beyond the normal programming effort and produce an "initial concept" according to Joel Neel, Associate Director in Facilities Planning and Capital Projects. Referred to as the "conceptual design," this "initial concept," or stacking and massing diagrams, based on the programming information, show building form, floor plans for each level, site circulation, and relationships to adjacent buildings and spaces. (Joel Neel 7 January 2009)

[†]Project phases following the programming phase.

subcontractors and owners each kept logs of the various documents (change orders, requests for information, submittals, change order requests, etc.), and generally only one person would have the latest, updated information. Logs were shared by photocopying and distribution with updates once or twice a month. With web-based project management, any team member with access rights, a computer and an internet portal can have the latest information any time within minutes. Additionally, each person is alerted automatically when they need to perform a task. A similar function occurs in web-based building information modeling but with the development of the building physical model.

Another way to look at web-based building information modeling is to consider it as a web-based design charrette with the players proposing ideas and expanding upon ideas proposed by other players, and each testing preliminarily “what if” scenarios. This process might occur over a period of perhaps a few weeks instead of several months.

In addressing building information modeling, this thesis will be limited to the programming and conceptual design phase of a project including the available information, its analysis, and how it affects building outcomes. Finith Jernigan has observed that many architects “make too many decisions at the wrong time, with too little information.”³ This thesis will look for areas where better information, presented earlier, may have changed the building outcome. In addition, it will contrast the standard approach to programming and project development versus an approach using building information modeling to program and develop the project.

By making the costing activity an integrated part of programming and moving it into the third stage where alternate blocking and stacking or three-dimensional schemes are developed, it is anticipated that some of the difficulties experienced in the development of the project may be avoided. The Center for Science at California Polytechnic State University (Cal Poly) in San Luis Obispo, California will be used as a case study. As part of that case study, viewing costing information in conjunction with alternate three-dimensional schemes will enhance

the early analysis, and allow the owner, architect and engineers to make a more informed decision in choosing conceptual design alternatives for the project.

Finally this thesis will conclude that using BIM in at least the programming phase and conceptual phase of an architectural project can have significant advantages in time and cost savings and quality of product.

Thesis Addressed Issues

This thesis will address the following issues:

- The process and procedural changes necessary in the programming and conceptual design phase (for connecting the project team members and affecting increased efficiency) given that BIM is changing how the construction industry's delivers and shares information.
- The benefits and difficulties of using BIM in the programming and conceptual design phase.
- The anticipated outcomes--similarities and differences--of using current procedures versus BIM for the case study Cal Poly Center for Science.
- Future areas for study.

This thesis will not deal with the various construction delivery models,^{*} nor show the effect BIM will have on them. However, some models such as Construction Manager at Risk and Design-Build, which involve the constructors early in the design and construction cycle, could derive more benefit by active participation in BIM.

^{*}Also referred to as the "project delivery method." Each delivery method can have variations; Construction Manager at Risk is a variation on the Construction Manager method. Refer to glossary.

Summary of Industry-wide Issues

History and Developments in Process and Tools

Design Process – Master Builder, A/E with Consultants, Collaborative Teams

Many of the buildings in Europe from the Renaissance Period were designed, engineered and built under the direction of one person, the master builder. “Hundreds of years ago, all of architecture could be held in the intelligence of a single maker, the master builder, part product and building engineer, and part material scientist, the master builder integrated all the elements of architecture in a single mind, heart, and hand.”⁴

As buildings became larger and taller, new materials and building systems, such as structural, mechanical, electrical and plumbing were developed, requiring special engineering knowledge. As noted by Paul Seletsky in an interview by Bryant Rousseau, “Traditionally, we’ve had a very linear process in the way we practice architecture.”⁵ Consultants were brought in when and as needed, usually after the architect had completed the schematic design (site plan, floor plan, and elevations). Keeping the consultants segregated with the architect doing all of the coordination did not cause major problems. Usually minor changes were made to the plans to accommodate the systems.

As buildings become more complex with the addition of more systems, uses, equipment, codes, regulations, standards and laws, the segregated approach resulted in deficiencies in the architectural process. Structural, plumbing, mechanical, electrical, communication and fire systems collided, while user needs and code requirements were missed. Users moved into spaces that did not live up to their expectations. Owners were faced with changes that became more costly as the project progressed. In *Refabricating Architecture*, the authors, both architects, point out that the “current architecture production is typified by stratification of the various components used in design and implementing a building.”⁶ They further acknowledge that the disciplines have little or no communication, and the benefit of their “collective intelligence” never makes it past the hierarchy into the project.⁷ It is interesting to note that collaborative

teams of designers and builders are used in other industries, such as automobile and aircraft industries, working together in an integrated and productive manner.⁸ For the construction industry to move forward, an integrated process will need to be adopted industry-wide.

Design Tools – Hand Drafting, CAD, BIM

Among the first documentation of architectural plans and specifications (or in this case, list of materials) in the United States was by Thomas Jefferson in planning his home, Monticello in Virginia.⁹ Similar hand drafting, using t-square, triangles and pencil on paper continues even today.

The use of CAD and word processing, which promised to revolutionize plans and specifications development and coordination between disciplines, never materialized. For example, AutoCAD operators tend to be among the least experienced persons working on a project, adding to the problems discovered during the construction phase. In discussing the ways in which architecture has failed to take advantage of new technologies, Kieran and Timberlake note: “The architecture industry’s move from T-Square and linen to computer as a means of documentation has essentially been only a switch in media.”¹⁰ Computers can be used for so much more than just 2-D representations. Other industries, such as aircraft and automobile, provide examples.

In the aircraft industries, airplanes are initially built and maintained as three-dimensional (3-D) models including non-graphical attributes about each component. After an airplane is constructed, the 3-D model and component attributes are maintained.¹¹

The term “Building Information Model (BIM)” was coined in early 2002, but has been used by some firms for more than 20 years, according to Kimon G. Onuma.¹² Leaders like Onuma are beginning to engage others in learning, trying and using BIM. Ask architects about the acceptance and use of BIM in the construction industry and those using it will state full use can be expected in about 3-5 years.¹³ Those not yet experiencing its use, such as Robert Kitamura, Director of Facilities and Planning at Cal Poly San Luis Obispo, estimate it will

take 15 years to become fully integrated.¹⁴ This validates comments by Mike Kenig, Vice Chairman of Holder Construction Company, in his interview with Bailey Webb that BIM users estimate five years or less, while non-users estimate ten years.¹⁵

BIM

2D and 3D CAD versus BIM

Two- and three-dimensional (2D and 3D) computer aided drawing (CAD) programs enable the drafter to use a computer to create drawings representing data as geometric entities with points, lines, rectangles, circles, polygons and planes. The nature of the data, however, limits its use as it does not contain information that indicates walls, floor, ceiling and the physical space. In order to see a wall in elevation, more lines must be drawn. In order to perform cost estimating or an energy analysis on the room, several calculations must be done. Simply put, the wall does not know it is a wall, and the space created by the walls does not exist as a physical area in a CAD program.

In BIM, information is represented as object-based building data models. Lachmi Khemlani, in "The IFC Building Model: A Look Under the Hood," explains:

A data model in any given domain describes the attributes of the entities in that domain as well as how these entities are related to each other. Since all computer programs deal with some kind of data, they must have some kind of underlying data model. Traditional 2D CAD and generic 3D modeling programs internally represent data using geometric entities such as points, lines, rectangles, planes, etc.¹⁶

For example, a room may be represented (drawn) as a rectangle with length and width defined as well as its point of origin (X and Y coordinate location on the drawing). CAD models then are inadequate for their lack of representation of real world scenarios as noted by Khemlani:

Thus, while these applications can accurately describe geometry in any domain, they cannot capture domain-specific information about the entities. In the case of the AEC industry, technological progress has been severely constrained by the limited intelligence of such applications in representing buildings and being able to extract the relevant information from the

representation that is needed for design, analysis, construction management, operation, and so on.

To overcome the limitation of general-purpose geometric representations, every design-related industry has been developing and using object-based data models that are specific to their domain. In the case of the building industry, this translates to a data model that is built around building entities and their relationship to one another.¹⁷

For instance, a room is represented (drawn) using walls with length, depth, height, type, connection to other walls, attached spaces with function, occupant and area, and with a starting point (X and Y coordinate location on the drawing)

The interrelationship of objects is vital in creating a more realistic interpretation of a building. Khemlani further explains that the geometry used in 2D and 3D is merely “one of the properties.”¹⁸ The building model can be viewed in plan, elevation, section or detail without drawing more lines. In other words, the wall knows it is a wall, the space a space, and the floor a floor. This allows the model to be created, viewed and altered in plan, elevation, section and detail with changes automatically updated for all views allowing the designer to see the implications of changes immediately. For example, move an exterior wall two feet out and the walls perpendicular to it lengthen and remain attached to it in plan, elevation, section and detail views. There is no need to “re-draw” the corresponding views.

BIM has further advantage as information about the building can be extracted from BIM and used to analyze, document, or visualize a building. Software programs used with BIM can extract information and analyze cost, energy, egress, code compliance, etc.

Project Information

The holistic nature of BIM provides significant opportunities for all members of the building team. For example, team members with access can be aware of all changes being made in real time—a substantial information sharing and coordinating opportunity. BIM can allow information created in the programming and conceptual design phase to be carried throughout subsequent phases with information being added or modified as the project progresses. BIM can reduce errors made by the design and construction team members by checking for

conflicts in the drawings, such as a pipe penetrating a duct; and a duct cutting through a critical structural member. It can free-up time spent on schedules, such as door and window, by creating dynamic schedules that update automatically as changes are made. It can be used to provide such analysis as daylight and energy usage simulations to aid in the design, and cost estimates for building systems to aid in decision making.

Using BIM in Conceptual Design Phase

Given that the conceptual design decisions set the building's function, general appearance and cost, and are carried throughout the project to completion and occupancy; it would be more efficient and advantageous to begin rigorously implementing BIM from the initial start of a project so that all project information, including options, decisions and costs, are documented and shared with the building team members. "Decisions are often made in the programming phase of a project that have enormous downstream implications—for aesthetics, cost, energy consumption, and the ultimate suitability of a building for its intended purpose—on the basis of inaccurate, incomplete, or unreliable information."¹⁹ It is at this point that various massing models, systems and assemblies can be considered. When tied to a cost estimating model, the design team can quickly see the relationship between initial design assumptions and cost. Initiating BIM at this phase creates additional substantial potential for efficiencies.

At the conceptual design phase, as many options as possible should be considered, as well as their cost impacts. Because these early decisions will be carried throughout the project, owners, architects, engineers and consultants will rely on them. It is far easier to scale back the project early in the design process than to continuously look for areas to cut costs in future phases as later changes become increasingly expensive to implement and have less value. The American Institute of Architects (AIA) reiterated the power of the focus on the early design phase when laying out Integrated Project Delivery (IPD) principles, noting that "integrated projects are uniquely distinguished by highly effective collaboration . . . commencing at early design."²⁰ In redefining project team procedures, the AIA suggests "moving design decisions upstream as far as

possible to where they are more effective and less costly.” This is illustrated by the MacLeamy Curve (Figure 1). In the IPD process, “conceptualization (expanded programming)” includes greater cost detail than in a conventional project.²¹ Costs linked to BIM and detailed by systems allow a better understanding of the cost ranges and importance of each system. The focus can then be directed to areas where improvements and costs have a larger impact.

Figure 1. MacLeamy Curve. Source: Graph from AIA National / AIA California Council, Integrated Project Delivery: A Guide, version 1 (The American Institute of Architects, 2007), table page 21.

Interoperability and Integration

The Role of Interoperability

To work in a fully integrated manner, the software applications used by each project team member must be able to share data seamlessly. To do so requires a non-proprietary object-based building data model used by all software vendors. Software interoperability will enable those involved in project design, construction, management and deconstruction to work in an integrated process.

“Software interoperability is seamless data exchange at the software level among diverse applications, each of which may have its own internal data structure.”²² It is suggested that when owners, designers, engineers and constructors collaborate by sharing a common database, projects will evolve more quickly, complex projects will be doable, and project costs more manageable.

Current Issues with IFC

The International Alliance for Interoperability (IAI), which facilitates interoperability in the construction industry, has created the IFC (Industry Foundation Classes), the common language for software. Khemlani states, “The IFC model is intended to support interoperability across the individual, discipline-specific applications that are used to design, construct, and operate buildings by capturing information about all aspects of a building throughout its lifecycle.”²³

There are several object-based building data model applications currently being used in the industry. These include Graphisoft’s ArchiCAD and Autodesk’s Revit, in addition to hybrid applications such as, Bentley Architecture based on MicroStation, and Autodesk Architectural Desktop based on AutoCAD. However, as Lachmi Khemlani in “The IFC Building Model: A Look Under the Hood” notes “these are applications by commercial vendors and their internal data models are proprietary.”²⁴ As she explains, this is why one software program cannot share its information with another without the use of specific translators. In other words, they do not speak the same language and cannot communicate. Sharing data from one of these software applications with other software, such as a Microsoft Excel spreadsheet, is impossible, or at best, extremely difficult. Integration and interoperability are the keys to information sharing.

