Construction Industry Institute®

Building Information Modeling Project Execution Planning Research Project

Computer Integrated Construction Research Group

The Pennsylvania State University

Research Report RES-CPF 2010-11

Construction Industry Institute

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BUILDING INFORMATION MODELING
PROJECT EXECUTION PLANNING
RESEARCH PROJECT

by

Computer Integrated Construction Research Group
The Pennsylvania State University

A buildingSMART alliance™ Project

Sponsored by:

The Charles Pankow Foundation

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A Report to
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EXECUTIVE SUMMARY:

This document describes a detailed description of the process used to complete the research to develop the BIM Project Execution Planning Guide and the related resources. The Guide was developed through a multistep research procedure that included a detailed literature review; industry expert interviews; focus group meetings; quasi-experiments; surveys; and fundamental process and information mapping tasks. After the Guide was developed, it was implemented on several case study projects to evaluate the ease of implementation and identify areas for improving the core planning procure documented in the Guide. It was also released for public comment with over 3,250 downloads from the project website.

The research goal as defined in the original project proposal is to develop and broadly disseminate a method to create a BIM Execution Plan in the early stages of a building project. The execution plan defines the scope of BIM implementation on a project, the team characteristics needed to achieve the modeling, the process impacts of using BIM, contract recommendations for BIM implementation, and the value proposition for the appropriate level of modeling at the various stages in the project lifecycle. The research objectives for the project include:

1) Identification of BIM methods and implementation strategies organized by project phase (planning, design, construction, and operations) and the definition of potential benefits, costs, and strategies for adopting these methods;
2) Develop the implementation guidelines and best practices for BIM implementation at various stages in the project; and
3) Disseminate the results through A) a BIM Execution Planning Guide; B) execution planning templates that will lead a project team through the collaborative planning process; C) presentations at buildingSMART, CII and other national conferences, e.g., AIA, BIM Forum, DBIA; D) a CII research summary and CII research report; and E) articles in industry and academic publications.

To achieve the research goal and objectives, the following research steps were conducted:

- Conduct Detailed Literature Review;
- Perform Industry Interviews to Define Primary BIM Uses;
- Develop the Draft BIM Project Execution Planning Procedure;
- Validation the BIM Project Execution Planning Procedure; and
- Revise and Update the Procedure, Guide and Templates.

The research methodology used throughout this study focused on the development and assessment of a comprehensive planning method which leverages information and input from many sources. The procedure is grounded in fundamental business process management techniques and lean theory for information management with targeted adaptations to meet the needs of planning the implementation of BIM throughout the project lifecycle. The procedure was tested through an extensive case study evaluation along with industry surveys and feedback. We received a large number of comments from industry members, both formal and informal, regarding the guide and the corresponding templates which have ultimately added to the quality of the final product of this research.

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CHAPTER 1: INTRODUCTION

The implementation of Building Information Modeling (BIM) in the Architecture, Engineering and Construction (AEC) industry is still in its formative stages. Today, project organizations suffer from the incompatibilities between information content and the data formats created by different stakeholders. Practitioners have reported that incompatibilities arise when users deploy different versions or apply different configurations of the same software. More importantly, the selection of a single software platform does not resolve the question of the required Building Information Model content. Additionally, in order to achieve the goal of interoperability, there is a need to define what information should be transferred, to whom and when. There is also a need to develop new methods to integrate processes which are facilitated by the use of BIM. The challenge thus lies in availing the widespread use of BIM to the extent possible and economical, which is deepened by the lack of a consistent BIM implementation procedure.

Implementation of Building Information Modeling (BIM) on a project level requires comprehensive planning by facility owners and project participants (designers, contractors, subcontractors, and manufacturers) to ensure successful transition from a traditional approach to incorporating this new technology into the project workflow. The current status of BIM reports a lack of planning in general, and limited guidelines available for team members involved in the process. This typically leads to BIM being used for targeted tasks, but not implemented throughout the lifecycle of a building. This is contrary to how BIM was conceived and it does not allow the new technology to reach its full potential in industry construction projects. A possible solution to the problem is to provide the early project team with a means for planning successful implementation of BIM throughout the various stages of the project (planning, design, construction, operations).

This project focused on the development of the BIM Project Execution Planning Procedure, Guide and Resources through a multi-step research process which included interviews with over 40 industry experts, detailed analysis of existing planning documents, focus group meetings with industry participants, process mapping research to design an efficient and effective mapping structure, and case study research to validate the procedure.

1.1 PROJECT EXECUTION PLANNING PROCEDURE FOR BUILDING INFORMATION MODELING

The last several years have seen a tremendous change in the awareness of architects, contractors and owners to factors beyond construction cost and 3D coordination (Hartmann and Fischer 2008). BIM has greatly impacted the industry as it enables better collaboration and information sharing (Gallaher et al. 2004), and reduces the time of construction (Suermann and Issa 2007). The eConstruction Roundtable held at New Orleans 2007 established that the owner community has begun to realize the potential of BIM to better manage projects with the objectives of reducing the life cycle cost and improving the overall quality of a facility (Hartmann and Fischer 2008).

Despite this vision, few project teams have been able to utilize the benefits of BIM to their fullest extent. It was further commented that some of the obstacles in achieving this have been the lack of knowledge in implementing BIM and the current project delivery process. A potential solution to this would be to provide the project team with a project execution plan for implementing BIM throughout the various stages of the project life cycle. Thus the, Project Execution Planning Procedure for Building Information Modeling would benefit both the facility owners and project team members.

The development of BIM is flourishing, yet there are some problems in the way it is implemented. These problems are primarily related to a lack of sharing of information between lifecycle phases since many practitioners are still focused on their phase(s) of the project and fail to recognize their stewardship role in the overall lifecycle of the facility. For BIM to be fully implemented and its potential fully realized, it must allow for the flow of information from one phase to the next, from inception onward (National Institute of Building Sciences 2007). This can only be achieved effectively through open standards, such as the Industry Foundation Classes (IFCs) for exchanging building information. However, direct use of IFCs alone is not possible. It is also important to note, that the decision of implementing BIM on a project is often dependent on the project characteristics, the parties involved, commitments, situations and challenges on a project or within the company. Agreements among stakeholder representatives must be created to define what specific information is to be provided by whom, to whom, and when.

The BIM Project Execution Procedure outlines a four-step method to develop a detailed implementation plan. The procedure was designed to guide owners, program managers, and early project participants through a structured process to develop detailed and consistent plans for projects. A goal of the BIM Project Execution Plan (hereinafter referred to as 'BIM Plan') is to steer the project team in making the implementation decisions early on, and to assist in a smooth transition between various parties involved during the different project phases. In doing so, it is critical that the BIM Plan is not developed in isolation. No one party within a construction project can adequately outline the execution plan while also obtaining the necessary team member commitments to BIM implementation. The team must conduct a series of planning meetings to develop the execution plan. This will make it easier for teams to accurately plan the execution strategy on a project.

If all organizations map their standard processes (refer to Figure 1.1), then the procedure is a design task, which compiles the different work processes from the various team members. It will also make it easier for team members including the owner to quickly and effectively understand and evaluate the execution plans since they will be organized in a standard format with consistent information.

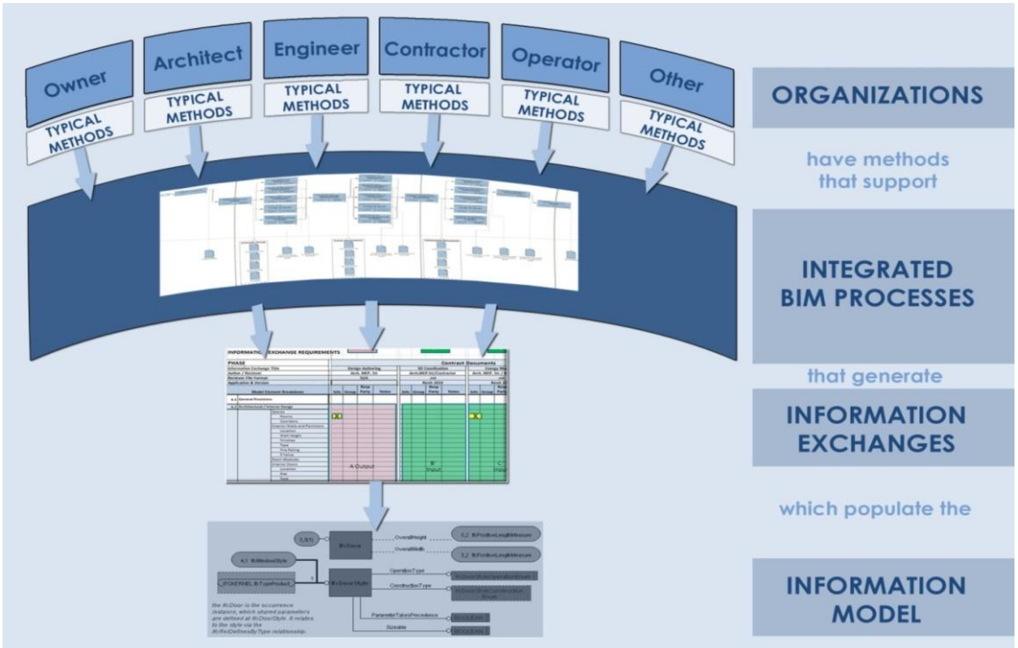


Figure 1.1: BIM Project Execution Planning Concept

1.2 Research Goal

The research goal for the BIM Project Execution Planning is to investigate the use of Building Information Modeling in the Architecture, Engineering and Construction (AEC) Industry and develop and disseminate a method to create a BIM Project Execution Plan in the early stages of a building project.

This research includes creating a taxonomy for BIM Uses, which is achieved by completing and analyzing expert interviews after performing detailed content analysis of available literature on BIM and its uses. The research also includes developing a BIM Process Mapping (PM) Procedure for planning the BIM implementation on a project. This includes a procedure to create the BIM PM (Step 2) and the design of the BIM Information Exchanges (IE) (Step 3). BIM PMs allow the team to understand the overall BIM process, and identify the information that will be exchanged between various parties, and clearly define the various processes to be performed for the identified BIM Uses. BIM IEs establish the information which is necessary to execute each BIM Use. Additionally the research contributes to creating structure for other supporting infrastructure (Step 4) necessary to complete a BIM project. The goal of the research project is to create a technique, which allows the team to efficiently perform these project execution procedure steps

1.3 Scope of Work

The project execution planning procedure was developed to encompass all phases of a capital facility project. The primary focus of the procedure targeted commercial building design and construction, but the procedure could be applied to a variety of facility types. The procedure is specifically focused on a project perspective, and designing a process that is efficient and effective from a project viewpoint. There have been companies who have also adapted the procedure to investigate a company or organizational perspective. The procedure also remains vendor neutral so that no specific software application or company is recommended throughout the research.

1.4 Research Objectives

The following research objectives were identified for the BIM Project Execution Procedure Project:

1. Identify BIM uses along with methods and implementation strategies in different project design phases.
2. Develop BIM use information sheets by listing their goal, objective, description, and benefits to be used as part of BIM Execution Planning Guide.
3. Develop a BIM Process Mapping Procedure: A procedure is developed which gives step-by-step instructions on how to create a BIM PM and IE. This procedure provides complete directions on how to quickly create a PM and fill out the IE worksheet.
4. Develop a structure for Defining Supporting Infrastructure for BIM Implementation.
5. Validate the BIM Project Execution Planning Procedure: Once the procedure was established, it was necessary to validate it. To accomplish this task, quasi-experiments, template maps, interviews, surveys and a case study validation were completed.

1.5 Integration of the Research Work with the NBIMS

The National Building Information Modeling Standard™ (NBIMS) is currently being developed by the buildingSMART alliance™, the North American Chapter of the buildingSMART International Ltd. The goal of the NBIMS is to identify and define standard IEs that are required on facility projects. The BIM Plan Procedure is designed to complement the standard exchange requirements under development in the NBIMS initiative. It will also make it easier for team members including the owner to quickly and effectively understand and evaluate the developed execution plans because they will be organized in a standard format with consistent information.

CHAPTER 2: RESEARCH METHODS

This chapter describes the detailed research methods used to create each step of the BIM Project Execution Procedure, Guide and Resources. This research project used qualitative and quantitative research methods performed through literature review, surveys and case study evaluations for developing and assessing the BIM Uses, the Process Maps (PMs), Information Exchanges (IEs), the Supporting Infrastructure for BIM Project Execution. The methods are further discussed to provide an explanation and justification for their selection. Several different research techniques were used in this study, and the rationale for their use is explained. The techniques, literature review, interviews and content analysis, are briefly described along with the research process performed.

2.1 BIM PROJECT EXECUTION PLANNING PROCEDURE RESEARCH STEPS:

The following research steps were used in the development of the BIM Project Execution Planning Procedure.

1. Reviewed available literature and resources;
2. Developed interview questions to identify current and future uses of BIM from industry experts;
3. Conducted interviews to identify BIM uses;
4. Analyzed the industry interviews through detailed content analysis, resulting in a list of BIM uses along with preliminary information for each;
5. Developed interview questions to investigate each BIM use;
6. Conducted interviews to gain further information for each BIM use;
7. Compiled BIM Use information descriptions from the interview results and the literature;
8. Developed the BIM Planning design process from business process mapping concepts;
9. Developed a method for representing information exchanges for shared information content between project participants; and
10. Identified BIM Execution Plan content through an analysis of industry interviews and an analysis of existing and proposed execution planning structures.

Once developed, the BIM Project Execution Planning Procedure was validated through quasi-experiments, surveys of Guide readers, and a series of case studies. These case studies focused on the implementation of the planning procedure for two primary audiences. First, the research team worked with project teams in the early stages of planning and design to create a BIM Project Execution Plan for the selected projects. Second, the research team worked with large owners to develop BIM Project Execution Planning Guidelines for adoption as requirements for future BIM Plan submissions. The results of each case study were documented and analyzed for potential improvements and modifications to the BIM Project Execution Guide and supporting templates to better support the two applications.

2.2 IDENTIFYING USES OF BIM

After a focused literature review on various BIM topics, interviews with design professionals, industry experts and BIM champions were conducted; and their perspectives and opinions of using this new technology were analyzed. Important lessons learned, success stories, and recommendations were documented from these interviews. The data received was summarized and conclusions were drawn with the purpose of being incorporated in the BIM Use taxonomy.

The following research steps were performed for this task:

1. Literature Review
2. Semi-structured Interviews
3. Content Analysis
4. BIM Uses Taxonomy.

2.2.1 Research Techniques for BIM Use Analysis

Since this research is exploratory in nature, social science research techniques have been chosen. These research techniques include literature review, expert interviews and content analysis. The data collected is qualitative in nature with some data collected that can be quantitatively analyzed.

An exploratory research strategy was selected because it is a good approach when (Marshall and Rossman, 1999):

- Investigating little understood phenomena,
- Identifying or discovering important variables, and
- Generating hypotheses for further research.

For an exploratory study, the research strategies used, literature review and interviews, were found to be the most appropriate since the project was operating in discovery, and not verification mode (Guba and Lincoln, 1981).

An interview is a qualitative method of data collection, where the interviewer asks the questions of interest either in person, over the phone or through some other form of communication. There are several forms of interviews that were considered for this research: structured, semi-structured and open-ended interviews (Yin, 1999).

1. Structured Interviews: This type of interview is close to a questionnaire survey in a sense that all the questions are carefully structured and ordered, and can have a limited number of possible responses choices.
2. Semi-structured Interviews: The interviewer follows a set of questions that need to be answered to collect data for a study. The respondents are free to talk but their discussion is guided and geared towards exploration rather than verification of the facts or hypotheses. The questions need to be carefully worded and delivered in a way to eliminate bias but yield useful insight. This type of interview was selected for the study at hand.
3. Open-ended Interview: The interviewees are asked about the facts, their opinions and suggestions; but are allowed to talk freely about the subject at hand and direct the interview since there are no strict guidelines about the information that needs to be collected.

The last technique used was a content analysis. Content analysis is an accepted technique of systematically analyzing data obtained through qualitative research (Holsti, 1969). As a research method, it was created to investigate and draw inferences from the content of conversation or verbal communication between participants. It can be described as information processing in which content is transformed, through objective and systematic application of categorization rules, into data that can be summarized and compared (Holsti, 1969). Some of the characteristics of content analysis based on Holsti (1969) and Guba and Lincoln (1981) that were used in this study are objectivity, systematic approach and generality.

2.2.2 Literature Review

This research began with a review of the available references on BIM implementation in practice. The literature review is intended to clarify the definition of Building Information Modeling so its uses can be clearly identified along with identifying various topics on BIM, its current status, challenges and success factors. Review was performed from the industry aspect including impact of BIM on design, issues, benefits, startup costs, cost-benefit ratio, return on investment, legal liabilities, contractual and organizational arrangements, best practices, lessons learned and critical success factors. The published research referenced in the literature review was in the form of journal papers, BIM guides and various expert articles on the topic.

2.2.3 Semi-Structured Interviews

The purpose of conducting interviews was to gain a better understanding of the issues that project teams face during BIM implementation in the design phase of a project. They outlined previous experiences, current best practices, major challenges, lessons learned, and the success factors for implementing BIM. Detailed results from the interviews are presented, along with the initial taxonomy for the BIM uses in the design process, as well as a discussion of the integration with other project stages and future research steps.

A draft list of questions was identified after the review of the available literature and brainstorming sessions with the Computer Integrated Construction (CIC) team members, also members of the BIM Execution Planning research project team. A draft of the interview questions was posted online for feedback and comments from buildingSMART Alliance team members. The outline of the interview questions was also presented at the buildingSMART project meeting. Based on the input from the team members, the interview questions were modified, and then pretested in two pilot interviews with industry members with expertise on the subject. The final set of questions was established based on the results from these two interviews and feedback received.

In-depth interviews which followed were performed with designers experienced in implementing BIM. The interview technique selected was semi-structured interviews, where the goal was not to get representative or typical responses like in structured interviews, but at the same time the qualitative data collected from the interviews has a certain structure. The interviewees were free to talk about the subject, but the discussion was guided so that the data collected could be analyzed, summarized and then reported. The rationale for selecting the semi-structured form of interview was that the interviewer was interested in pursuing this subject in depth, was dealing with experts who have special knowledge and was operating in discovery, rather than verification mode (Guba and Lincoln, 1981). In this manner, the interviewer's bias is reduced and semi-structured interviews allow the interviewee to lead the conversation and provide their own input on the topic outside of the interview's framework.