Time and Money

Currently, when architects, engineers, and cost estimators need certain project information embedded in a software program, they must first retrieve the data needed and then re-enter it into their specific software analysis program. Translating the information back to the drawing stage takes the same effort, and therefore, testing many building configuration options is time intensive and cost

prohibitive on most projects. BIM offers the potential for fully integrated systems for all users.

Using the IFC model to capture building information, commercial building-model based applications can exchange data with each other quickly and accurately. Instead of spending time to enter and check data, and then re-enter it again, project team members can put more design time into project space and detail development, and can test more options with the goal of creating more effective and efficient design and engineering solutions.

¹Jeff Yoder, "Further Down the Merry Road to BIM," *Building Design and Construction* (1 November 2007). <http://www.bdcnetwork.com/article/CA6501465.html> (accessed 11 December 2007).

²Onuma, Inc., "Onuma Planning System," under "Products," <http://www.onuma.com> (accessed 5 February 2008).

³Finith Jernigan, *BIG BIM little bim* (Salisbury: 4Site Press, 2007), 19.

⁴Stephan Kieran and James Timberlake, *Refabricating Architecture* (New York: McGraw-Hill, 2004), xi-xiii.

⁵Bryant Rousseau, "The ArchRecord Interview: SOM's Carl Galioto and Paul Seletsky on BIM," *Architectural Record* (2008), <http://aec.cadalyst.com/aec/Column%3A+1-2-3+Revit/1-2-3-Revit-BIM-and-Visualization-Part-1/ArticleStandard/Article/detail/438584?contextCategoryId+6569> (accessed 26 November 2007).

⁶Kieran and Timberlake, 12.

⁷Kieran and Timberlake, 12.

⁸Kieran and Timberlake, 9-11.

⁹I.T. Frary, *Thomas Jefferson Architect and Builder* (Richmond: Garrett and Massie, 1939), 5.

¹⁰Kieran and Timberlake, 58.

¹¹Kieran and Timberlake, 59.

¹²Kim Onuma, Forward, *BIGBIM little bim* (Salisbury: 4Site Press, 2007), 3.

¹³Kim Onuma and Yong Ku Kim, "BIMStorm LAX – Overview and Players' Perspectives." (5 February 2008), Webinar.

¹⁴Robert Kitamura, interview by author, San Luis Obispo, CA, 2008.

¹⁵Bailey Webb, "BIM dream becoming a reality," *Atlanta Business Chronicle* (July 6, 2007), <http://www.bizjournals.com/Atlanta/stories/2007/07/09/focus7.html> (accessed 10 January 2009).

¹⁶Lachmi Khemlani, "The IFC Building Model: A Look Under the Hood," *AECbytes* (30 March 2004), <http://www.aecbytes.com/feature/2004/IFCmodel.html> (accessed 13 February 2008).

¹⁷Khemlani *IFC*.

¹⁸Khemlani *IFC*.

¹⁹Michael Tardif, "Architect Creates Design Synthesis Software," *AIArchitect – The American Institute of Architects* (17 August 2007), http://www.aia.org/aiarchitect/thisweek07/0/17/0817rc_face.dfm (accessed 18 February 2008).

²⁰AIA National / AIA California Council, *Integrated Project Delivery: A Guide, version 1*, (The American Institute of Architects, 2007), Sub-title page.

²¹AIA *IPD*, 24.

²²National Institute of Building Sciences (NIBS), Facility Information Council (FIC), *National Building Information Modeling Standard, Version 1 – Part 1: Overview, Principles, and Methodologies* (2007), 7.

²³Khemlani, *IFC*.

²⁴Khemlani, *IFC*.

CHAPTER 2

Methods

Before proposing changes in the methods used to develop programming and conceptual design studies, current industry procedures were examined in order to lay the foundation for the case study of the Cal Poly Center for Science project. Additionally, to understand the expectations for administration of the project, CSU policies and procedures were reviewed and documented.

Industry Project Procedures

Standard Model

The typical project team composition and the predesign* process are the framework for the CSU process. In this section, the construction delivery method selected for the Center for Science is defined. Lastly, to understand the goals of Programming during the predesign phase, the programming process is outlined.

Project Team

“The construction of a facility is the culmination of the collective needs, ideas, talents, and services of a diverse group of individuals.”¹ These individuals can be classified into four basic teams as shown in Table 1, or separate participant groups, organized to conceive, design and build a project (Figure 2). These separate teams of owner, designer, contractor and supplier are brought into the project during the particular phases as dictated by the type of delivery method. For example, in the Design-Bid-Build method, contractors join the project team at the Construction Phase. In the CM at Risk method, the contractor joins the project team usually after the Schematic Phase.

* Programming, concept and feasibility.

Table 1. Typical Project Team Participants

Teams	Owner	Design	Contractor	Supplier
Team Participants	<ul style="list-style-type: none">• Owner• Facility Manager• Facility Maintenance Engineer• Construction Manager• Tenant• Facility User	<ul style="list-style-type: none">• Architect / Engineer• Interior Designer• Specifier• Construction Contract Administrator• Specialty Consultant	<ul style="list-style-type: none">• Contractor• Contractor's Project Manager• Construction Manager• Superintendent• Subcontractor(s)	<ul style="list-style-type: none">• Manufacturer's Employee• Independent Project Representative• Distributor / Supplier

Source: Data from The Construction Specifications Institute, The Project Resource Manual – CSI Manual of Practice, Fifth Edition, (McGraw-Hill, 2005) Figure page 1.2.

The Project Team Typical

Figure 2. The Project Team, Typical. Source: Data adapted from The Construction Specifications Institute, The Project Resource Manual – CSI Manual of Practice, Fifth Edition, (McGraw-Hill, 2005) Figure page 1.2.

Construction Delivery Method – Construction Manager as Contractor

In the Construction Manager as Contractor (CMc) construction delivery method, also referred to as “at-risk construction management,” the “CMc is responsible for the completed project and bears the financial risk in the same manner as a contractor.”² As with other delivery methods, the contractor and the architect each have a direct contract with the owner, but not with each other (Figure 3). They are, however, required to communicate and work together to accomplish the project.

Construction Manager as Contractor (CMc)

Note: A solid line indicates a contract or purchase order, a dashed line indicates communication.

Figure 3. Construction Manager as Contractor (CMc). Source: Data from The Construction Specifications Institute, The Project Resource Manual – CSI Manual of Practice, Fifth Edition, (McGraw-Hill, 2005) Figure page 3.24.

Traditional Predesign Process

In the traditional predesign process, the Architect does not usually involve their Design Consultants (civil, structural, mechanical, electrical, plumbing, controls, special, etc.) in programming or predesign. Quite often, the first time Design Consultants see a project is in the Schematic Design Phase, and in some cases, not fully until the Design Development Phase. In the traditional design-bid-build project delivery method, Constructors (contractors) and Sub-constructors (subcontractors) are not involved until the construction phase, and actually obtain their first look at the project during the Bidding Phase. Each party's involvement in the project phases is illustrated by Figure 4.

Figure 4. Traditional Design Process. Source: Data from AIA National / AIA California Council, Integrated Project Delivery: A Guide, version 1 (The American Institute of Architects, 2007), table page 22.

Defining Programming

The Dictionary of Architecture and Construction defines a program as:

A statement prepared by or for an owner . . . setting forth the conditions and objectives for a building project including its general purpose and detailed requirement, such as a complete listing of the rooms required, their sizes, special facilities, etc.³

Programming is generally approached in a similar manner by most architects regardless of the size or complexity of the building. In the standard model, a building project begins with an idea. For example, the owners or users realize they have outgrown their current facilities and need to expand incorporating newer technology and working processes. The architect is asked to look at current operations and functions, help the users organize their thoughts about how they would like to work, and development a program. In defining what constitutes the planning process leading to the program, the authors of From Problem Seeking search for “sufficient information to clarify, to understand, to state the problem.”⁴ Furthermore, they have formalized the programming process into a five step, linear procedure:

Goals – Project Goals, including Mission, Goals and Objectives, and Policies; Operational Goals

Facts – Staffing requirements, User Description, Evaluation of Existing Facility, Site Analysis, Climate Analysis, Zoning Regulations, Code Survey, Cost Parameters, Project Delivery Schedule

Concepts – Organizational Structure, Functional Relationships, Priorities, Narrative Functional Descriptions, Operational Concepts

Needs – Space Requirements, Parking Requirements, Land Requirements, Project Phasing, Budget Analysis for Renovation and New Construction

Problem Statements – Design Problem, Operational Problem 5

CSU Capital Projects

To better understand the policies, procedures and nuances of projects in the CSU system, and the documentation required to submit for and receive funding approval, the CSU model was studied with an eye toward recognizing areas where information can be contained within and required forms generated from the BIM. For instance, if the campus student population and existing classroom information were held within the BIM, it could be used to generate additional space and associated funding requirements.

CSU Model

The California State University (CSU) requires each of its twenty-three campuses to develop a Capital Outlay Program that anticipates and plans for student enrollment utilizing “proper planning, programming, budgeting and project administration,” and State policy requires all capital outlay projects be “carefully conceived and justified to provide cost effective solutions for program delivery.”⁶ Campuses are responsible for the initial planning, cost benefit analysis and feasibility studies needed to submit a proposed project to the CSU for funding. The results of these efforts – plans (site and individual room), outline specifications (equipment, furnishings, special requirements by room) and cost estimate—are used in preparing the CSU submission to the Board of Trustees for the proposed capital outlay program.⁷

Campus Square Footage Requirements

First, each campus calculates the space requirements to accommodate the projected full-time equivalent (FTE) students on the campus resulting in an assignable square footage (ASF) entitlement. The existing ASF is subtracted from the entitlement to determine the additional space needed. The example in Table 2 illustrates a portion of the CSU Form CPDC 2-3 used to calculate the additional space for a fictitious lecture and teaching lab on a CSU campus.

Table 2. Calculation of Space Requirements

Type of Instruction	Projected FTE ^a	Weekly Student Contact Hrs. /100	100 WSCH ^b	Standard (ASF ^c /100 WSCH)	ASF ^c Entitlement	Existing ASF ^c to be retained	Additional Space Needed
Lecture	1500	0.15	225	52	11,700	1,700	10,000
Teaching Lab (LD)	250	0.45	112.5	255	28,688	8,088	20,600
Subtotals	1750				40,388	9,788	30,600

Source: Data adapted from The California State University, "Calculation of Space Requirements for Instructional Projects, Form CPDC 2-3," under "Major Capital Outlay Forms," http://www.calstate.edu/cpdc/Facilities_Planning/forms.shtml (assessed 27 May 2008).

Notes:

^a Full-time Equivalent

^b Weekly Student Contact Hours

^c Assignable Square Feet

Campus Allowable Costs

CSU allowable costs for a project are determined by multiplying the additional space needed on a campus by a predetermined cost per square foot. The allowable cost per square foot is determined by the type and function of space found in the CSU Budget Composite Matrix (Form CPDC 2-6.5). For instance, a general classroom would have an allowance of \$316 per gross square foot, whereas a lab for science would have an allowance of \$411 per gross square foot.⁸ The areas are multiplied by the respective allowance plus additional square footage for building support areas (restroom, corridors, custodial, etc.) and systems (mechanical, electrical, etc.) to arrive at the total building construction cost. Table 3 is an illustration of applying the allowance to the "additional space needed" as shown in Table 2. (For clarity, the building support areas such as stairs, elevators, restrooms, custodial, etc. are excluded.)

Table 3. Calculation of Budget Requirements

Space Type	ASF	EFF.	GSF	\$/GSF	BLDG. COST
Classroom (General)	10,000	63%	15,873	\$316	\$5,015,873
Teaching Lab (LD)	20,600	59%	34,915	\$411	\$14,350,169
Subtotals	30,600		50,788		\$19,366,043

Source: Data adapted from The California State University, "Budget Composite Matrix, Form CPDC 2-6.5," under "Major Capital Outlay Forms," http://www.calstate.edu/cpdc/Facilities_Planning/forms.shtml (assessed 27 May 2008).

Costs for the building site and landscaping are dependent on site conditions and vary by campus and project location. Some campuses, built on hills will have higher site costs than those built in level valleys. Accordingly, site location on the campus at Cal Poly affects the site construction costs. For instance, the Center for Science is located on the upper part of the campus core and bedrock is located near the earth's surface. Engineering III and IV are located in an area of campus that is flatter and composed of soil depth of 25 to 65 feet to bedrock. Site excavation and substructure construction are both affected by the type of soil and the depth to bedrock.

Other costs, such as fees for services are either formula driven or determined based on previous projects. These costs include design, engineering, testing, plan checking and construction management, and are known in the industry as soft costs. The hard costs for building, site and landscaping are added to the soft costs for the grand total project costs. At this point in the project process, building costs are represented by building systems organized by CSI UniFormat categories show in Table 4.