2.2.4 Interviews' Candidates: Selection of Interviewees

Several criteria were used to select the participants for the study. The industry participants were limited to architects or engineers having at least one or more years of experience with implementing BIM, as well as an interest in being part of this study and sharing their experiences. This provided a wide range and a broad perspective of implementation strategies and experiences with BIM. First, a list of possible design offices or companies was developed based on the literature review of the published expert articles and previous BIM experiences with the help and suggestions of the BIM Execution Planning and CIC Research Group members. Another list was compiled based on the local Washington DC Metro Area BIM users group that meet once a month to exchange experiences and discuss new technology implementation. The last list, retrieved from The Clark Construction Group database, courtesy of their BIM Group and Marketing and Communications Department, was populated with the names of the consultants and business partners knowledgeable and experienced in BIM. A final list was compiled with approximately one hundred names of industry participants. All potential interviewees were contacted via e-mail, with an invitation for participation in the research, which was followed by phone calls within a week after the invitations were sent. This approach yielded many positive responses and resulted in over 40 interveiws scheduled and conducted from August through November of 2008.

2.2.5 Interview Process/Procedure

In-depth interviews with designers, contractors and owners experienced with BIM implementation were conducted over a period of four months using a semi-structured interview format. The participant's permission to audio record was requested before the start of the interview and an Institutional Review Board (IRB) form, for protecting the rights and welfare of participants, was shared. The participants were briefed about the scope of the research, informed of its larger picture, and ensured about confidentiality of the data collected. Most interviews lasted between 45 minutes and one hour. The interview questions were categorized into six sections: Background Information, BIM Execution Planning, BIM Uses in Design, BIM Impact, Case Study, and Concluding Questions.

Background information focused on the position and responsibilities of the interviewees and their previous experience with BIM implementation. The BIM Execution Plan questions determined if a plan for implementation typically exists, and what were some of the major decisions and process steps. They identified major uses and answered questions about model detail and content, process, applications, team competencies, legal issues, insurance and contract considerations. A BIM Impact series of questions collected information on possible metrics and results, along with impact on time, cost, quality, and changes in staff. Major success factors, issues, concerns and risks were also collected. Case Study questions identified potential projects and studies that can be done in the future. Concluding Questions finished the interview with future trends, additional comments and references to other firms or experts. The questions extended beyond the scope of BIM uses for the purpose of achieving the secondary goal of the research which is to provide a broad overview of BIM implementation in practice.

The interviews were performed in person or via phone with one written response. The written response gave a chance to the interviewee to consider questions longer, but also was under scrutiny of upper management who read and approved the responses. The email response to the questions was one of the shortest set of responses, but included assumed revisions from the management and offered few pieces of information. The interviews conducted over the phone, were more to the point, but shorter in length and less revealing than the ones performed in person. This approach is faster at obtaining information, but the interview period was short and impersonal. The face-to-face interviews provide some control over the interview process, but have a higher risk of the interviewer's bias, more so then interview done in written form or over the phone.

Interviewer's bias was reduced by asking open-ended questions that do not require an answer within the researcher's framework, and also navigating the interview, but not offering judgments or leading the answer. Proper measures were taken to avoid bias during the interviews by carefully composing the questions and the delivery. The wording and delivery of the questions was kept as neutral as possible. An additional measure to reduce bias was taken by systematically analyzing the qualitative data using the content analysis procedure, and being objective while analyzing and interpreting the responses given (Simon and Burstein, 1985). The interviews were also audio recorded and transcribed for future reference. Recording the interviews aided accuracy of data collection and interpretation since all the interviews were transcribed and mind mapped in order to be summarized and used for content analysis on a later note which ensures reliability.

2.2.6 Content Analysis

The interviews collected were systematically interpreted according to similar classification categories depending on the topic at hand. A content analysis was performed for each of the interviews conducted. With this approach, communication content was transformed by applying categorization rules systematically and objectively into data that can be classified, summarized and compared (Holsti, 1969). All the interviews were transcribed from the audio recordings, and then the most frequent concepts were identified, grouped and organized with establishing possible relationships or connections.

2.3 **Defining the BIM Process**

Many researchers and practitioners have documented that BIM is a new approach in practice for sharing and communicating the required information for the design, construction and operation of facilities (Eastman et al. 2008; Jernigan 2007; Smith and Tardiff 2009). It is moving the industry from traditional paper based communications towards an integrated process in which the tasks have been collapsed into a collaborative process that maximizes web communication and computing capabilities into information capture (National Institute of Building Sciences 2007). However, to use BIM effectively, the quality of communication between different participants and tasks in the construction industry needs significant improvement, which lays the premise for the research. To make the information exchange between project participants more reliable and improve information quality, there is an urgent need to address the evolution of information for important BIM related processes throughout the project life cycle. Many BIM processes and applications have been discussed through single case studies, and white papers provided by specific vendors (Autodesk White Paper 2002; Bentley and Workman 2003; Eastman et al. 2008; Leicht and Messner 2008; Messner and Lynch 2002; Smith and Tardiff 2009; Staub-French and Khanzode 2007). Though it is fascinating to learn about the cases and anecdotes, it is important to develop an implementation procedure in the form of a process flow that has a common structure which is applicable across many projects.

2.3.1 Research Process

The following steps define the research process adopted to accomplish the process mapping objectives, (see Figure 2.1).

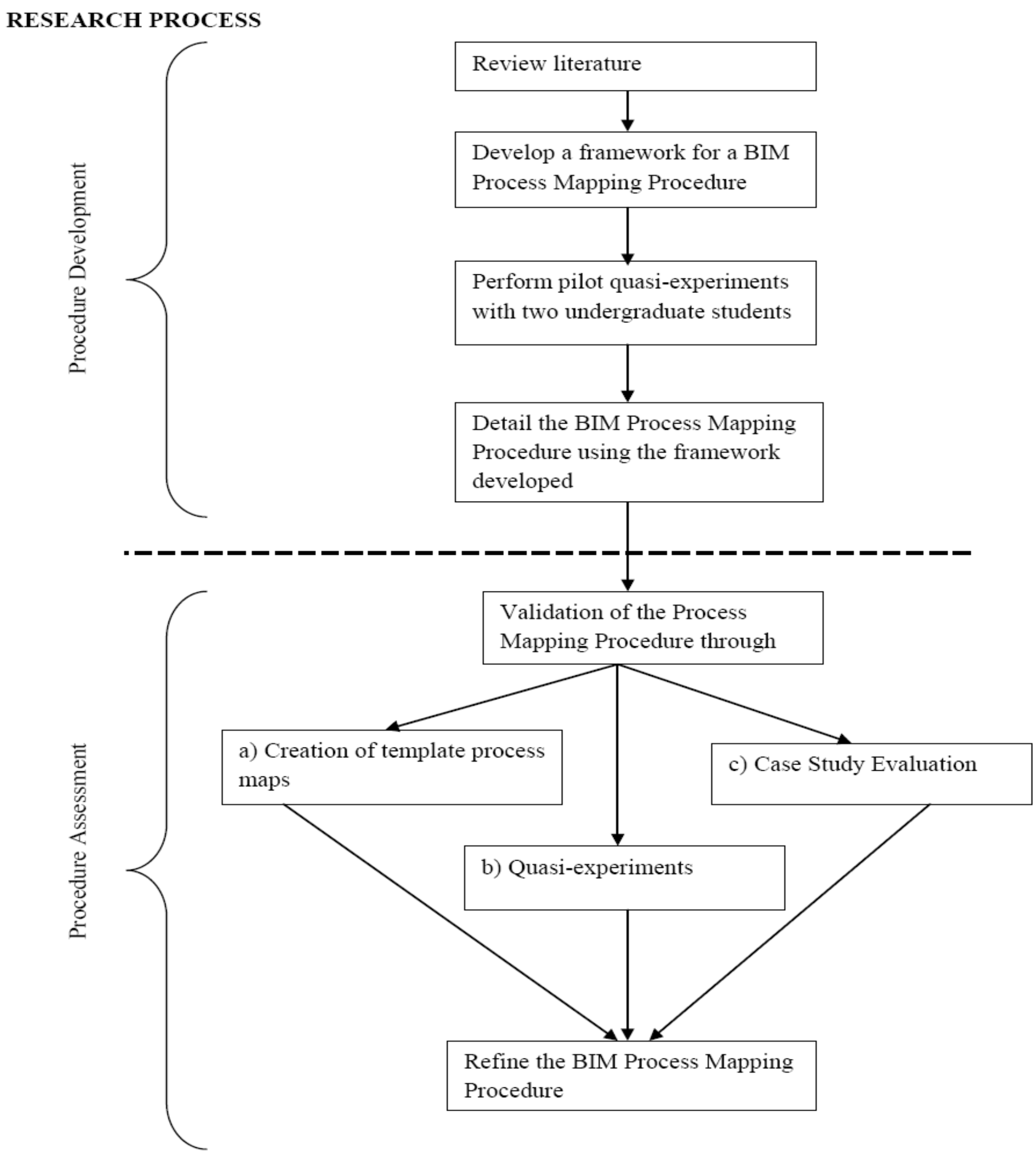


Figure 2.1: Research process for BIM Process Mapping Procedure development and assessment

2.3.1.1 BIM Process Mapping Procedure Definition and Development

Literature was reviewed for information on the use of process mapping and the several different models of process modeling in the construction industry. Additionally, literature was reviewed in the areas of advancements in the exchange of building product data, and several types of BIM execution plans currently being implemented in the building industry.

Following the literature review, relevant BIM Process Mapping Procedure components were defined. First, components for the PM were developed (*activity, resource, result and agent*). Next, a strategy was established to develop the Procedure to create a PM. This strategy led to the definition of the Process Mapping Procedure steps. These steps were then represented using the Building Process Modeling Notation (BPMN) framework, which was selected as the modeling methodology to represent the Template PMs. On a separate track, the components identified for IE (*model element breakdown, information content, and responsible party*) were developed to define the BIM deliverables. The outcome of this step is a preliminary definition of the BIM Process Mapping Procedure.

Two pilot quasi-experiments were conducted to further refine the Process Mapping Procedure steps. Two undergraduate students from the Department of Architectural Engineering at Penn State as part of their undergraduate work developed a PM for 3D MEP Coordination and 4D Modeling using the developed Process Mapping Procedure. The steps and the BPMN representation of the Procedure were consistently refined over a period of two months in response to the feedback received. The revisions were aimed in making the Procedure easily understandable and providing clear and concise instructions to develop a PM.

2.3.1.2 BIM Process Mapping Procedure Assessment

Having established a BIM Process Mapping Procedure, the next task was to validate the procedure. The Procedure was assessed in three different manners.

The first focused on the assessment of the developed procedure steps to create a BIM PM for a selected BIM Use. This was accomplished by conducting quasi-experiments for a larger sample of participants. This assessment was completed to determine the comprehensiveness of the Process Mapping Procedure steps and its BPMN representation.

The second assessment of the BIM Process Mapping Procedure was performed through the mapping of a case study project. This was done to ensure that the Procedure was comprehensive, and to determine if the information produced with the created BIM PMs and IEs was understandable.

The third assessment of the BIM Process Mapping Procedure was completed by developing Template PMs. The Template Maps are generic maps which outline a set of sequential activities that need to be performed to accomplish a BIM Use. Template PMs were created for five different BIM Uses; which identify the reference information content, contain a logical sequence of activities to complete a BIM Use, and show IEs required internally or between responsible parties to accomplish the task. This was completed to ensure that the BIM Process Mapping Procedure was effective in showing how the detailed processes relate to a particular organization or in some cases several organizations.

2.3.2 Research Techniques

2.3.2.1 Quasi-experiment

Cook and Campbell (1979) pointed out that quasi-experiments are “experiments that have treatments, outcome measures, and experimental units like true experiments; but do not use random assignment to create comparative studies.” The term quasi-experiments is used in situations in which the experimenter cannot randomly assign subjects to experimental groups, but the performance can still be manipulated through a set of metrics (Corbetta 2003).

For this study, the task for the participants was to create a BIM Use PM. These BIM Uses were not randomly assigned. The PM created at the completion of the task was studied and the observed deviations were documented as part of content analysis.

2.3.2.1.1 Data Collection: Questionnaire

Data for the quasi-experiment was primarily collected through a questionnaire. The questionnaire is a widely used and useful instrument for collecting survey information; providing structured, often numerical data, and often being comparatively straightforward to analyze (Cohen et al. 2007). There are several kinds of questionnaire items, including, dichotomous questions, multiple choice questions, rating scales, constant sum questions, ratio data and open ended questions (Cohen et al. 2007). In general closed questions, e.g. multiple choice and rating scales are quick to complete and simple to analyze. On the other hand, these questions do not enable respondents to add remarks, qualifications and explanations to the categories, and there is a risk that the categories might not be exhaustive and may be biased (Oppenheim 1992). Open questions, however, enable participants to write a free account in their own terms and avoid the limitations of pre-set categories (Cohen et al. 2007).

A rating scale is a closed type of questionnaire, widely used in research, combining the opportunity for a flexible response with the ability to determine frequencies, correlations and other forms of quantitative analysis. Cohen et al. (2007) argues that though rating scales are powerful and useful in research, it is important to be aware of their limitations.

For this study, at the end of the quasi-experiment, the participants were asked to complete a questionnaire survey with rating scale type questions to gain insight on the ease of creating a PMs using the Process Mapping Procedure, and if this Procedure assisted in the generation of additional ideas. Another section of open ended questions was also added which mainly asked for feedback related to the Procedure or additional instructions to improve the Procedure to which the respondents could reply in their own terms and opinion.

2.3.2.1.2 Content Analysis

Krippendorff (2004) defines content analysis as a research technique for making replicable and valid inferences from texts or other meaningful matter to the contexts of their use. As a research technique, content analysis provides new insights, increasing the researcher’s understanding of a particular phenomenon. Krippendorff (2004) further elaborates that every text requires a context on which it will be examined.

For this study, the PMs produced by the participants at the end of the quasi-experiment were analyzed. All the participants created a PM for their chosen BIM use using the Procedure steps in a BPMN application. The objective of the content analysis, as applied in this study, was to verify if the Procedure steps were or were not followed by the participants. Additionally, with careful scrutiny, the researcher documented the irregularities observed in the produced PMs and redefined the Procedure to more clearly define the topic in an attempt to address most of these observed irregularities.

2.3.2.2 Case Study

Yin (2003) points out that the case study method has been a common research methodology, used on many situations, 'to contribute to the knowledge of individual, group, organizational, social, political, social and related phenomena'. Yin (2003) further suggests that the case study research is very useful where (1) the research question typically answers to 'how' or 'why', (2) the investigator has a little/no possibility to control the events, and (3) the focus of the study is contemporary phenomenon in a real-life context. In this study, the research question addresses 'how' projects can utilize BIM Process Mapping Procedure. Also, since the real world decisions of BIM implementation for the case study project is discussed, the researcher did not have much control over the variables of investigation.

Case studies typically combine data collection methods such as archives, interviews, questionnaires, and observations. The evidence may be qualitative (e.g., words), quantitative (e.g., numbers) or both (Eisenhardt 1989).

Finally, case studies can be used to accomplish various aims: to provide description, and to test or generate theory (Eisenhardt 1989). The interest here is in the second aim of testing a theory. The goal of the case study was to use historical mapping technique to validate the BIM Project Mapping Procedure.

2.3.2.2.1 Data Collection for the Case Study Project

Yin (2003) identifies six sources of evidence that can be collected during case studies:

- Documents;
- Archival records;
- Interviews;
- Direct observations;
- Participant observation; and
- Physical artifacts.

For this study, evidence was collected via document access and direct observations. Yin (2003) recommends "documentation as stable evidence because it can be reviewed repeatedly, it is unobtrusive, it is exact and it has a broad coverage." However, it can also be "difficult to retrieve; the selection and reporting can be biased; and the access can deliberately be blocked." On the other hand; "direct observations have the advantage of being real-time and contextual, but they can be time consuming, selective, the observed event may react different due to the observation, and is time consuming."

The researcher attended several (about ten) of the weekly design coordination meetings starting from the BIM coordination kickoff meeting. The BIM Coordinator for the case study project also made the necessary documentation available throughout the course of the study.

2.3.2.2.2 Data Analysis for the Case Study Project

Data analysis in case study research consists of three concurrent flows of action: data reduction, data display, and conclusions and verification (Miles and Huberman 1994). For this study, the collected data was methodologically analyzed and linked to the BIM Process Mapping Procedure to produce a set of PMs and corresponding IEs. The documentation produced for the case study was later approved by the Project Manager and the BIM Coordinator for interpretation and accuracy.

2.3.3 METHODS OF VALIDATING THE BIM PROCESS MAPPING PROCEDURE

During the course of this study, three methods were adopted to validate the BIM Process Mapping Procedure:

1. **Quasi-experiments**: To ensure if the Procedure steps and the BPMN representation of the Process Mapping Procedure were self explanatory, quasi-experiments were conducted with eleven graduate students from the Department of Architecture and Architectural Engineering at The Penn State University. Before conducting the quasi-experiments, a pilot study was performed with two undergraduate students at the Department of Architectural Engineering. Using the Process Mapping Procedure and the BPMN representation of the framework, these two students created Template PMs for 3D MEP Coordination and 4D Modeling BIM use, as a requirement of their thesis work. The piloting of the quasi-experiments was done in an attempt to create a consistent and understandable Procedure and the BPMN representation. During the quasi-experiments, all the participants were made familiar with the process modeling notation adopted to create PMs. A post experiment survey was conducted to get feedback on the Process Mapping Procedure. The quasi-experiment was done to ensure that the Process Mapping Procedure could be followed and understood to create a PM. The deviations in the PMs produced were documented as part of the content analysis and relevant changes were made to the Procedure to address these challenges. Documentation on quasi-experiment design, process map outcome and analysis and the survey results is in Chapter 5.
2. **Case study evaluation:** BIM PMs and IEs were created for the selected BIM Uses for the case study project. The aim here was to validate the BIM Plan Procedure and create a BIM implementation plan for a project team addressing the relevant BIM factors. The scope of the thesis research is to document Step 2 and Step 3 of the BIM Plan Procedure. The information for the case study project was received on a first hand basis by having informal discussions with BIM Coordinator on the project. The PMs and the IEs created for the case study evaluation was finally reviewed and approved by the Project Manager and BIM Coordinator on the project for accuracy. It was also necessary for the study to capture the communication value and effectiveness of the created BIM PMs and IEs. This was accomplished by conducting a focus group meeting with the key project team members to discuss the created BIM Execution plan, any issues related to it, and to determine future scope of improvement.
3. **Template Process Maps:** The third assessment of the BIM Process Mapping Procedure was done by developing Template PMs for five BIM Uses. The Template Maps are generic maps which outline a set of sequential activities that need to be done in order to accomplish a BIM Use. It is realized that there could be many different ways of accomplishing a BIM Use. A generic map can be used to create a more detailed map based on the project requirements and chosen software application. For example, a Quantity Takeoff task includes the following three

activities: export BIM for analysis, calculate quantities, and review quantities. Template PMs with this level of detail were created for five different BIM Uses, identifying the reference information content, a logical sequence of activities to complete a BIM Use, and IEs required internally or between responsible parties to accomplish the task. These BIM Uses were chosen from each of the building lifecycle phases, i.e. Plan, Design, Construct, and Operate. One BIM Use was chosen from a multiphase use which spans in multiple phases. Refer to Figure 2.2 for the list of identified BIM Uses. This was done to ensure that the BIM Process Mapping Procedure can be used for a variety of tasks and scenarios across the lifecycle of a project. In accordance with these criteria, Template PMs have been created the most widely used and understood BIM Uses: The Template PMs have been included in Appendix of this report.