Table 4. UniFormat Categories

Levels	Construction Systems and Assemblies
A SUBSTRUCTURE	
A10	Foundations
A20	Basement Construction
B SHELL	
B10	Superstructure
B20	Exterior Enclosure
B30	Roofing
C INTERIORS	
C10	Interior Construction
C20	Stairs
C30	Interior Finishes
D SERVICES	
D10	Conveying
D20	Plumbing
D30	Heating, Ventilating, and Air Conditioning (HVAC)
D40	Fire Protection
D50	Electrical
E EQUIPMENT AND FURNISHINGS	
E10	Equipment
E20	Furnishings
F SPECIAL CONSTRUCTION AND DEMOLITION	
F10	Special Construction
F20	Selective Demolition
G BUILDING SITEWORK	
G10	Site Preparation
G20	Site Improvements
G30	Site Civil / Mechanical Utilities
G40	Site Electrical Utilities
G90	Other Site Construction
Z GENERAL	
Z10	General Requirements
Z20	Contingencies

Source: Data from The Construction Specifications Institute, UniFormat™, Third Printing – January 2000 (The Construction Specifications Institute, 2007), page 20-23.

Projected amounts are entered into the CSU Capital Outlay Estimate (Form CPDC 2-7),⁹ a portion of which is illustrated in Table 5. An additional column in the Form, to the right of the total (not shown), provides a cost per gross square foot. This allows the CSU to compare costs across campuses for similar space and construction types, and campuses to monitor the cost of each system.

Table 5. Cost in UniFormat Categories

Levels	Construction Assemblies	Systems and	Subtotal	Total
A	SUBSTRUCTURE			\$1,370,135
A10	Foundations		\$1,370,135	
A20	Basement Construction		0	
B	SHELL			7,037,189
B10	Superstructure		3,088,903	
B20	Exterior Enclosure		2,013,886	
B30	Roofing		1,934,401	
C	INTERIORS			2,043,398
C10	Interior Construction		1,065,180	
C20	Stairs		0	
C30	Interior Finishes		978,218	
D	SERVICES			7,452,322
D10	Conveying		525,704	
D20	Plumbing		554,035	
D30	HVAC		2,714,693	
D40	Fire Protection		438,742	
D50	Electrical		3,219,148	
E	EQUIPMENT AND FURNISHINGS			
E10	Equipment		0	
E20	Furnishings		0	
F	SPECIAL CONSTRUCTION AND DEMOLITION			1,462,999
F10	Special Construction		1,462,999	
F20	Selective Demolition		0	
				\$19,366,043

Source: Data adapted from The Construction Specifications Institute, UniFormat™, Third Printing – January 2000 (The Construction Specifications Institute, 2007), page 20-23.

Cal Poly Center for Science Project

Case Study

The Center for Science was chosen as the case study for comparison of the traditional project management approach versus using building information modeling (Figure 5). It is a complex project, located in the educational core of the Campus, and presents many challenges in its design, construction and occupancy.

CENTER FOR SCIENCE

Figure 5. Center for Science. Source: California Polytechnic State University, San Luis Obispo, Facilities Planning and Capital Project, Center for Science Project, drawing by ZGF (16 June 2007).

This section will provide a brief history of the project, how the Project Team structure was identified, the method used to develop the project budget, an analysis of the cost estimates at each design phase, and a summary of the cost changes over time by building.

A significant difference in implementation and effectiveness was expected to be found between using the industry' traditional standard model versus using a

Building Information Model (BIM) approach. The results highlight the need for a shift to BIM to significantly improve quality and efficiency.

Study Area

In an interview with Barbara Queen, Project Manager for the Center for Science, two negative key areas of the building design were identified as potentially benefiting from the use of BIM--the shell or exterior enclosure, and the labs and fume hoods. These two items were not significantly explored by the design team, nor were experts consulted or potential options given enough consideration during the programming through design development phases. Limited information provided the basis for the decisions on these two items. Subsequent options and future potential savings were limited and handicapped by the need to rework architectural and engineering solutions to reverse unfavorable decisions. By not having explored and carried forward potential options for these building systems, the project budget continued unresolved during the construction document phase as the project team explored potential savings in building systems.

The Center for Science case study was limited to the exterior enclosure of the building and specifically, this thesis investigates the decisions made during the three phases—Schematic, Design Development and Construction Documents. Assumptions and decisions made by the team members were documented.

Project History

The University began planning the Center for Science project in 1999. Over fourteen University groups were represented in the study. At that time, it was anticipated to include the Mathematics Department and an applied research component. However, over several years, the project scope was revised as illustrated by the graph in Figure 6. The changes in total construction costs (by fund and square footage) submitted to the California State University (CSU) in the Capital Outlay Budget Change Proposal (COBCP) are typical of project iterations before CSU scope and funding approval is obtained. In 2005, the applied research component was removed and with a reduced scope, the project was approved and slated to receive initial funding in early 2007.¹⁰ In the interim,

the committees and design team, originally established to work on the project, were brought together to validate the scope.¹¹ The Center for Science, which is a replacement and growth project, is scheduled to commence construction in May 2009, after completion of the working documents phase.

Figure 6. Total construction costs and areas. Source: Data adapted from California Polytechnic State University, COBCP, Years 2002/03, 2004/05, 2006/07, 2007/08 and 2009/10, Capital Outlay Estimates (Form CPDC 2-7).

Project Team

In Figure 7, the Project Team organization chart exemplifies the complexity of the temporary organization established to accomplish a project within the CSU system. Unlike typical team illustrations, this organization chart is shown from the campus Project Manager point-of-view. As the owner's representative, the Project Manager is responsible for keeping all team members on track.

Project Team

Figure 7. Project Team. Source: Data adapted from Facilities Planning & Capital Projects.

Cal Poly often hires one architectural firm to provide services during the Programming Phase, and later on a different firm for the Design and Construction Phases. The Program Architect for the Center for Science was RRM Design Group of San Luis Obispo, California. RRM helped Cal Poly to establish the initial scope and budget for the Center for Science project.

After the project received funding for design services, the Architect, Zimmer Gunsul Frasca Architects LLP (ZGF) of Los Angeles, California, was selected to begin work on the Schematic Design Phase. Upon completion of the Schematic Design Phase, Gilbane Building Company of San Jose, California, was selected the Construction Manager at-Risk*, and brought on-board at initiation of the Design Development Phase.¹² In the Center for Science Project, the Owner is represented by Cal Poly's Facilities Planning and Capital Projects Department staff. The User is the College of Science and Math led by the Dean and Associate Dean. The project team relationships with the design architect and construction manager are illustrated in Figure 8.

*In the Construction Manager at-Risk (CM at Risk) projects, the CM is issued a service agreement for the preconstruction (project design) services, and works with the architect performing value engineering, constructability reviews, cost estimating, etc. to produce the optimum project value for the money available, and complete and accurate construction documents that the CM can then distribute to the trade contractors to bid to secure a Guaranteed Maximum Price (GMAX). Once the CM obtains the GMAX bid, the owner enters into a construction agreement with the CM for the construction phase of the project. <http://www.calstate.edu/BF/Newsletters/letters04-05/1104issue.pdf> (accessed 07 January 2009)

Center for Science Project Team

Figure 8. Center for Science Project Team. Source: Data adapted from Facilities Planning & Capital Projects.

Project Budget

During the Programming Phase, two independent estimates were prepared and reconciled. The results were found to be above the CSU allowable costs requiring that the Program be modified. Two additional independent estimates were then prepared and reconciled with the results demonstrating that the allowable costs were inadequate for the project.¹³ RRM, the program architect, cautioned that areas for cost savings would need to be explored as the project moved forward, and included further recommendations to reduce costs while maintaining building performance: 1) simplified building layout to reduce envelope, 2) integrated systems design to reduce redundancy, and 3) phased implementation of the Centennial Green.¹⁴ These recommendations continued to be considered throughout project development, and long after the study was completed.

The CSU Programming budget, the results from the two final Programming Phase estimates for the building and site construction, and the final budget from

the May 18, 2007 campus allowable costs (CSU Allocation) are listed in Table 6. The sitework construction is shown as a lump sum cost since it is considered separately from the building cost by the CSU. For purposes of consistency throughout this report, the CSU Allocation will be shown as the last, revised amount approved by the CSU on May 18, 2007, and obtained from Cal Poly Facilities Planning and Capital Projects Department.

Table 6. Programming Phase Allowable Costs versus Estimates

Levels	UniFormat Cat.	CSU Budget ^a	Davis Langdon	O'Connor	CSU Allocation ^b
A SUBSTRUCTURE					
A10	Foundations	972,657	2,243,000	1,387,184	627,000
A20	Basement Construction	2,583,730	0	2,532,942	0
B SHELL					
B10	Superstructure	7,038,619	8,670,000	8,327,124	8,221,000
B20	Exterior Enclosure	4,981,283	4,884,000	7,970,902	4,873,000
B30	Roofing	437,901	761,000	1,524,096	474,000
C INTERIORS					
C10	Interior Construction	6,180,103	5,162,000	3,483,393	1,838,000
C20	Stairs	149,685	^c	548,092	^c
C30	Interior Finishes	3,010,030	2,239,000	2,699,843	2,154,000
D SERVICES					
D10	Conveying	347,999	1255000	933,914	785000
D20	Plumbing	11,233,361	6,172,000	4,448,392	3,166,000
D30	HVAC	13,829,989	13,747,000	12,371,700	9,086,000
D40	Fire Protection	1,583,389	879,000	945,663	783,000
D50	Electrical	10,918,414	8,719,000	8,652,113	7,286,000
E EQUIPMENT. & FURNISHINGS.					
E10	Equipment	12,653,431	7,495,000	10,854,146	8,186,000
E20	Furnishings	^d	^d	^d	^d
F SPECIAL CONSTRUCTION & DEMOLITION					
F10	Special Construction		0	339,210	0
F20	Selective Demolition	652,501	0	1,044,185	0
Total Building		76,573,092	62,226,000	47,477,000	68,362,000
Total Sitework		7,893,402	14,411,000	12,146,000	16,134,000
Escalation for Construction		6,355,000	15,639,000	19,323,000	5,901,000
General Conditions, OH&P, Contingency		16,693,000	36,749,000	40,244,000	10,848,000
Grand Total		107,514,494	116,787,000	115,170,000	122,087,000

Source: Data from RRM Design Group. The Center for Science: Program Document and Feasibility Study. California Polytechnic State University, San Luis Obispo, October 2006.

Notes:

- ^a Initial CSU 2-7 Budget.
- ^b Final CSU 2-7 Budget and fund allocation.
- ^c Included in D10-Conveying.
- ^d Included in E10-Equipment.

Exterior Enclosure

While the building information model assumptions will be limited to the Programming and Conceptual Design Phase, this portion of the research examined the exterior enclosure cost estimates and Basis of Design from Programming and Conceptual Design through the Construction Documents.

Programming and Conceptual Design

In the Programming and Conceptual Design Phase, independent cost estimates were prepared by two firms—Davis Langdon (the Program Architect's estimator) and O'Connor Construction Management (the University's estimator). In Table 7, the descriptions used by each estimator were compared and correlated where possible. Variations in descriptions occurred because each has a separate cost data base from which to work. Items broken-out by one may be lumped together by another. Quantities may be determined in a different manner by each. At this phase in the project, cost estimating is as much an art as it is a science in that to a large extent the information is sketchy at best. Each estimator used experience and judgment in making assumptions for inclusion and exclusion of items in preparing the estimates.

While it is interesting to note the differences between the two approaches, the two estimates are within three percent of each other—an acceptable variance. They are, however, far below the final CSU allocation of \$7,970,902, at approximately 60 percent of the allocation. Cost escalation may be a portion of the higher cost, but insufficient information at this phase would seem a more likely reason. Even taking into account a 20 percent design contingency, both estimates are still below what the project will end up costing.

Table 7. Cost Estimates at Programming & Feasibility Study Phase

Summary

Description	Davis Langdon	O'Connor
Opaque Wall Construction	\$ 2,709,250	\$ 2,841,300
Exterior Glazing Systems	\$ 1,680,250	\$ 2,156,000
Exterior Doors	\$ 99,300	\$ 56,379
Miscellaneous	\$ 395,500	\$ -
Total	\$ 4,884,300	\$ 5,053,679

Variance between:

DL & OC	3%
DL & CSU 2-7	63%
OC & CSU 2-7	58%
Average DL & OC to CSU 2-7	60%

CSU 2-7 final project budget amount: \$ 7,970,902

Description	Davis Langdon				O'Connor			
	Quantity	Unit	Cost /Unit	Total	Quantity	Unit	Cost /Unit	Total
Wall framing, furring and insulation								
Waterproofing	45,500	SF	3.50	\$ 159,250				
Exterior sheathing	45,500	SF	2.50	\$ 113,750				
6" light gauge framing	45,500	SF	7.50	\$ 341,250	42,000	SF	9.70	\$ 407,400
Batt insulation	45,500	SF	1.00	\$ 45,500	42,000	SF	1.62	\$ 68,040
Blocking, caulking	45,500	SF	1.00	\$ 45,500				
Applied exterior finishes								
Precast panels	34,100	SF	40.00	\$ 1,364,000	42,000	SF	53.90	\$ 2,263,800
Prefabricated cladding panels								
Metal cladding panels	11,400	SF	40.00	\$ 456,000				
Interior finish to exterior walls								
Furring & gypboard at basement walls	9,900	SF	2.50	\$ 24,750				
Gypsum board, traped & sanded	45,500	SF	2.50	\$ 113,750	42,000	SF	2.43	\$ 102,060
Paint finish	45,500	SF	1.00	\$ 45,500				
Windows, glazing and louvers								
Aluminum glazed curtainwall system	8,750	SF	85.00	\$ 743,750	15,000	SF	97.02	\$ 1,455,300
Aluminum glazed storefront	12,400	SF	60.00	\$ 744,000				\$ -
Aluminum glazed windows	3,850	SF	50.00	\$ 192,500	10,000	SF	70.07	\$ 700,700
Exterior doors, frames and hardware								
Aluminum glazed entrances	16	EA	3,300.00	\$ 52,800				\$ -
Hollow metal entrances	10	EA	1,650.00	\$ 16,500	10	EA	1,724.80	\$ 17,248
Roll-down door, 23'x14', s.s. finish	2	EA	10,000.00	\$ 20,000	3	PR	3,341.80	\$ 10,025
Extra over for hold opens	2	EA	5,000.00	\$ 10,000	2	PR	8,085.00	\$ 16,170
Fire rating					16	LEAF	269.50	\$ 4,312
Panic hardware					16	LEAF	539.00	\$ 8,624
Canopies								
Canopy roofing, flashing and soffit	2,000	SF	85.00	\$ 170,000				
Fascias, bands, screens and trim								
Aluminum glazed curtainwall roof screen	1,500	SF	50.00	\$ 75,000				
Structural steel support-galvanized	15	T	3,500.00	\$ 52,500				
Balustrades	150	LF	350.00	\$ 52,500				
Miscellaneous								
Miscellaneous cladding	45,500	SF	1.00	\$ 45,500				
Total				\$ 4,884,300				\$ 5,053,679

*Schematic Design Phase**

In the Schematic Design Phase, independent cost estimates were prepared by Davis Langdon, the cost estimator for the design architect, ZGF, and by the construction manager, Gilbane Building Company. In organizing Table 8, the descriptions used by each estimator were compared and correlated where possible.

Two areas of disagreement in the estimates emerged – materials and quantities. It is also interesting to note that the quantities used by each estimator for the same items differ. For example, the Curtain Wall System quantities differ by 6832 square feet for concealed header/jamb and 3044 square feet for the 2” deep horizontal snap caps. The cost difference totals \$1,272,340 for these two items. Even the total number of doors is different—40 total for Davis Langdon and 36 total for Gilbane. Several items listed by one are described differently by the other, or omitted completely. For example, the 8” CMU Penthouse Walls are not included in the Davis Langdon estimate.

At this phase in the project, the architect is attempting to hold the costs down, while the construction manager is trying to include every possible contingency. The variance between the two estimates is 31 percent. Davis Langdon is 9 percent below the final CSU allocation of \$7,970,902, and Gilbane is 19 percent above it. The average of their differences is 5 percent from the CSU allocation.

Variation in costs may be partially due to different approaches to cost data and lack of detailed information leading to different assumptions at this early phase of the project.

*Interprets the project requirements to show relationship of the facility to the site, other buildings, and the campus; exterior design of the facility; relationship of interior areas; materials to be used in construction: types of structural, mechanical, electrical, and telecommunication systems to be utilized; construction costs; and life cycle cost analysis. Documents include drawings, outline specifications and cost estimates.

Table 8. Cost Estimates at Schematic Design Phase

Summary

Description	Davis Langdon	Gilbane
Opaque Wall Construction	\$ 3,761,913	\$ 5,149,532
Exterior Glazing Systems	\$ 2,165,810	\$ 3,459,230
Exterior Doors	\$ 122,050	\$ 152,500
Miscellaneous	\$ 630,289	\$ -
Total	\$ 6,680,062	\$ 8,761,262

Variance between:

DL & OC	31%
DL & CSU 2-7	19%
OC & CSU 2-7	-9%
Average DL & OC to CSU 2-7	5%

CSU 2-7 final project budget amount: \$ 7,970,902 -

Description	Davis Langdon				Gilbane			
	Quantity	Unit	Cost /Unit	Total	Quantity	Unit	Cost /Unit	Total
Opaque Wall Construction								
8" CMU Penthouse Walls					3,140	SF	22.45	\$ 70,493
4" Furring to basement walls	3,310	SF	3.50	\$ 11,585				
Steel Lintels (angles)	49,048	SF	1.50	\$ 73,572	25	Ton	2,759.14	\$ 68,979
8"light gauge framing	63,113	SF	8.50	\$ 536,461				
Rigid insulation	63,113	SF	2.50	\$ 157,783				
Waterproofing	63,113	SF	4.00	\$ 252,452				
Exterior sheathing, dens-glass	63,113	SF	2.75	\$ 173,561				
Metal Panel System (Zinc Panels)	24,974	SF	27.50	\$ 686,785				
Zinc Panels on 8" stud back-up					13,344	SF	60.00	\$ 800,640
Zinc Panels - Return to Remove Protective Shielding					13,344	SF	10.00	\$ 133,440
Zinc Panels on Structural Steel Framing (incl Steel)					11,425	SF	90.00	\$ 1,028,250
Brick Veneer	49,048	SF	32.50	\$ 1,594,060	48,841	SF	50.00	\$ 2,442,050
Gypsum board to exterior walls-taped, sanded & painted	66,423	SF	4.15	\$ 275,655				
Exterior Wall Back-up - Drywall Furring on 3-5/8" Studs					62,185	SF	8.00	\$ 497,480
Exterior Soffits					4,200	SF	21.00	\$ 88,200
Sub - Louvers & Grilles					1	LS	20,000.00	\$ 20,000
Exterior Glazing Systems								
Interior window Sills					5,000	LF	20.00	\$ 100,000
Exterior Wall Mock Up					1	ALW	25,000.00	\$ 25,000
Curtain Wall System - Concealed Header/Jamb	5,731	SF	100.00	\$ 573,100	12,563	SF	70.00	\$ 879,410
Curtain Wall System - 2" Deep Horiz Snap Caps	18,721	SF	70.00	\$ 1,310,470	22,765	SF	100.00	\$ 2,276,500
Structurally Glazed Double-height Curtainwall	2,352	SF	120.00	\$ 282,240	1,486	SF	120.00	\$ 178,320
Exterior Doors								
Doors/Frames/hardware, Exterior HM					8	LEAF	1,500.00	\$ 12,000
--Single leaf	5	EA	1,700.00	\$ 8,500				
--Double leaf	7	EA	3,250.00	\$ 22,750				
Overhead Doors Elec Operated					1	EA	2,500.00	\$ 2,500
Entrance Doors - Glass/Alum					15	LEAF	4,000.00	\$ 60,000
--Single leaf	1	EA	3,300.00	\$ 3,300				
--Double leaf	10	EA	6,150.00	\$ 61,500				
Entrance Door Auto Assist HW - Fire Glass/Alum, 2 hr FR					12	LEAF	6,500.00	\$ 78,000
Auto Openers	4	EA	6,500.00	\$ 26,000				
Miscellaneous								
Soffits - Metal Panel	2,102	SF	47.50	\$ 99,845				
Soffits - Cement Planter	892	SF	30.00	\$ 26,760				
Roof screen including structural support, metal panel (12')	6,744	SF	50.00	\$ 337,200				
Galvanized guardrail at terraces, 4 feet high	240	LF	220.00	\$ 52,800				
Fascias, bands, screens & trim	113,684	SF	0.50	\$ 56,842				
Architectural detailing	113,684	SF	0.5	56842				
Total				\$6,680,062				\$ 8,761,262

*Design Development Phase**

Again in the Design Development Phase, independent cost estimates were prepared by Davis Langdon, and by Gilbane. In organizing Table 9, the descriptions and quantities were compared. The cost estimates are becoming more detailed as the building systems are defined.

Both ZGF and Gilbane were attempting to maintain the design intent, while holding to the construction budget. The variance between the two estimates is 26 percent. Both Davis Langdon and Gilbane are above the final CSU allocation of \$7,970,902 (9 percent and 27 percent, respectively). The average of their differences is 18 percent above the CSU allocation.

Optional materials and details for the exterior were explored in an attempt to bring the final building in-line with the budget. It was becoming increasingly clear that the budget approved by the CSU was inadequate, even after exploring and applying several value engineering options, including a less durable exterior material. The cost of other building systems would have to be reduced to make-up for the shortfall in the exterior enclosure costs, and to bring the overall project costs in-line with the budget.

*Confirms or adjusts all aspects of the schematic plans (exterior design, mechanical and electrical systems, telecommunications system, structural systems, area arrangements, foundation plans, etc.). Documents include plans, outline specifications and cost estimates developed in further detail than schematic documents.

Table 9. Cost Estimates at Design Development Phase

Summary

Description	Davis Langdon	Gilbane
Opaque Wall Construction	\$ 5,536,972	\$ 6,882,309
Exterior Glazing Systems	\$ 2,095,190	\$ 3,823,925
Exterior Doors	\$ 153,800	\$ 190,540
Miscellaneous	\$ 960,599	\$ 95,780
Total	\$ 8,746,561	\$ 10,992,554

Variance between:

DL & OC	26%
DL & CSU 2-7	-9%
OC & CSU 2-7	-27%
Average DL & OC to CSU 2-7	-18%

CSU 2-7 final project budget amount: \$ 7,970,902

Cost Estimates at Design Development								
Description	Davis Langdon				Gilbane			
	Quantity	Unit	Cost /Unit	Total	Quantity	Unit	Cost /Unit	Total
Opaque Wall Construction								
4" Furring to basement walls	4,165	SF	3.50	\$ 14,578				
Steel Lintels (angles)	58,450	SF	1.50	\$ 87,675	12	Ton	2,759.14	\$ 33,110
Tube Steel at Bump-outs					10	Ton	8,500.00	\$ 85,000
Metal support anchor, 4"x4"	28,522	SF	3.50	\$ 99,827				
Screen Wall Supports					10	Ton	8,500.00	\$ 85,000
Metal angle, 1-1/2" x 1-1/2"	28,522	SF	4.00	\$ 114,088				
Shelf Angles to Support Brick					30	Ton	8,050.91	\$ 241,527
Z-profile framing, 1"	28,522	SF	2.50	\$ 71,305				
Rigid insulation	86,972	SF	3.50	\$ 304,402	95,384	SF	2.07	\$ 197,445
Waterproofing	86,972	SF	4.00	\$ 347,888	88,329	SF	4.10	\$ 362,149
Basement Wall Waterproofing					7,283	SF	2.41	\$ 17,571
Exterior sheathing, dens-glass o/6" stud framing	86,972	SF	10.25	\$ 891,463	88,329	SF	13.80	\$ 1,218,940
Flashing at Opaque Wall					5,000	LF	11.28	\$ 56,390
Aluminum Dri-p Edge at Window Head/Sill					2,536	LF	7.00	\$ 17,752
Metal wall panels-screen walls & light monitors; at back of parapet					2,318	SF	35.00	\$ 81,130
Brick Veneer, including anchors	58,450	SF	33.50	\$ 1,958,075	50,714	SF	38.25	\$ 1,939,811
Brick Veneer with projecting horiz bands					8,495	SF	42.50	\$ 361,038
Column cladding, GFRG	56	LF	275.00	\$ 15,400	60	LF	60.00	\$ 3,600
Fiber cement siding	28,522	SF	40.00	\$ 1,140,880	43,129	SF	37.50	\$ 1,617,220
Gypsum board to exterior walls-taped, sanded & painted	86,972	SF	5.65	\$ 491,392	88	LF	5.40	
Drywall Furring on Hat Channels					88,329	SF	5.40	\$ 476,977
Sub - Louvers & Grilles					1	LS	20,000.00	\$ 20,000
Louvers attached to aluminum & SwissPearl System					1,353	SF	50.00	\$ 67,650
Exterior Glazing Systems								
Aluminum glazed curtainwall at knuckles	2080	SF	100.00	\$ 208,000	705	SF	150.00	\$ 105,750
Aluminum glazed curtainwall	4745	SF	100.00	\$ 474,500	5331	SF	90.00	\$ 479,790
Sloped aluminum window	342	SF	110.00	\$ 37,620	354	SF	110.00	\$ 38,940
Aluminum windows / store front	14055	SF	70.00	\$ 983,850	7337	SF	82.94	\$ 608,555
Windows-in Bumpouts & Clerestory					6230	SF	75.00	\$ 467,250
Aluminum mullion system, 11" deep	19561	SF	20.00	\$ 391,220				
Curtainwall Support Steel Framing					25	Ton	9,000.00	\$ 225,000
Sunshade - Mullion system & horiz. Louvers/sunshade					23,376	SF	69.19	\$ 1,617,320
Windows-Operable					1,541	SF	120.00	\$ 184,920
Glazing at light monitors - operable					714	SF	100.00	\$ 71,400
Exterior Wall Mock Up					1	ALW	25,000.00	\$ 25,000
Exterior Doors								
Doors/Frames/hardware, Exterior HM								
--Single leaf	10	EA	1,750.00	\$ 17,500				
--Double leaf	3	EA	3,250.00	\$ 9,750				
Doors Frames, Exterior HM, rated					6	EA	960.00	\$ 5,760
--Single leaf					3	EA	1,600.00	\$ 4,800
--Double leaf								
Doors Frames, Exterior HM, non-rated					2	EA	880.00	\$ 1,760
--Single leaf					1	EA	1,520.00	\$ 1,520
--Double leaf					24	LEAF	4,000.00	\$ 96,000
Entrance Doors - Glass/Alum								
--Single leaf	8	EA	3,300.00	\$ 26,400				
--Double leaf	10	EA	6,150.00	\$ 61,500				
Solid metal door - Exterior, rated					10	LEAF	1,400.00	\$ 14,000
Solid metal door with lite - Exterior					2	LEAF	1,500.00	\$ 3,000
Solid wood door with metal frame and hardware					4	LEAF	1,300.00	\$ 5,200
--Single leaf	5	EA	1,600.00	\$ 8,000				
--Double leaf	1	EA	3,150.00	\$ 3,150				
Premium for fire rating	10	EA	150.00	\$ 1,500				
Entrance Door Auto Assist HW - Fire Glass/Alum, 2 hr FR					9	LEAF	6,500.00	\$ 58,500
Auto Openers	4	EA	6,500.00	\$ 26,000				
Miscellaneous								
Soffits								
--Fiber cement	2,909	SF	50.00	\$ 145,450				
--Cement Planter	418	SF	25.00	\$ 10,450				
Balustrades & roof screen								
--Roof Screen including fiber cement siding o/structural steel o/concrete curb	5,472	SF	81.46	\$ 445,740				
--Maintenance walkway suspended	1,854	SF	38.00	\$ 70,452				
--Galvanized guardrail at terraces, 4 feet high	227	LF	250.00	\$ 56,750				
Fascias, bands, screens & trim								
--Aluminum louvers / sunshade (4 fin assembly)	650	LF	175.00	\$ 113,750				
--Allow for fascias, bands, screens & trim	118,007	SF	0.50	\$ 59,004				
--Architectural detailing	118,007	SF	0.50	\$ 59,004				
Millwork - Interior wood window sills					1,485	LF	20.00	\$ 29,700
Millwork - Interior wood window sills @ 21"wide windows					826	LF	80.00	\$ 66,080
Total				\$ 8,746,561				\$ 10,992,554