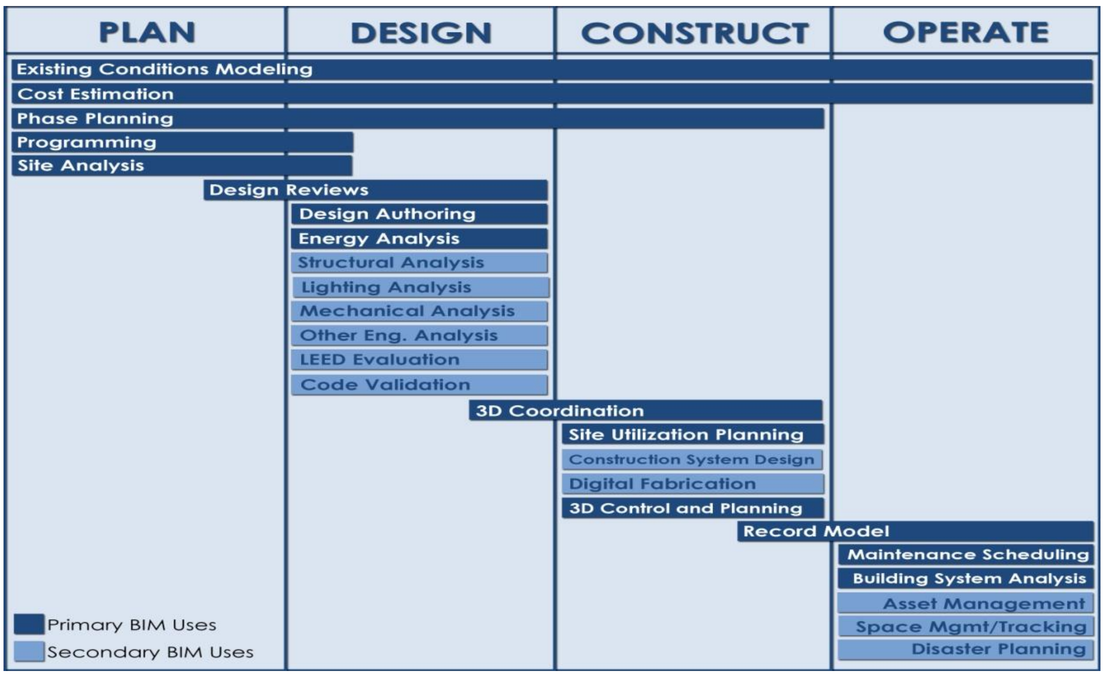


Figure 2.2: BIM Uses throughout a building's lifecycle

2.4 DEVELOPING THE INFORMATION EXCHANGES

An important aspect to the success of a building project is the planning of information exchanged between project team members. Because the AEC industry is project centered, and several companies work collaboratively towards the design and construction of a facility, the availability and accuracy of information can become constrained. Building Information Modeling has the potential to improve efficiency in the AEC industry; however, if the information exchange process is not planned early in the project lifecycle, the benefits of using the authored data may be mitigated by process waste. From a company perspective, the objective of information management is to ensure that valuable information is acquired and exploited to its fullest extent (Willpower, 2005).

The development of the information exchange process is grounded in lean theory. The overarching concept of BIM Project Execution Planning is “Begin with the End in Mind,” which means for project team members to identify what the information is to be used for once the project is turned over to the owner and/or end user. Different from the traditional design/bid/build approach, the downstream stakeholders should have a say in the information produced and transferred to create value. This concept as well as others in the BIM Plan falls in line with the five principles of Lean Thinking (Womack & Jones, 2003);

1. **Value** – Specify value in the eyes of the customer
2. **Value Stream** – Identify all the steps in the value stream and eliminate waste
3. **Flow** – Allow the value to flow without interruptions
4. **Pull** – Let the customer pull value form the process
5. **Continuously improve** in pursuit of perfection

The main theory behind the lean approach is to improve process speed and reduce cost by eliminating waste (Jugulum & Samuel, 2008). This concept is discussed in further detail in section 2.6. By following the five basic principles, team members can increase the effectiveness of design and improve downstream processes on a building project.

In conjunction with the theory above, the information exchange worksheet was developed using a focus group approach. The outcome of the several focus group sessions was to utilize a pull driven system. Specifically, the downstream stakeholder should request the information that will increase the value of their workflow. Additionally, a work breakdown structure was developed with UNIFORMAT II providing the base structure. It is important to note the BIM Plans need to remain malleable; therefore the work breakdown structure provided in the template can be swapped out for a more applicable choice based on project specific requirements. Once developed, the Information Exchange Worksheet was validated through case studies, which is discussed in more detail in Chapter 9.

2.5 DEFINING SUPPORTING INFRASTRUCTURE

The process to develop the fourth step in the procedure, Defining the Supporting Infrastructure, was very similar to other step was revised heavy by the US Army Corps of Engineers Contact Language workgroup after the research team developed the initial template. The steps that were employed to create the procedure for defining supporting infrastructure include:

- Collect BIM Execution/Implementation Plan Data
    - Literature Review the elements of a BIM Execution/Implementation Plan
    - Reviewed other BIM Implementation Plans and Templates
    - Interviews and Focus Group
- Development Procedure and Template
- Validate Procedure and Template
    - Unsolicited Industry Review
    - Reviewed By USACE BIM Contract Language Team
- Updated Procedure and Template

2.5.1 Collect BIM Execution/Implementation Plan Data

The first step of the process to develop the defining supporting infrastructure procedure and templates was to collect data about the current execution plans and what should be put into the creating of new execution plans

2.5.1.1 Literature Review the elements of a BIM Execution/Implementation Plan

Several documents have been published that explain the necessary elements that should be contained in BIM Implementation/Execution Plan. Some examples of these are:

1. AIA BIM Protocol (E202)
2. Autodesk Communication Specification
3. Consensus Docs BIM Addendum
4. US Army Corp of Engineers BIM Roadmap

More detailed review of these documents can be found in Chapter 3 of this report.

2.5.1.2 Reviewed other BIM Implementation Plans and Templates

In addition to the published documents, the team had the opportunity to review proprietary BIM implementation plans provided that they were not published directly. Six industry partners contributed examples for this purpose.

2.5.1.3 Interviews and Focus Group

Moreover, the team conducted focus group meeting and interviews to help determine the necessary elements of an implementation plan. Most of the interviews were from industry members in the DC area and those interviews were often part of the advisory board.

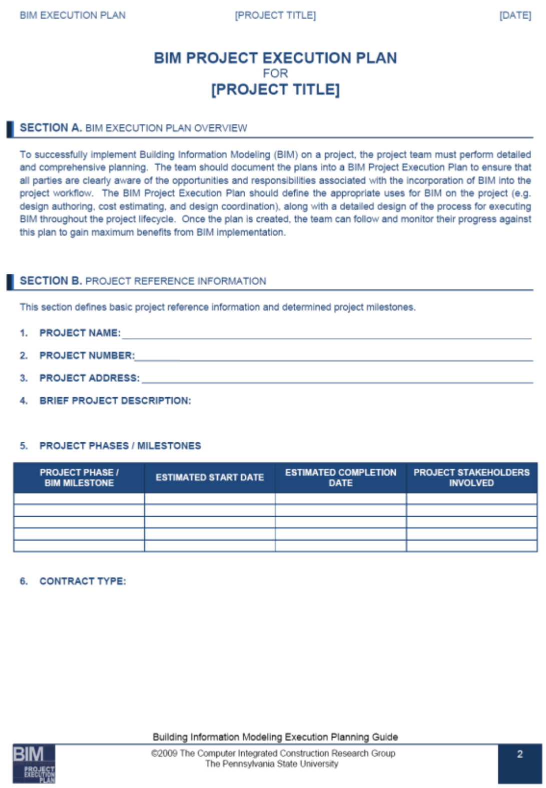
2.5.2 Development Procedure and Template

After all the data was collected, the team located common elements from all the plans. Table 2.1 shows a category breakdown of all of the elements contained in the published plans. Additional information from the proprietary BIM implementation plans was also considered. These common elements were compiled and document in the BIM Project Execution Plan Version 1.0.