*Construction Documents Phase**

During the 50% Construction Documents Phase, Davis Langdon and Gilbane had highly detailed information in the Construction Documents from which to prepare their independent cost estimates. At this point in the project, the exterior skin plans included elevations, sections, details and specifications (Figure 9).

Figure 9. Center for Science – Building Elevations. Source: California Polytechnic State University, San Luis Obispo, Facilities Planning and Capital Project, Center for Science Project, drawings by ZGF (10 July 2007).

*Sets forth, in detail, all aspects of project design, function, and construction. Documents area used for estimating the cost of the project, securing bids for its construction, and directing the contractor during the construction period. Documents include detailed construction drawings, and material and building system specifications.

In organizing Table 10, the descriptions were compared and correlated. At this phase in the project, ZGF and Gilbane continued to maintain the design intent, while holding to the construction budget.

Both Davis Langdon and Gilbane are above the final CSU allocation of \$7,970,902 (23 percent and 26 percent, respectively). The average of their differences is 25 percent above the CSU allocation, while they differ from each other by only 3 percent.

Refinement of optional materials and the details for the exterior and cost reduction of other building elements were needed to bring the final building in-line with the budget. The analysis of the cost estimates show that the initial assumptions and the final CSU allocation for the exterior skin of the building were too low.

Table 10. Cost Estimates at Construction Documents Phase

Summary		
Description	Davis Langdon	Gilbane
Opaque Wall Construction	\$ 5,077,312	\$ 6,019,055
Exterior Glazing Systems	\$ 3,863,115	\$ 4,485,375
Exterior Doors	\$ 350,600	\$ 173,230
Miscellaneous	\$ 1,108,602	\$ 78,440
Total	\$ 10,399,629	\$ 10,756,100

Variance between:

DL & OC	3%
DL & CSU 2-7	-23%
OC & CSU 2-7	-26%
Average DL & OC to CSU 2-7	-25%

CSU 2-7 final project budget amount: \$ 7,970,902

Cost Changes Over Time by Building System

From the time the Construction Manager first looked at the project to the 50 percent Construction Documents (a twelve-month period), the Project Team increased costs for two systems, and decreased costs for two systems, plus decreased overhead and profit (OH&P), General Condition expenses and Project Contingency (Figure 10). The exterior enclosure costs doubled from \$6 million to \$12 million. Costs for two other building systems remained relatively constant.

Figure 10. Cost Changes Over Time by Building Systems. Sources: Data adapted from RRM "Program," and Gilbane "Schematic," "Design Development," and "Schematic."

With the total costs above budget, two building systems were explored further in the hopes of decreasing costs. Ultimately, the project was brought in-line with the budget by reducing costs in building services (specifically mechanical), and equipment and furnishings. The costs were reduced to 2 percent below the CSU

allocation, and the project continued to completion of the 100 percent Construction Documents (Table 11).

Table 11. Difference between Budget and Construction Costs

Budget	Costs	Percentage
CSU 2-7 final	\$ 95,723,000	100%
Gilbane	\$ 93,520,626	98%
Difference	\$ 2,202,374	2%

The costs for many of the building systems over the twelve-month period differ greatly from the budget established during the programming phase and from the final CSU budget (Figure 10). For the exterior skin, and specifically the curtain wall system, the architect and constructor were each envisioning a different system. The program architect originally envisioned a standard curtainwall system, while the design architect envisioned creating a unique curtainwall system and did not realize the cost implications. In the end, the architect and constructor worked together to arrive at a solution that preserve the design intent, improved on other building systems and maintained the CSU project budget. The design and material assumptions were the areas of consistent tension in the costs estimates. While both estimators were reviewing the same information, each made different assumptions about materials, systems and quantities. Although their cost estimates differed consistently by system during the Schematic and Design Development phases, and their final cost estimates for the Construction Documents phase differs slightly for some building systems, both agreed on the overall project costs for the construction budget at the 50 percent point in the Construction Documents phase (Figure 11).

Figure 11. Cost Changes Over Time by Phase. Sources: Data adapted from RRM “Program,” and Gilbane “Schematic,” “Design Development,” and “Schematic.”

Ideally, the options, assumptions, and decisions for the Center for Science would have been known to all Project Team members at each phase of the project. Because the project information was developed and shared in a 2-D format, visualization of the project and all its components was open to a wide range of assumptions and interpretations by each team member.

Interoperability, the process, and Building Information Modeling, the tool, present new ways of developing, documenting and viewing project information. As observed by Brent Pilgrim, if used as intended, BIM would allow architects to make earlier and more definite assumptions, and to share those assumptions with the rest of the team. He notes that this can be uncomfortable for architects, because each assumption is documented and a cost applied. However, Pilgrim also states that “one can expect the assumptions to change later, but everyone

knows the assumptions, and the cost estimate is in-line with those assumptions.”¹⁵

BIM would allow options to be carried in the project data until a clear choice is determined. Having information about the options in the model as the project progresses would allow the Project Team members to add and analyze information leading to a decision. If the BIM were viewed as a puzzle, then Team members would be able to watch and participate in solving the puzzle by adding pieces where needed, discarding pieces that don't fit, and working together to make sure no pieces were missing.

Dane Dodd-Hansen, an architect and specification consultant, who chairs CSI's BIM Technology Committee states that BIM enables “moving the decision-making process and information gathering process to the front end of the project.”¹⁶ He continues that it is important to share information with all team members from initiation of the project. “Basically, the thing that they are doing right from the beginning is to bring everybody that's involved in the process into the same room, right from the get go on every project.”¹⁷

Case Study Conclusions

Realizing the need to work differently by involving more team members earlier in the design process, the AIA has gone from recommending a Traditional Design process (Figure 4) to an “Integrated Project” process as is illustrated in Figure 12. In the Integrated Project process, Design Consultants (civil, structural, mechanical, electrical, plumbing, controls, special, etc.) and Constructors are brought in earlier during what was previously known as the Predesign Phase in the traditional design process.

In the Integrated Project process, Design Consultants (civil, structural, mechanical, electrical, plumbing, controls, special, etc.) and Constructors are brought in earlier during what was previously known as the Predesign Phase in the traditional design process. “Shifting design decision making forward,” with “early input from constructors, installers, fabricators and suppliers,” and with “the ability to model and simulate the project accurately using BIM tools” enables “the

design to be brought to a much higher level of completion before the documentation phase is started.”¹⁸

Figure 12. Integrated Design Process Model. Source: Data from AIA National/AIA California Council, Integrated Project Delivery: A Guide, version 1 (The American Institute of Architects, 2007), table page 22.

Derived from Brent Pilgrim’s examination of the cost estimates prepared at each project phase by two separate estimators, he speculates that without clear definition of the project assumptions, each estimate was based on individual interpretation of the design intent. This is reflected in part by the variations in materials, systems and quantities in the estimates. In his opinion, the Center for

Science project would have benefitted greatly if the entire team had been brought together to visualize and communicate the project, including assumptions and options, clearly defining the project using a 3-D tool and building information modeling.¹⁹

In the viewpoint of Chris Pechacek, BIM would have benefited the Center for Science project by illuminating the gaps in project definition required to develop the cost estimate. He further adds that using BIM would have eliminated disconnects in obtaining accurate costing information by enabling the project team to be tied into the design process to fill in the gaps and contribute to the project solution, noting that “every time we rehandle information, we introduce error.”²⁰ Pechacek is also a proponent of using information for different purposes to create more value and save time. He observed that had the Center for Science project been created in a BIM, the information could have been used to create the renderings, drawings and cost estimates, and further down the road, the shop drawings.

Based on the appraisal of the Center for Science project as the construction manager, Mark Miller of Gilbane Building Company believes that the project would have benefitted if the complex project elements had been developed using BIM. Miller stated that the real benefit of BIM is “seeing how all the elements come together,”²¹ and that would have been helpful, especially on the east section of the 4th floor. He noted that the numerous building elements and seismic bracing were causing conflicts that the architect had not visualized during design and was having difficulty understanding the challenges seismic bracing was causing in an area congested with mechanical ducts and equipment.

In considering the potential benefits to the Center for Science project, Cal Poly project administrator, Johan Uyttewaal is of the belief that the advantages of BIM are greatest for the construction manager, especially in the clash detection and as a tool for the construction process.²²

Based on the opinion of Cal Poly project manager, Barbara Queen, had an integrated process using BIM software been utilized on the Center for Science

project from the start, time would have been saved by the campus, architects, consultants and construction manager since all would have had access to complete project information and been able to utilize it at every step in the work.²³ Also, the knowledge and input of these team members would have helped to reduce waste and maximize efficiency from programming through design.

Thorton Tomasetti, an international engineering company, notes on their website that BIM promises to provide “enhanced visualization, linked data sets, improved design team coordination, expedited quantity takeoffs, better scope definition and improved schedule,” and that IPD will enhance the project delivery as it leverages “the many advantages inherent in BIM.”²⁴

With the knowledge gained from examining the Center for Science case study and the professional opinions and consensus of the project team members, plus the insight gained from experts in the construction industry, an approach and recommendations were developed for the university to initiate incorporating the advantages of IPD and BIM into its projects. These recommendations, enumerated in Chapter 3, are intended as the first steps.

¹The Construction Specifications Institute, *The Project Resource Manual-CSI Manual of Practice*, 5th ed. (New York: McGraw-Hill, 2005), 1.1.

²CSI *PRM*, 3.23.

³Cyril M. Harris, *Dictionary of Architecture and Construction*, 4th ed. (New York: McGraw-Hill, 2006), 767-768.

⁴William Peña, Steven Parshall, and Kevin Kelley, *Problem Seeking: An Architectural Programming Primer* (Washington: AIA Press, 1987), 15.

⁵Peña, Parshall, and Kelley, 181-182.

⁶The California State University, “SUAM, Section I – Capital Outlay and Public Works Contracts, Sections 9000-9004” (Rev 11.02), <http://www.calstate.edu/CPDC/SUAM/SUAM9000-9004.pdf> (accessed 13 May 2008), Section 9001.