Table 2.1: BIM Execution Planning Category Guide

BIM Execution Planning Guide	AIA BIM Protocol Ex.	Autodesk Comm. Spec.	Consensus Docs BIM Add.	US ACE BIM Roadmaps
Project Reference Information				
Project Overview Information		X		
BIM Contractual Requirements			X	
Key Project Contacts		X	X	X
Project Goals/BIM Objectives				
Purpose of BIM Implementation		X		X
Why Key BIM Use Decisions		X		X
BIM Process Design				
Process Maps for BIM Project Activities		X		
Define Information Exchanges		X		X
Delivery Strategy/Contract				
Definition of Delivery Structure		X	X	
Definition of Selection				
Definition of Contracting			X	
BIM Scope Definitions				
Model Elements by Discipline	X			
Level of Detail	X	X	X	X
Specific Model Attributes	X	X	X	X
Organizational Roles and Responsibilities				
Roles and Responsibilities of Each Organization	X	X		X
Define Contracting Strategies for Organizations			X	
Communication Procedures				
Electronic Communication Procedures		X		
Meeting Communication Procedure				
Technology Infrastructure Needs				
Hardware		X		X
Software		X	X	X
Space			X	
Networking Requirements		X		X
Model Quality Control Procedures				
Methods to ensure model accuracy	X	X	X	X
Glossary of Terms	X	X	X	X

After the common elements were documented into the guide, the team began to develop a template document that project teams could use to assist them when developing a BIM Project Execution Plan. This template was first developed in Adobe LiveCycle because the most project teams are able to use pdf and it would be possible to have some of the data in the document autocompleted as the project team would complete the document. In order to develop the template a rough draft was created and then reviewed by the research team in small focus group meetings. Suggests for improvement were made and the template was updated. Figure 2.3 shows an example of the BIM Project Execution Plan Template created in LiveCycle.



BIM EXECUTION PLAN [PROJECT TITLE] [DATE]

BIM PROJECT EXECUTION PLAN
FOR
[PROJECT TITLE]

SECTION A. BIM EXECUTION PLAN OVERVIEW

To successfully implement Building Information Modeling (BIM) on a project, the project team must perform detailed and comprehensive planning. The team should document the plans into a BIM Project Execution Plan to ensure that all parties are clearly aware of the opportunities and responsibilities associated with the incorporation of BIM into the project workflow. The BIM Project Execution Plan should define the appropriate uses for BIM on the project (e.g. design authoring, cost estimating, and design coordination), along with a detailed design of the process for executing BIM throughout the project lifecycle. Once the plan is created, the team can follow and monitor their progress against this plan to gain maximum benefits from BIM implementation.

SECTION B. PROJECT REFERENCE INFORMATION

This section defines basic project reference information and determined project milestones.

1. **PROJECT NAME:**
2. **PROJECT NUMBER:**
3. **PROJECT ADDRESS:**
4. **BRIEF PROJECT DESCRIPTION:**

5. **PROJECT PHASES / MILESTONES**

PROJECT PHASE / BIM MILESTONE	ESTIMATED START DATE	ESTIMATED COMPLETION DATE	PROJECT STAKEHOLDERS INVOLVED

6. **CONTRACT TYPE:**

Building Information Modeling Execution Planning Guide
©2009 The Computer Integrated Construction Research Group
The Pennsylvania State University
2

Figure 2.3: BIM Project Execution Plan Template Created in Adobe LiveCycle

After some time, the research team determined that the Adobe LiveCycle was not flexible enough to allow some of the changes suggested by the project team. Therefore, the team moved to creating the document, much as it had been in LiveCycle, in Microsoft Word. Figure 2.4 displays an image of Version 1.0 of the template.

[PROJECT TITLE] [DATE]

SECTION D. PROJECT GOALS / BIM OBJECTIVES

See the BIM Goals worksheet in Appendix A for the detailed BIM Goals.

1. **LIST MAJOR BIM GOALS / OBJECTIVES**

BIM GOAL	DESCRIPTION	COMPLETE

BIM GOAL WORKSHEET: [FILE NAME AND LOCATION] ATTACH

2. **BIM USE SELECTION WORKSHEET:** [FILE NAME AND LOCATION] ATTACH

3. **CHOOSE FINALIZED BIM USES:**

OPERATE	CONSTRUCT	DESIGN	PLAN
BUILDING MAINTENANCE SCHEDULING	SITE UTILIZATION PLANNING	DESIGN AUTHORING	PROGRAMMING
BUILDING SYSTEM ANALYSIS	CONSTRUCTION SYSTEM DESIGN	DESIGN REVIEWS	SITE ANALYSIS
ASSET MANAGEMENT	DIGITAL FABRICATION	STRUCTURAL ANALYSIS	
SPACE MANAGEMENT / TRACKING	3D CONTROL AND PLANNING	LIGHTING ANALYSIS	
DISASTER PLANNING	3D COORDINATION	ENERGY ANALYSIS	
RECORD MODEL		MECHANICAL ANALYSIS	
		OTHER ENG. ANALYSIS	
		LEED EVALUATION	
		CODE VALIDATION	
4D MODELING	4D MODELING	4D MODELING	4D MODELING
COST ESTIMATION	COST ESTIMATION	COST ESTIMATION	COST ESTIMATION
EXISTING CONDITIONS MODELING	EXISTING CONDITIONS MODELING	EXISTING CONDITIONS MODELING	EXISTING CONDITIONS MODELING

DRAFT

BIM PROJECT EXECUTION PLAN BUILDING INFORMATION MODELING EXECUTION PLAN 4

Figure 2.4: Image of Version 1.0 of the BIM Project Execution Plan Template

Once Version 1.0 of the template was completed in late October 2009, it was released for review and use by the public on the research project website.

2.5.3 Validate Procedure and Template

After the template was released it was reviewed by industry members on a general level as well as correcting minor mistakes. More importantly the template was reviewed at length through a line by line analysis by the US Army Corps of Engineers BIM industry advisory group when they were adapting the document for adoption within the US ACE contracting requirements.

2.5.3.1 Unsolicited Industry Review

The research team made an announcement to those who had downloaded the guide, that the template was available for download. As soon as this occurred, the website received more downloads, and the template was published and referenced on several other industry websites. Thereafter, the research team started to receive comments on the template. These comments were then used to update the template, guide and procedure as appropriate.

2.5.3.2 Reviewed By USACE BIM Contract Language Team

After the template was released, the project team was contacted by Steve Hutsell, lead of the US Army Corps of Engineers (USACE) BIM Contract Language Workgroup. USACE was interested in customizing the template for use by their project teams. USACE wanted to customize the template because USACE's BIM requirements specified that project teams must submit a BIM implementation plan to USACE for review after their contract had been award. The BIM implementation plans were very inconsistent. They ranged from one-page documents to 100 page documents. It was very challenging to review the documents and the team had independently decided to make a template for project teams to use. Once the template was release they decided that it would be a better use of their time to customize the BIM Project Execution Plan Template.

To accomplish this, the USACE BIM Contract Language Workgroup conducted three two-day workshops to review and update the template. Each workshop was about one month apart. At the workshops, the workgroup went through each line of the template and discussed whether or not they felt it should be contained in the USACE Specific Project Execution Plan (PxP) Template. In order to accomplish this task, about an hour was spent on each section of template during each workshop. Between workshops additional revisions were made to the USACE Specific PxP Template. At the next workshop the entire document was reviewed line by line. Therefore the template was reviewed by the workgroup completely and thoroughly at least three times. Figure 2.5 is a section from the USACE Specific PxP template that was created by the workgroup.

SECTION C: PROJECT GOALS / BIM OBJECTIVES

Describe how the BIM Model and Facility Data are utilized to maximize project value (e.g. design alternatives, life-cycle analysis, energy analysis, sustainability analysis scheduling, estimating, material selection, pre-fabrication opportunities, site placement, etc.) Reference www.engr.psu.edu/bim/download for BIM Goal & Use Analysis Worksheet.

1. MAJOR BIM GOALS / OBJECTIVES:

State BIM Goals / Objectives

BIM GOAL	DESCRIPTION

2. BIM USES:

The BIM Uses currently highlighted/shaded/checked(x) are required by USACE RFP Section 01 33 16, Design after Award, Attachment F to be developed by use of the BIM Model. Highlight in yellow and place an X next to the additional BIM Uses as selected by the project team. See BIM Project Execution Planning Guide at www.engr.psu.edu/BIM/BIM_Uses for Use descriptions. Include additional BIM Uses as applicable in empty cells.

X	PLAN	X	DESIGN	X	CONSTRUCT	X	OPERATE
	PROGRAMMING	X	DESIGN AUTHORING		SITE UTILIZATION PLANNING		BUILDING SYSTEM ANALYSIS
	SITE ANALYSIS	X	PROGRESS REVIEWS		CONSTRUCTION SYSTEM DESIGN		ASSET MANAGEMENT
		X	INTERFERENCE MANAGEMENT (3D COORDINATION)	X	INTERFERENCE MANAGEMENT (3D COORDINATION)		SPACE MANAGEMENT / TRACKING
			STRUCTURAL ANALYSIS		DIGITAL FABRICATION		DISASTER PLANNING
			LIGHTING ANALYSIS		3D CONTROL AND PLANNING		
		X	ENERGY ANALYSIS	X	RECORD MODELING		OPERATION & MAINTENANCE RECORD MODELING
			PROGRAM VALIDATION		FIELD / MATERIAL TRACKING		
			MECHANICAL ANALYSIS		DIGITAL LAYOUT		
			OTHER ENG. ANALYSIS				
			SUSTAINABILITY (LEED) EVALUATION				
			CODE VALIDATION				
	PHASE PLANNING (4D)		PRELIMINARY CONSTRUCTION SCHEDULING (4D)		CONSTRUCTION SCHEDULING (4D)		BUILDING MAINTENANCE SCHEDULING (4D)
	COST ESTIMATION (5D)		COST ESTIMATION (5D)		COST ESTIMATION (5D)		COST ESTIMATION (5D)
	EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING

Figure 2.5: Section of the USACE Project Execution Plan Template

2.5.4 Updated Procedure and Template

The unsolicited review and the review by USACE were then used to update the procedure, guide and template. The review by USACE was especially valuable when revising the plan. Almost all of their final recommendations were incorporated into the procedure and template. Also, great effort was taken to keep consistency between the USACE specific PxP Template and the more general BIM Project Execution Plan Template. To accomplish this, each section contained in the two documents are consistent, and the only difference that exists is the detail of information that USACE is requiring in their template.