⁷The California State University, “SUAM, Section I – Capital Outlay and Public Works Contracts, Sections 9025-9040,” (Rev 12.02), <http://www.calstate.edu/CPDC/SUAM/SUAM9025-9040.pdf> (accessed 13 May 2008), Section 9028.

⁸The California State University, “SUAM, Appendix B: Facilities Planning,” <http://www.calstate.edu/cpdc/suam/Appendices/Appendix B.shtml> (accessed 20 May 2008).

⁹The California State University, "SUAM, Appendix B: Facilities Planning," <http://www.calstate.edu/cpdc/suam/Appendices/Appendix B.shtml> (accessed 20 May 2008), CSU CPDC Form.

¹⁰*Capital Outlay Budget Change Proposal: 2007/08 State and Non-State Capital Outlay Program* (November 2006); RRM Design Group, *The Center for Science: Program Document and Feasibility Study*, California Polytechnic State University, San Luis Obispo (October 2006), 8.

¹¹RRM, 8.

¹²California Polytechnic State University, "Request for Proposal – Construction Manager at Risk with Guaranteed Maximum Price – Center for Science RFP MAJ 06-310, Article B – Information for Proposers," (15 January 2007), 6.

¹³RRM, 57.

¹⁴RRM, 57.

¹⁵Brent Pilgrim, telephone interview by author, (26 November 2008).

¹⁶Dane Dodd-Hansen, telephone interview by author, (21 November 2008).

¹⁷Dodd-Hansen.

¹⁸AIA National / AIA California Council, *Integrated Project Delivery: A Guide, version 1* (The American Institute of Architects, 2007,: 22.

¹⁹Pilgrim.

²⁰Christopher Pechacek, telephone interview by author, (26 November 2008).

²¹Mark Miller, telephone interview by author, (09 January 2009).

²²Barbara Queen and Johan Uyttewaal, interview by author, San Luis Obispo, CA, (09 January 2009).

²³Queen and Uyttewaal.

²⁴Thorton Tomasetti, Website, http://www.thorntontomasetti.com/project_delivery.php (accessed 6 January 2009).

CHAPTER 3

Justification, Assumptions and Recommendations

Justification of Issues

Industry Changes Necessitate Process Changes

As the construction industry moves toward BIM, propelled by new software tools, integrated project delivery is becoming the process that will allow the project team to work in a better, more efficient manner through all phases of a project. As tools for each participant are developed and information becomes integrated into a complete and accessible building information model, the industry must respond by changing to an integrated design process to benefit fully from the interoperability of the systems. Until this occurs, project information will be fragmented and lost, and the construction industry will continue to be inefficient and frustrated by the ever increasing building complexity. The benefits are many and available to those who participate using BIM and an integrated process.

The individual experts interviewed for this thesis each have a different approach to projects. Each demonstrates in a different way how they are modeling their business to embrace BIM and improve upon the work processes and the project outcomes. Beck Technology has responded to the industry changes by providing integrated project services similar to design-build. However, they are unique in that design and construction are all part of the same company and all share the same bottom line.¹

Dodd-Hansen Consulting has expanded their specification writing services (to assist firms moving into new initial delivery processes) by gathering information on materials and systems at the beginning of a project to provide the means for earlier decision making. Dane Dodd-Hansen describes the Basis of Design in the conceptual phase as “essentially a response to the owner’s requirements for the project” where the probable products and systems are defined, and “put together in a component specification.”² This allows information to be provided

earlier to all team members so that all are working from the same assumptions. Dodd-Hansen notes the advantage, “It moves everybody onto that early page very, very effectively.”³

Onuma, Inc. is focusing on early planning and facility management. Their web-based software tools allow owners to do early programming and feasibility analysis. When initiating a project, the requirements can be cataloged or assembled and shared with the project team. Instead of a static document, information can continue to be added throughout the life cycle of the building. Additionally, owners with large and multiple facilities benefit greatly by being able to manage their space allocation and requirements. For large and multiple facility owners, such as the United States General Services Administration (GSA) and the United States Coast Guard, these types of tools enable them to manage existing facilities and plan for future facilities.⁴

In 2003, GSA began a pilot program to leverage 3-D-based BIM to improve “cost predictability.”⁵ GSA hoped to “ensure better as-built documentation, communication, design delivery, and coordination.”⁶ As a result of the successes with the pilot program, the Commissioner of the Public Buildings Services mandated the use of interoperable BIM for cost-effective delivery of GSA projects.”⁷

Transformation of Information Sharing

The holistic nature of BIM provides significant opportunities for all members of the building team. For example, team members with access to the project information can be aware of all changes being made in real time—a substantial information sharing and coordinating opportunity. BIM can allow information created in the programming and conceptual design phase to be carried throughout subsequent phases with information being added or modified as the project progresses. BIM can reduce errors made by the design and construction team members by checking for conflicts in the drawings, such as a pipe penetrating a duct and a duct cutting through a critical structural member. It can free-up time spent on door and window schedules by creating dynamic

schedules that update automatically as changes are made. It can be used to provide analysis such as daylighting and energy usage simulations, and to aid the design, cost estimating, and decision making for building systems.

GSA realized direct benefits to their pilot projects. These included a 19 percent reduction in the construction schedule duration, improvement in as-built documentation, early discovery of design errors and omissions, and improvement in the means of communication with tenant agencies and during pre-bidding conferences.⁸ As team members obtain access to all changes being made in real time, the transformation of information sharing will be realized, and information created in programming will be carried throughout subsequent phases.

Working in a Collaborative Environment

As the industry embraces the use of BIM, and team members have access to information and changes in real time, project teams will need to collaborate to work in the best interests of the project. The Integrated Project Delivery requires close cooperation among team members, and aligns “participant success to project success.”⁹ The focus by team members will shift from individual expectations to “collectively achieving shared goals.”¹⁰

Assumptions and Recommendations

Approach

Chris Pechacek of Parsons Corporation, an engineering and construction firm recommends starting at the end and working towards the beginning of a project (as is done by constructors with Reverse Phase Scheduling) to identify what is needed, from whom it is needed and when it is needed.¹¹ Rather than going to the end of a building’s life at the de-commissioning phase, the assumptions in this thesis are based on working backwards from the Schematic Design and Design Development Phases, and determining what information should be passed onto the Design Architect from the Program Architect. Although the approach used in this thesis was developed using Reverse Phase Scheduling

concepts beginning at the design phase, the assumptions are introduced in project sequence beginning with the information the University may provide to the Program Architect at the project initiation.

Project Initiation – Need and Vision Statement

For universities within the CSU system, project need is based on the projected number of additional full-time equivalent (FTE) students and the resulting requirement for the additional square footage (Table 2). To begin defining the project scope, a vision for the project is developed by the Dean working in concert with the Provost, or the Department Head working in concert with the Vice-President, and is presented as a Vision Statement. Both the Dean and the Department Head typically involve a committee to collaborate and develop the vision as the project idea originates. With the vision statement ready, the University hires a Program Architect to develop the programming and feasibility study. The criteria given to the potential Program Architects includes the Vision Statement, the FTE number, the approximate size and the anticipated CSU construction budget. Additional information is provided once a Program Architect is selected and programming begins.

University to Program Architect

At initiation of the programming and feasibility study, the University provides site, topographical and utility maps, surveys, existing building plans and specifications, and campus and CSU standards to the Program Architect. This information is available in various forms, including on-line as pdf and AutoCAD files, and in electronic and hard copy for programming, planning, building consideration and analysis and is used by the Program Architect to define site and building options and constraints. (Table 12)

Table 12. List of Information Provided by Cal Poly to Program Architect

Information	On-line	PDF	AutoCAD	Word	Excel	Hard Copy
Campus Master Plan	●	●	●			
Existing Buildings Plans & Specs	●	●	●			●
Site Utility Maps	●	●	●			
Room Data Sheets Layout		●				
Existing Buildings Area					●	
Existing Buildings Usage					●	
CSU Program Summary Spreadsheet Format					●	
Campus Standards		●		●		
FTEs to accommodate				●	●	
CSU Building Design Standards	●	●				

Source: Data from interview with Rex Wolf, Facility Services, California Polytechnic State University, 9 December 2008.

Considering the information that will be developed and the formats most likely to be utilized, three recommendations are provided to the University. When information can be developed in an alternate format more compatible to a BIM, an alternate is given.

Recommendation #1 – Improve upon the information received from others and provided to the Program Architect.

It would be beneficial for information to be in an open standard, such as IFC format, so that it can be accessed by the Project Team. In the interim, continue to provide the information in its original software file configuration. For example, if the Campus Utility Plan maps are available in AutoCAD, continue to allow the Program Architect access to the files for utilization of the information without

having to recreate it. This same desire would apply to other maps and building information.

Better yet, if the information could be provided in a parametric, 3-dimension format, such as GIS* or Revit,† then the underground depth and relationship to other utilities could be established resulting in more accurate analysis, scope and cost estimate. According to Rex Wolf in Facility Services at Cal Poly, the University currently has no plans to research and document underground utility data into a 3-D model, but would accept the information as it is developed and submitted for campus projects. The University should require their consultants to provide project information in a parametric 3-D format on future projects.

Recommendation #2 – Develop “Basic Assumption Models.”

Many of the building spaces required by the University are standardized for size, material, equipment and furniture. It would be beneficial to Program Architects to be able to receive space-type information in the form of “Basic Assumption Models”¹² rather than requiring each firm to create these. Presently at conclusion of programming, this information is provided to the University in a non editable format and cannot be changed except by the originating firm (Figure 13).

*Geographic Information System that integrates hardware, software, and data of geographically referenced information. Refer to Glossary for further information.

†Building design software for building information modeling. Refer to Glossary for further information.

Room Data Schedule			
Room ID Number:	CLS.02	Room Size:	1,300 sqft
		Capacity:	52 seat
Audio/Visual:		Security Requirements:	Electrical/Lighting:
a. A / V Console	YES	a. Security Cameras	NO
b. Ceiling Projector	YES	b. Motion Detector	NO
c. Motorized Projection Screen(s)	YES	c. Door Monitoring	NO
d. Marker Boards	YES	d. Other	NO
e. Wall-mounted Flat-panel Monitor(s)	NO		
f. Smart Board(s)	YES		
g. Recording Capabilities	YES		
h. Other	NONE		
IT/ Communications:		HVAC Requirements:	Finishes:
a. Wireless	YES	a. Special Temperature	Floor: Carpet
b. In-room Computer	YES	Needs	Walls: Acoustic wall paneling and GWB
c. Phone	YES	b. Humidity Control	Ceiling: Acoustic tiles
d. Other	NO	c. Other	Other: NONE
Acoustic Control:		Furniture:	Other Comments:
a. Normal	NO	Tables and chairs	
b. Privacy	YES	Lectern and AV cabinet	
c. Other	NONE		

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Figure 13. Room Data Sheet. Source: Data from Killefer Flammang "Program." Page 189.

The University should require the Program Architect to provide Room Data Sheet information in a configuration that will become part of the data base to be reused and revised as the project progresses (Figure 14). If the Basic Assumption Models were incorporated into a campus project data base, then it would be available for use whenever the need arose. To initiate creation of this endeavor, Cal Poly should develop a format for 3-D and non-3-D parts of the room data sheets that would make utilization and sharing of the information easier. As Onuma suggests, the owner “instead of having a whole stack of Excel files or documents, and saying here’s the project we are thinking of doing, actually hand them a BIM data file saying here’s all the pieces that we are considering using.”¹³ The benefit to the University would be that the Program Architect could spend more time on developing and analyzing options, and less time on producing standard, seldom changing information.

Figure 14. Basic Assumption Model - Data Base with Room Data Sheet Information. Source: Clip Art from Microsoft Office 2003.

Recommendation #3 – Provide CSU CPDC Forms to the Program Architect, and develop innovative ways to extract and present the information using BIM.

Until the CSU Campus Planning, Design and Construction (CPDC) begins to implement BIM in capital planning, the forms required for inclusion in the Capital

Outlay Program should be added to the list of information provided to the Program Architect (Table 13). This would guide the Program Architect in the type of information needed by the University, and make the information provided by the campus to the CSU easier to extract.

Table 13. List of CSU CPDC Forms to Provide to Program Architect

CPDC Form Name	Form #	Purpose	Benefit Program Architect to	Benefit to Cal Poly
COBCP Project Description	1-4	Summary of proposal for Capital Outlay Program, including alternatives, recommended solutions, consistency with State AB 857 and AB 32	Information to analyze and develop	Information required of University for submittal to CSU for project approval and funding allocation
Summary of Space Requirements for a Building	2-4	List of spaces proposed by project, description, type, size, stations, FTEs	Use to develop program	Information required of University for submittal
Room Specifications	2-6	Room Data Sheets; program on a room by room basis	Format required by University	Information presented in a reusable format
Summary of Component Costs	2-7.5	Summary of Project Costs	Define UniFormat level and components for cost estimate summary	Eliminate need for translating information into CSU format
Energy & Utilities Planning Checklist	2-8	Questions and issues to address prior to submitting project to CSU	Checklist of information to consider and provide University	Information required of University for submittal
Information Technology Planning Sheet	2-8.5	Provides guidance crucial to the design and implementation of cable system interface	List of information to consider, develop and provide University	Information required of University for submittal
Equipment List	2-23	List and estimated cost of Group II Equipment	Information to be included on Room Data Sheets	Development of Group II equipment lists

Source: The California State University, "Major Capital Outlay Forms," http://www.calstate.edu/cpdc/Facilities_Planning/majorcapoutlay.shtml (assessed 08 December 2008).

The next level up would be to put this information into the BIM, and extract it in a format compatible with the CSU Forms. Also, CSU may want to consider

revising these forms and the manner in which the information is presented, shared, and utilized.

Program Architect to Design Architect

The Program Architect provides the project program, planning concepts, building considerations and analysis, and a project budget (Table 14). The information for the program comes from working with the campus project committee to develop the programming and feasibility study, and is available as an electronic document and hard copy. The recommendations, which follow, were developed on two levels—one is a small step up from the current formats toward BIM, and the other utilizes BIM formats.

Table 14. List of Program Architect Information to Provide to Design Architect

Program Information	Purpose	Information Format	Suggested Format
Program Overview			
Executive Summary	Introduction to project and goals	pdf	Word
Introduction	Introduction to campus and project origination	pdf	Word
Project Team	List of participants in previous phase to understand composition of project team and contributors	pdf	Word
Project Program			
Project Goals	Program, and Building and Site goals	pdf	Word
Project Description	Description of spaces	pdf	Word
Program Summary	List of spaces, names, sizes and number of stations	pdf	Excel
Planning Concepts			
Site Analysis	Location, topography, site area, utilities, circulation	pdf	Word & 3-D
Campus Master Plan	Planning objectives for building footprint and massing, open space, integration with campus and adjacent buildings, pedestrian and vehicular circulation	pdf	Word & 3-D
Building Design	Concept, levels with types of spaces	pdf	Word & 3-D

Program Information	Purpose	Information Format	Suggested Format
Building Considerations & Analysis			
Codes & Standards	Applicable codes, requirements and standards	pdf	Word & 3-D
Architectural Basis of Design	Organizational Concept and massing, modular planning and feasibility, orientation, materials, exterior, interior, and technology infrastructure and equipment	pdf	Word & 3-D
Construction Phasing	Issues to be addressed during construction	pdf	Word & Scheduling
Sustainability	CSU requirements, site considerations, water efficiency, materials and resources, energy and Atmosphere, LEED checklist	pdf	Word & Excel
Landscape Basis of Design	Functional requirements, master plan goals	pdf	Word & 3-D
Site Utilities	District Heating and Cooling, storm water drainage, fire hydrants, gas, sewer, water, telecommunications, street lights, SCADA fiberoptic	pdf	Word & 3-D
Structural Basis of Design	Existing structural systems, building materials, condition	pdf	Word & Structural Analysis
Mechanical Basis of Design	Passive strategies, energy efficiency, occupant comfort	pdf	Word & Mechanical Analysis
Plumbing & Fire Protection Basis of Design	Domestic water service, sanitary drainage and vent systems, storm water, fire protection, LEED criteria and sustainability	pdf	Word & Plumbing Analysis
Electrical Basis of Design	Electrical system description, distribution equipment, minimum bus sizes, feeder size, method of distribution, grounding, receptacle power, electrical associated with mechanical and plumbing, general lighting, telecommunication system, fire alarm system and LEED criteria and sustainability	pdf	Word & Electrical Analysis
Project Budget			
Cost Basis of Design	Cost estimate, inclusions and exclusions, market conditions	pdf	Word & Excel
Other Information			
Room Data Sheets	Size, occupants, systems, equipment and furnishings	pdf	3-D & Excel
Work Session Agendas & Meeting Minutes	Information from Programming sessions	pdf	Word

Source: Data adapted from Killefer Flammang "Program."

Recommendation #1 – Receive information from consultants in the original software format.

Cal Poly should require programming and feasibility information be delivered in the software formats in which it was developed and assembled. Information in its original format can be shared with others saving the time required to input information into a software program, and may possibly be transferred to other software applications without degradation of the information. This is a small step up from the electronic non editable files, and is noted under “Suggested Format” in Table 14.

Recommendation #2 – Acquire and utilize a web-based planning program as the repository of information for all phases of the campus projects to aid in developing a collaborative environment.

Cal Poly should establish a goal of developing a collaborative project work environment where an open standard is required, information is stored in a Web-accessible data base (repository of information), and systems are able to talk to each other. According to Kimon Onuma, it is not realistic to “imagine building a Revit model and all its connections.” He further notes that many owners “have their own data base of how they configure and operate,” but with “an open standard you can start creating systems that talk to each other,” handle “complex interconnections,” and eliminate many errors and disconnects.¹⁴

The University should acquire and begin utilizing a web-based software program, such as Onuma Planning Systems (OPS) with an open standard system, that allows users to interact via the Internet, to populate BIM designs with data from simple programs such as Excel and Google Earth, and to contribute designs and information from many different software types integrating it all into a building modeling format.

Firms such as Onuma Inc. have created a specialized business developing tools and engines focusing on helping the owner analyze operational requirements, and perform preliminary analysis before initiating a project. Tools that provide for early planning help the owner make decisions sooner. For instance, the owner

may analyze operational requirements and develop potential options before deciding to hire a Program Architect.¹⁵

Onuma sees architects getting involved with the owner much earlier in a project to provide another perspective instead of reacting to what the owner wants. He notes that:

Some owners are looking at ways to change how they even request information from the architects. So instead of having a whole stack of Excel files, or documents, and saying here's the project we are thinking of doing, actually hand them a BIM data file saying here's all the pieces that we're considering using. Provide your planning part . . . back to us in this format.¹⁶

This repository of information would not be the actual design, estimating, scheduling and analysis software needed to plan, design, construct, maintain and occupy a campus facility. That would still reside with the various project team members. However, the information created by each team member would be added to the repository as the project progresses. In the interim, Cal Poly would need to require the files in their software vendor format, and encourage the use of IFC format software.

Recommendation #3 – Provide, add to and maintain information for all campus buildings and projects in a web-accessible BIM data base.

To improve upon the information provided by the Program Architect to pass onto the Design Architect, it would be beneficial for the information to be in BIM in its original software configuration so that it can be accessed by the Design Team. For example, if the utility maps were provided in a Revit file, it would be easier for the Design Architect to add to the information. This same desire would apply to the room data sheets and cost estimates. Better yet, if the software utilized could be provided in IFC format, then the information added by the Program Architect would be more accurate and save time that could be devoted to analysis of options and systems. As the project repository of information (BIM) continues to grow, the team members would have access to continue to utilize and add to it (Figure15).

Figure 15. Repository of Information, or BIM. Sources: Concept by Author, and Clip Art from Microsoft Office 2003.

When Brent Pilgrim of Beck Technology, an integrated (design and construction) project services firm, begins the conceptual phase, the team members collaborate to prepare a macro-BIM cost model. Together they visualize and document assumptions about the project. While one can expect the assumptions to change later on, project team members know the assumptions, and the project costing can easily be prepared in-line with those assumptions. As the assumptions change, the costs are adjusted.¹⁷

Beck Technology has used DProfiler, a conceptual cost estimating BIM application, for the last three years to visualize, estimate and communicate the project information. The costs are so heavily involved in a project that rarely do they have a budget problem.¹⁸ Tools such as DProfiler in IFC format would allow analysis of building systems, costing (4-D), and construction phasing (5-D) in a more efficient manner saving time and money for all members of the project team.

Recommendation #4 – Clearly define the methods and BIM deliverables.

To encourage the implementation of BIM on projects, a list of specific methods and deliverables should be identified and included in the agreements with the Program Architect, Design Architect, and Contractor, including:

- 1) a requirement to utilize the Integrated Project Delivery approach outlined by the American Institutes of Architects, or the Lean Construction principles used by many construction firms;¹⁹
- 2) the software to be utilized by each participant; and
- 3) a specific list of deliverables.

Rather than asking what BIM capacity a firm has in-house and its number of BIM stations (as is done in the CSU Application for Architectural Prequalification), Cal Poly should take a more active role and clearly define the BIM deliverables desired by the University. Cal Poly should also require that the firms use an integrated project team approach and successfully demonstrate how the software is utilized in developing a project.

¹Brent Pilgrim, telephone interview by author, (26 November 2008).

²Dane Dodd-Hansen, telephone interview by author, (21 November 2008).

³Dodd-Hansen.

⁴Kim Onuma, telephone interview by author, (22 November 2008).

⁵Charles Matta, and Calvin Kam, "The GSA's BIM Pilot Program," <http://www.aia.org/SiteObjects/files/gsa.pdf> (accessed 16 December 2008).

⁶Matta and Kam.

⁷Matta and Kam.

⁸Matta and Kam.

⁹AIA National / AIA California Council, *Integrated Project Delivery: A Guide, version 1*, (The American Institute of Architects, 2007), 7.

¹⁰AIA IPD, 7.

¹¹Christopher Pechacek, telephone interview by author, (26 November 2008).

¹²Pechacek.

¹³Onuma.

¹⁴Onuma.

¹⁵Onuma.

¹⁶Onuma.

¹⁷Pilgrim.

¹⁸Pilgrim.

¹⁹AIA *IPD*, Appendix-Glossary.

CHAPTER 4

Results

Summary

Future of Industry

As experts from architects to contractors weigh in with their opinions, each view BIM as the future of the industry with its advantages and challenges through a different lens. For each, BIM offers increasing analysis and accuracy with efficiencies in time and costs.

Kimon Onuma believes that the construction-side of the industry has been ahead in the use of BIM and in more advanced ways because it affects their bottom line. BIM use has been greatly project-focused with collision detection and highly detailed models.

Chris Pechacek believes that the industry members are dissimilar in implementing and using BIM, and sums up the progress thus far:

I think that the subcontractors are leading it. The general contractors are half a step behind. The structural engineers on the design team are much further ahead than the architects. The owners desire it; they want it; they don't understand it. . . . Hopefully, we have a snowball that is heading down the mountain.¹

Brent Pilgrim predicts that within the next five years the industry will make huge steps forward to being better and more efficient because of BIM tools. His assumptions are based on the adaption rate by architecture firms and other industry firms to the use of Revit, and the suite of products interacting with other products. For instance, he points to Navisworks' benefits and value currently seen by team members during the construction phase. Navisworks allows for viewing 3-D models, simulating 4-D construction schedule, and clash detection. He anticipates that BIM tools will be the standard in the industry, and in five to ten years, this will translate to a data model that will be used for facilities management as well.²

Advantages

Beck Technology is using BIM as a building 3-D communication tool to pull everybody to the same start.³ When Beck begins a project at the conceptual phase, the architecture and construction groups meet and perform a macro-BIM cost model as the project is visualized and communicated to everyone.⁴

Onuma, Inc. is able to offer owners a web-based space, building and project management tool to aid in programming and quick analysis of potential projects. This tool can be used throughout the project as a way to gather, contribute and share project information. Sharing data among users is seen as one of the major benefits of BIM.

BIM is being widely adopted in the construction industry. The McGraw-Hill reports that “over 50% of each survey segment—architect, engineers, contractors, and owners—[are] utilizing the tools at moderate levels or higher.”⁵ Those tracking their return on investment have seen improvements of 100 percent to 1000 percent. Contractors in the two case studies conducted by McGraw-Hill have seen a return on investment of 300 to 500 percent. As firms become more experienced with the use of BIM data, they are more able to leverage data analysis and improve upon their bottom line.

Challenges

Kim Onuma states that the biggest challenge is the “cultural shift.” For example, he notes:

You can have a system that works right before your eyes, but the biggest resistance that you have is entrenched ways of doing things. If a company or group [has been] doing things a certain way for the last 30 years and they are making money . . . I see great resistance.⁶

Onuma explains that the resistance exists because the perception is that it will cut into the company’s contract and profit even when shown that a change will take one-tenth the time. He gives this observation from his experience in encouraging others to embrace BIM:

It's more advantageous for that group to keep doing it inefficiently because that's tied to people working on it and putting hours into it. That goes all the way through contracting and everything. So there is a lot of confusion when these new technologies come around to wanting to make that shift. You can't do it half way. If you start doing things half here and half there, it sometimes works, but if you don't have buy-in from the top down, it doesn't work.⁷

People tend to be focused on producing drawings rather than the information in BIM. Kimon Onuma acknowledges that firms are often "document focused," and even though his firm focuses on the project, they also focus on the system where he sees immense opportunities.⁸ There are Architects who want to become more competitive and efficient internally, and offer clients a different, new specialty based on BIM tools.