Of particular note within the case study implementation is the organizational implementation in the US Army Corp of Engineers (USACE). During this case study, members of the research team participated in a series of detailed meetings over six months in which a group of leading BIM implementers on USACE projects from industry performed a very detailed analysis of the entire BIM Project Execution Planning template. Though this process, there were many very valuable suggestions and revisions to the BIM Project Execution Planning Template and Guide. Figure 2.6 show the current template. In addition to the adoption by USACE, this template has been customized for use by multiple other organizations such as Jacobs, HDR, CH2M, Mortenson, Mason and Hanger, Perkins and Will, Penn State Office of Physical Plant and others.

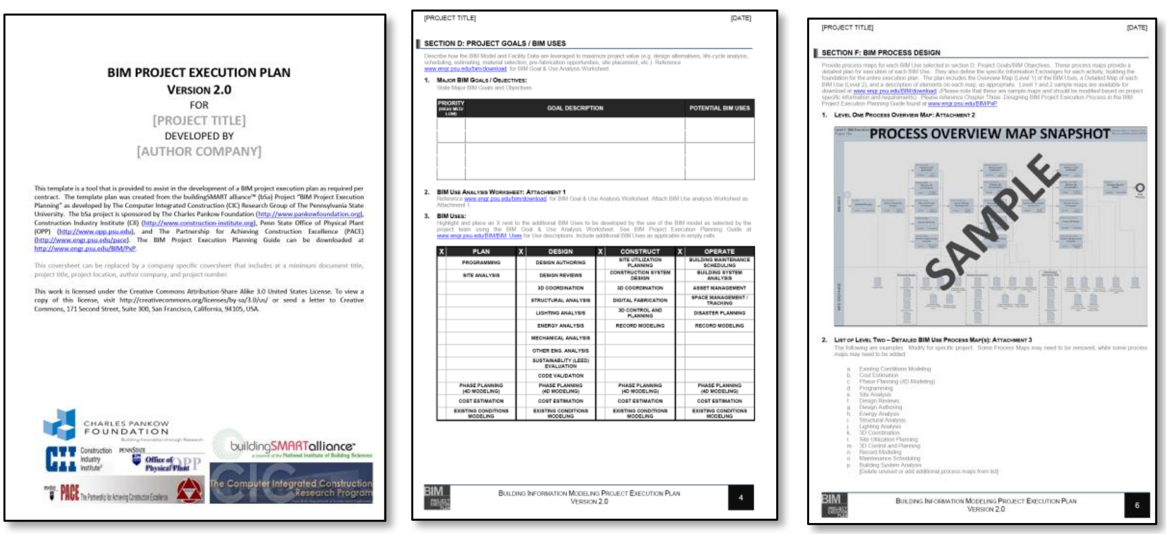


Figure 2.6: Portions of Current BIM Project Execution Plan Template

2.6 Validating the BIM Project Execution Planning Procedure

After the Draft Guide was developed and released in October 2009, the team focused on the validation of the Planning Process through a quasi-experiment, surveys, and industry case studies. The value of the BIM Execution Planning Procedure is evaluated in case studies according to the following steps:

1. Perform Case Study observations of the development of a BIM Plan. A standard procedure for project implementation includes:

- Meeting 1 – Identify BIM Uses to be implemented on a project (Step #1)
- Meeting 2 – Review Project Specific Process Maps (Step #2)
- Meeting 3 – Review Developed Information Exchanges (Step #3)
- Meeting 4 – Review Draft BIM Plan with Team
- BIM Plan – Version 1.0 – revisit on a monthly basis

2. Survey Project Team Participants regarding value of the Procedure documented in the guide and the Final Product (BIM Project Execution Plan);
3. Document Case Study Content including project descriptions, process followed by the team, lessons learned, and human and project factors which influenced the success or failure of the implementation;
4. Analyze case study and survey results through detailed content analysis. The result of this process will identify necessary revisions to BIM Project Execution Planning process;
5. Revise BIM Project Execution Planning Guide based on results.

Seven detailed project implementation case studies were performed, along with three organizational implementation case studies. In addition, we performed two academic case studies in which students within the Architectural Engineering program at Penn State used the Guide and Templates to develop execution plans for integrated group design projects using BIM as the foundation for communication.

2.7 Chapter Summary

This Chapter presented the research process and techniques that the researcher had employed to define the BIM Uses, the BIM Process Mapping Procedure, Information Exchange Procedure and BIM Developing the Supporting Infrastructure (including the BIM Project Execution Plan Template). The premise for the research is the lack of a common implementation strategy across various organizations and information interoperability. The goal for developing this structured planning procedure is to stimulate and direct communication and planning by the team in the early phases of a project. While there is no single best method for BIM implementation on every project, each team must effectively design a tailored execution strategy by understanding the project goals and characteristics. Once the BIM Project Execution Planning Procedure was developed, it was necessary to validate the research through various techniques. Quasi-experiments, surveys, and case studies were adopted for the assessment and evaluation of the BIM Project Execution Planning Procedure.

CHAPTER 3: LITERATURE REVIEW

3.1 BACKGROUND ON BIM

After careful review of the available literature, Building Information Modeling can be seen as a paradigm change in the Architecture, Engineering and Construction (AEC) Industry. Its strength lies in the possibility to communicate easily and in a more appropriate format the design intent and complex construction information to the project team and participants including the owners, designers, engineers, contractors, fabricators, facility managers and end users. Building virtual models has proven to be a successful technique in the industrial, automobile, aircraft, spacecraft and shipbuilding industry for years (Birx, 2006). The Construction Industry is the only one so far that does not use the full benefits of virtual modeling prior to construction to reduce flaws (Birx, 2006).

The National BIM Standards (NBIMS) offer a definition of BIM:

> *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 basic 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 (NBIMS, 2007).*

FMI in collaboration with CMAA's Emerging Technology committee developed an alternative definition of BIM:

> *Building Information Modeling (BIM) refers to the creation and coordinated use of a collection of digital information about a building project. The information can include cost, schedule, fabrication, maintenance, energy, and 3D models. The information is used for design decision-making, production of high-quality construction documents, predicting performance, cost estimating, and construction planning, and eventually, for managing and operating the facility (D'Agostino et al., 2007).*

Currently BIM is being used in "preconstruction, design visualization, constructability reviews, design coordination, planning of trades and systems, 4D construction scheduling and sequencing, 5D quantity survey estimating, prefabrication and modularization, and as-built modeling for facilities operations and maintenance" (Campbell, 2006).

The impact of BIM can be mostly detected in the conceptual phase of a project because it supports greater integration and better feedback for early design decisions, followed by the construction level modeling including "detailing, specifications and cost estimation, then the integration of engineering services and supporting new information workflows, and last but not least collaborative design-construction integration" (Eastman et al., 2007). The benefits that come with BIM implementation are consistency across all drawings and reports, automating spatial interference checking, a strong base for interfacing analysis/simulation/cost applications and enhanced visualization. Some of the issues reported are replacing 2D drawings with 3D digital models, managing the level of detail within building models, the development and management of libraries of components and assemblies, and new ways of integrating specifications and cost estimation. On the other hand, practical concerns that firms are facing when implementing BIM are the selection and evaluation of BIM authoring tools, training, initiating a BIM project, and planning ahead for the new roles and services that are emerging with BIM (Eastman et al., 2007).

3.1.1 State of the Industry

FMI/CMAA Eighth Annual Survey of Owners highlights the changes in the construction industry and the impact of BIM. The number of new owners using BIM has risen from 3% in 2003, 4% in 2004, 6% in 2005, and 11% in 2006. The results show the following.

- Close to 35% of the respondents have used BIM for one or more years. But the frequency of BIM compared to total expenditure is much lower and believed to be below 5% by FMI's opinion, since the owners were not asked this in particular.
- The two greatest obstacles to BIM adoption reported by owners are lack of expertise and lack of industry standards.
- 74% of current BIM users would be likely or very likely to recommend BIM.
- The greatest benefits of BIM that were reported were improved communication and collaboration among project participants. Also other important benefits are: higher quality project execution and decision making, greater assurance of project archival and more comprehensive planning and scheduling (D'Agostino et al., 2007).

Owners that decided to use BIM most often did that after their own investigation (35% of the time), or by recommendation coming from designers and/or construction managers. 74% of BIM users are extremely likely or likely to recommend BIM to others. Only 11% would not recommend it (D'Agostino et al., 2007).

According to the 2006 AIA Firm Survey, 16% of AIA member owned architectural firms have purchased BIM software, and out of this number, 64% are using BIM for billable work. BIM usage was defined by "The Architect's Handbook of Professional Practice" as "the use of virtual building information models to develop building design solutions, design documentation, and to analyze construction processes." AIA-owned firms that already implemented BIM reported that this new technology is widely being used for design development (91%), schematic design (86%), and construction documentation (81%) phases (Riskus, 2007).