Chris Pechacek believes that the biggest winners would be the facility managers, but BIM applications for operating and maintaining facilities are deficient:

I think the injustice is that the facilities management applications have not kept up. So when you look at what is the biggest benefit of having all this information and knowledge, it is for the owners to be able to use that [BIM] to manage their facilities. Currently, owners can do portfolio and asset property management, but not much more software is available.⁹

Initial costs and learning curves may be drawbacks to design firms and this has been the reason most have been slow to adopt software programs such as Revit and ArchiCAD observes Dane Dodd-Hansen. While contractors can save time and money right away, design firms won't see the results for a while.¹⁰

When architects are busy, they don't have time to try new software and adopt new project processes and procedures. Many times in the past, Onuma has tried to get architects interested in working with BIM and OPS, but are told "we don't have the time to even consider this."¹¹

In a survey of architects, engineers, contractors and owners conducted between June 18 and August 8, 2008, by McGraw-Hill Construction, challenges to adoption of BIM included training, costs of software and hardware, staff buy-in and other factors of less frequent concern, such as lack of external incentives, potential risk of losing intellectual property, and liability issues.¹²

Significance for Cal Poly and the CSU

Cal Poly and the CSU should not wait for BIM to become the industry standard and should take a major role in developing ways to incorporate it now. Onuma, Inc. has been using BIM for years to produce the construction documents their way without telling their clients and consultants. Kimon Onuma explains their approach:

We have to identify where all the stake holders have comfort; what their comfort levels [are] with working with the technology, and not push it too far; take baby steps. You can be ahead of the curve by using new processes and new tools that they are not even aware of.¹³

The University is already using BIM and also may not be aware of it. Cal Poly maintains Excel spreadsheets populated with space data, including size and function. Information for the newer buildings is available in CAD files, while older building plans have been scanned and are available in electronic format. Cal Poly also has Campus Standards in electronic format for use by project managers and consultants. This is all information appropriate for BIM. Cal Poly and its consultants share information by posting on a website. Cost estimates and project budgets are produced and shared electronically.

The next step for Cal Poly is to begin collecting all this building information into a database where it can be easily accessed, updated and shared as a project progresses. BIM is not Revit or ArchiCAD; it is so much more. It is all the project information from conception through decommissioning. It is the “Building Information Model.”

Advice for Future Study

Rocks and Boulders

BIM is less about software and more about process. To fully understand the Building Information Model is at best a difficult endeavor. However, one can begin by looking at obstacles and create a plan to conquer each one. Chris Pechacek recommends defining what is of value for a project, and using BIM to eliminate disconnects.¹⁴ For instance, on the Center for Science the architect

was not filling in the gaps for the cost estimators who were forced into making assumptions about the materials and systems. Evaluating the obstacles that prevented the architect from filling in the gaps sooner would be beneficial to the design process. In conquering the constraints on a project, Pechacek suggests getting the big rocks out of the way first and cautions to watch for the small rocks as one will usually “trip over the small rocks” while avoiding “the boulders.”¹⁵

Study Areas

Building information modeling is still a new approach for the construction industry. It is driving changes in how people work, and opening up opportunities for every aspect of the building planning, design, construction, facility management and deconstruction. Each segment of the industry will benefit in numerous ways from BIM. Its potential is only beginning to be explored and promises to be vast. The following recommendations for areas of further study are based on concerns being raised in the industry in implementing building information modeling.

Role of Educators at Colleges and Universities

How are colleges and universities preparing students for a future of BIM? What role should they play, and what is the best way to prepare future graduates?

Industry Standards

What industry standards are being developed to enable the industry to work with BIM? Are there additional areas not yet covered such as sustainability?

Changes to Owner-Architect-Contractor Agreements

What changes are industry organizations and building owners recommending? Owners should determine and make their BIM needs a part of the agreement. Architects, consultants, contractors, subcontractors and suppliers each will have BIM needs, and industry organizations, such as American General Contractors (AGC) and AIA, have already begun making recommendations.

Overcoming Obstacles to BIM

How are organizations overcoming the obstacles in the implementation of BIM? What difficulties have they encountered, and how can others build upon the successes?

Implementing Lean Principles for Planning and Feasibility Studies

What benefits can be derived for Planning and Feasibility from studying and implementing Lean Principles?

Conclusion

During the one year time period spent researching BIM for this thesis, its potential impacts on the future of the construction industry, and how Cal Poly and CSU might begin to take advantage of it, the BIM movement has been gathering momentum. As this thesis was being finalized, CSI issued an announcement on their website that McGraw-Hill Construction had just released a report showing the growing enthusiasm and potential for intensify usage in 2009 of BIM. This statement from the CSI announcement succinctly states the direction of the construction industry:

“Users plan to significantly increase their investment in BIM in 2009 to realize greater productivity, improved communications, and a competitive edge.”¹⁶

CSU and Cal Poly have an opportunity to begin shaping the use of BIM for university projects. Rather than waiting to see what firms can offer in relationship to BIM, Cal Poly should take the approach of determining the information needed to program, design, construct, operate and maintain buildings on the campus in a BIM format, and include the requirements for consultants in their contracts. Program architects should provide information needed by campus, the CSU and the design architect to meet the campus needs. The design architect should provide information needed by the contractor to construct a facility; and finally, the contractor should provide information needed by the campus to operate and maintain a facility.

As the construction industry moves toward integrated project development, campus planning, design and construction will change rapidly. The opportunities

for utilization of BIM continue to increase as the industry realizes additional facets and benefits of the information aspects, the “I” for Information in BIM.

¹Christopher Pechacek, telephone interview by author, (26 November 2008).

²Brent Pilgrim, telephone interview by author, (26 November 2008).

³Pilgrim.

⁴Pilgrim.

⁵McGraw-Hill Construction, “SmartMarket Report on Building Information Modeling: Transforming Design and Construction to Achieve Greater Industry Productivity,” (McGraw-Hill Construction, 2008) http://www.csinet.org/s_csi/sec.asp?TRACKID=&CID=30&DID=16527 (accessed 17 December 2008), 2

⁶ Kimon Onuma, telephone interview by author, (22 November 2008).

⁷ Onuma.

⁸Onuma.

⁹Pechacek.

¹⁰Dane Dodd-Hansen, telephone interview by author, (21 November 2008).

¹¹Onuma.

¹²McGraw-Hill, 9.

¹³Onuma.

¹⁴Pechacek.

¹⁵Pechacek.

¹⁶The Construction Specifications Institute, “BIM Report Shows Growing Demand for Digital Models Training,” http://www.csinet.org/s_csi/sec.asp?TRACKID=&CID=2473&DID=16527 (accessed 17 December 2008).

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APPENDICES

A - Glossary

2-D

A geometric model of an object; a two-dimensional figure on one plane. Often used as components of a 3-D model.

3-D

A geometric model having three dimensions (width, length, and depth).

4-D

Cost estimating information usually tied to a 3-D model.

5-D

Scheduling information usually tied to a 3-D model.

Building Information Model

A Building Information Model, (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. A basis premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder. The BIM is a shared digital representation founded on open standards for interoperability.

Construction Documents Phase

Sets forth, in detail, all aspects of project design, function, and construction. Documents are used for estimating the cost of the project, securing bids for its construction, and directing the contractor during the construction period. Documents include detailed construction drawings and materials and building systems specifications.

Reference: <http://www.calstate.edu/CPDC/SUAM/SUAM9230-9237.pdf>, SUAM 9235

Cost Model

A breakdown of the construction and project budget into detailed “cost targets.” The construction budget is developed in both a detailed Component(s) based format and a CSI based format based on the project’s goals, detailed program and performance requirements. The cost targets are developed collaboratively by the integrated team prior to commencing the conceptualization phase of the project process. The structure provides the benchmark for the team to support continuous cost management as the project progresses to ensure that it will be completed within the targeted budget.

CSI UniFormat

UniFormat, a publication of CSI and CSC, is the Uniform Classification System for organizing preliminary construction information into a standard order or sequence on the basis of functional elements. Functional elements often referred to as systems or assemblies, are major components common to most buildings that usually perform a given function regardless of the design specifications, construction method, or materials used. UniFormat users can easily understand and compare information since it is linked to a standardized elemental classification structure. The use of UniFormat can provide consistent comparable data across an entire building life cycle. The use of its elemental framework reduces the time and cost of evaluating alternatives in the early design stages of a project, assuring faster and more accurate economic analysis of alternative design decisions.

Website: http://www.csinet.org/s_csi/sec.asp?CID=1379&DID=11342

Design Development Phase

Confirms or adjusts all aspects of the schematic plans (exterior design, mechanical and electrical systems, telecommunications system, structural systems, area arrangements, foundation plans, etc. Documents include plans, outline specifications and cost estimates developed in further detail than schematic documents.

Reference: <http://www.calstate.edu/CPDC/SUAM/SUAM9230-9237.pdf>, SUAM 9234

DProfiler

DProfiler, developed by Beck Technology, is a macro Building Information Modeling (BIM) program, integrating 3D modeling with conceptual cost estimating, integrated energy analysis, and export capabilities. The platform is aimed at reducing rework due to late-stage design changes.

Website: <http://www.beck-technology.com/index.asp>

GIS

A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows for an individual to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts.

Website: <http://www.gis.com/>

Integrated Project Coordinator

An individual responsible for overall facilitation, coordination and direction of the integrated team. This role may or may not shift among members of the team depending on delivery model and project phase. Leadership and consensus building skills are critical to this role. In some instances, this role may be filled by an outside party.

Lean Construction

Lean construction is a translation and adaption of lean manufacturing principles and practices to the end-to-end design and construction process. Unlike manufacturing, construction is a project based-production process. Lean construction is concerned with the holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, salvaging, and recycling. This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs.

Website: http://en.wikipedia.org/wiki/Lean_Construction

Key Supporting Participant

A person or organization whose contribution is critically necessary to achieve project goals but is not a primary participant.

Integration

The coming together of primary participations (which could include owner, design, constructor, design consultants, and trade contractors, key systems suppliers, etc.) at the beginning of a project, for the purpose of designing and constructing the project together as a team.

Navisworks®

Software from Autodesk® to help control, collaborate and aggregate information on project models for viewing and analyzing digital information. Features allow navigation and exploration of design, identification, inspection, and reporting of potential interferences in a 3-D project model.

Website: <http://usa.autodesk.com/adsk/servlet/index?id=10571060&siteID=123112>

Open Interoperability Standards

Non-proprietary protocols and data structures that support the exchange or joint use of digital information by different software tools.

ONUMA Planning System™ (OPS)

A web-enabled planning, programming and project system developed by Onuma, Inc.

Website: <http://www.onuma.com/products/OnumaPlanningSystem.php>

Primary Participant

Core group of team members involved in and responsible for the project from inception through completion.

Project Delivery Methods

“Project delivery is the contractual relationships between the owner, architect/engineer, contractor, and the management services utilized to design and construction a project. Project delivery methods include design-bid build, design-negotiate-build, design-build, construction manager, or owner-build. Each delivery method can have variations in types of contract payment (such as lump sum, unit price, and cost-plus), scheduling (such as fast-track), and number of contracts (such as single or multiple-prime contracts.)”

Reference: The Construction Specifications Institute. The Project Resource Manual-CSI Manual of Practice, Fifth Edition. New York: McGraw-Hill, 2005; 3.1.

Project Phases

Development of a facility requires a number of project steps or phases from initial project conception through occupancy. Typical project stages in sequence are Programming, Schematic Design, Design Development, Construction Documents, Bidding or Negotiations, Construction, and Occupancy.

Reference: The Construction Specifications Institute. The Project Resource Manual-CSI Manual of Practice, Fifth Edition. New York: McGraw-Hill, 2005.

Reverse Phase Scheduling

Phase scheduling that maximizes value generation, is understood and supported by everyone involved, defines specific handoffs between work groups, and is developed working backwards from the completion date incorporating interim milestones.

Website: [http://p2sl.berkeley.edu/2008-04-30/1%20-%20Ballard%20-%20Phase%20Scheduling.ppt#271,11,Phase Scheduling Process](http://p2sl.berkeley.edu/2008-04-30/1%20-%20Ballard%20-%20Phase%20Scheduling.ppt#271,11,Phase%20Scheduling%20Process) (accessed 17 December 2008)

Revit®

Building design software for building information modeling (BIM). Changes are automatically coordinated throughout a project. The software allows for quick and easy changes to major compositional elements, to create comprehensive design proposals, and to view ideas on the fly with 3-D views.

Website:

<http://usa.autodesk.com/adsk/servlet/index?id=3781831&siteID=123112>

Schematic Design Phase

Interprets the project requirements to show relationship of the facility to the site, other buildings, and the campus; exterior design of the facility; relationship of interior areas; materials to be used in construction; types of structural, mechanical, electrical, and telecommunication systems to be utilized; construction cost; and life cycle cost analysis. Documents include drawings, outline specifications and cost estimates.

Reference: <http://www.calstate.edu/CPDC/SUAM/SUAM9230-9237.pdf> SUAM 9233

Solibri

Solibri, Inc. develops and provides software that automates the BIM model checking, design review, analysis and code checking process.

Website: <http://www.solibri.com/>

Vision Statement

A vision statement outlines what the project wants to be. It concentrates on the future, is a source of inspiration, and provides clear decision-making criteria.