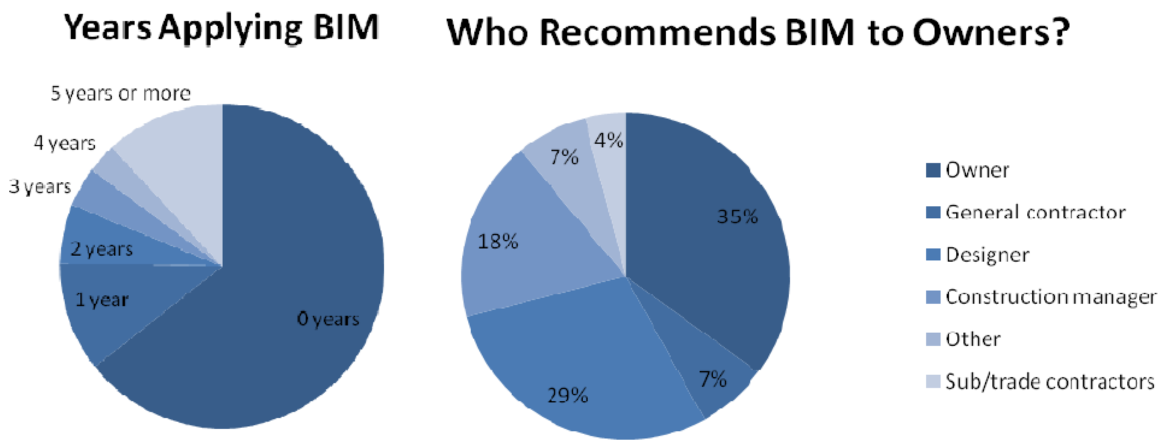


Figure 3.1: Years Applying BIM and Who Recommends BIM to Owners? (source: FMI/CMAA Eighth Annual Survey of Owners: The Perfect Storm – Construction Style.

Large AIA member owned architectural firms with over $5 million in gross billing have implemented BIM at a higher level (46%) as compared to smaller firms with gross billing under $5 million (15%). Smaller firms might be waiting for more industry reports on implementation of BIM before deciding to purchase certain BIM software based on its performance so far. A high percentage of international firms also acquired BIM software(35%), along with 20% of firms with an institutional specialization, 15% of firms with a residential specialization , and 16% of firms with a commercial/industrial focus. This may be due to the General Services Administration (GSA establishing the National 3D-4D-BIM program in 2003, setting a requirement for firms working on institutional projects to implement BIM and hand over the model for operation and maintenance purposes (Riskus, 2007).

The monthly AIA Work-on-the-Boards survey panel of firm leaders in early 2007 reported the greatest benefits and concerns/risks perceived by the firms. Firms using BIM list enhance project quality through fewer change order and more accurate documents as the greatest benefit; and firms not using BIM list enhanced process through sharing digital models for easier collaboration as the greatest benefit. For the greatest concerns/risks, firms that adopted BIM list that a higher percent of project costs are incurred earlier, changing the traditional phase client billing. The ones that are still hesitant with BIM implementation list the lack of client demand as the main reason for not investing yet in BIM, which is not perceived by the BIM experienced firms at all, and can be seen as simple resistance to change (Riskus, 2007).

3.1.2 Design Services

Traditionally designers have been using plans, elevations and perspectives to represent their design intent. Drawings are still predominantly used in design and engineering, though computers have been adopted in the last fifteen years to support design and drafting mostly in 2D. BIM is making an enormous shift in approach to design since it is replacing 2D drawings with 3D models. Traditional architectural services offered are: feasibility studies, pre-design, schematic design, design development, construction detailing, and construction review. According to the traditional approach and AIA, contract for architectural services comprises of the following distribution of effort or payment schedule: 15% for schematic design, 30% for design development, and 55% for construction documents (AIA 1994). It is widely felt that BIM has an effect on redistribution of the time and effort spent in these different phases by greatly reducing the time spent on the production of construction documents (Eastman et al, 2007).

Standard contracts between owners and designers describe the design phases and the deliverables for each phase. The American Institute of Architects' B141 – 1997 breaks the design into: schematic design, design development, construction documents and bidding. The design starts with the schematic phase in which owner and designers determine the program, schedule and budget of the project. The result of this step is drawings and other documents providing the information about the size and relationship of project components, and the initial selection of building materials and major systems. Based on the schematic design, the designers progress with defining architectural, structural, mechanical and electrical systems and construction materials; and produce a set of drawings documenting form, size and project character. The next phase of the traditional process is the preparation and handover of the construction documents and specifications, addressing building codes and jurisdictional requirements. The standard design contract defines what is to be built but not how it is to be built, which is up to the contractor to resolve. This is one reason for inefficiencies and losses incurred in traditional project delivery. The design phase is followed by the construction phase in which the contractor dominates and takes all the responsibility; while the designers supervise the construction process, administers the contract, and reports to the owner on the progress and quality. The contractor provides at the end of this phase the operations and maintenance information and as-built drawings to the owner. The construction phase is finalized by closeout and commissioning involving the acceptance of the building, handing over the required documentation and processing final payments (NBIMS, 2007).

The traditional fee structure so far has been 15 percent for schematic design, 30 percent for design development, 40 percent for construction documents, and 15 percent for construction administration. This structure would have to change when BIM is used. Since the model needs to e precisely developed in the schematic design phase, more fee might be requested for this stage. Birx (2005) has proposed that this fee structure should have the following new breakdown: 25 percent for SD, 25 percent for DD, 25 percent for CDs, and 25 percent for construction administration. Being the initial creators of the information database, designers might be able to generate more fee for themselves (Birx, 2005).

3.1.3 Design Coordination Process

Most people feel that the introduction of 2D computer drafting in design firms did not significantly change the way architects practiced, but it simply computerized their practice. 3D computer modeling and BIM on the other hand bring a culture change that infuses all aspects of practice not just the drafting portion. But BIM cannot be equalized with 3D computer modeling, since BIM is predominantly a design tool that has many capabilities of which, one is modeling and producing construction documents. The bottom line, according to Birx (2005) is that architects have more time to spend designing and less time for drafting, and if the 3D model is managed properly, it can be used all the way from design through construction, resulting in construction documents of much better quality. Second, the database lies in the model, which is an advantage because all the information is stored in a central location and the model is a file or a series of files merged together. As a result, any modifications made lead to updating all the other building information. But at the same time, the size of this data can be hard to handle and manage. Still multiple users can work on it at the same time, since BIM software can have a central file system, as long as the users are not modifying the exact same object simultaneously. Third, BIM software creates hundreds of views of the project, and cutting sections or viewing elevations is simplified, and any modifications made are updated in all the sections and views (Birx, 2005).

Going from 2D to 3D is not easy and requires serious preparation and an organized approach. Staub-French and Khanzode (2007) identify the following steps in this process:

1. Identify the Potential Uses of the 3D Models: The way the model would be used decides the level of detail and modeling techniques. 3D models would differ depending if they were used for thermal simulation, cost estimating, fabrication, shop drawings or user group visualization for example.
2. Identify the Modeling Requirements: Establish who would create the 3D model, when the model would be created and how.
    a. Identify the modeling responsibilities for the various scope of work. Establish the responsible party and the transition of the 3D model between parties. For example, a mechanical engineer can model the system to a certain degree in 2D, and then a mechanical subcontractor would detail the scope in 3D. This could be done differently as well.
    b. Establish the scope of the 3D modeling effort and the level of detail to be modeled. Consider how the 3D model would be used, as well as cost-benefit of modeling a scope of work in 3D.
    c. Establish the work breakdown structure. Create a breakdown structure of the project, and determine how the models would be done for each part and integrated and coordinated later.
    d. Create a schedule that identifies key modeling activities. Determine when the models would be created, coordinated, updated and approved for fabrication.
3. Establish the Drawing Protocol: Establish a protocol for drawing conventions so that the 3D models can be easily integrated and coordinated: project reference point (0, 0, 0), file naming convention, version control, layering convention, and color scheme.
4. Establish a Conflict Resolution Process: Set up a process for identifying and resolving conflicts. Identify the specific design review software that would be used, establish the process for sharing drawing files, establish the timing and general meeting process for coordinating the 3D models, and identify a responsible party to facilitate the electronic design coordination process.
5. Develop a Protocol for Addressing Design Questions. Especially if contractors are responsible for developing 3D models, they should be able to contact designers quickly and not to go through the long RFI process.

All design coordination problems can be easily identified by a command in the BIM software. Before even an experienced staff member in charge of coordination would miss numerous conflicts which would lead to “errors and omissions”, requests for change orders, delaying of construction, and payment by the designer for the mistakes. Now with clearly marked in red coordination issues, no conflict can go undetected and unresolved before the construction (Birx, 2005).

3.1.4 Integrated Delivery: Design-Construction Integration

BIM is proven to enable design-construction integration. Some of the benefits of the designer teaming with the contractor are: early identification of long lead-time items, value engineering as design proceeds with cost estimates and schedules, sharing the model developed by designers with contractors and fabricators, and as a result shortening fabrication and detailing (Eastman et al., 2007).

Construction-level building models are one of the main advantages of BIM. Designers approach the development of models in two ways. The model is expressing in detail the design intent of the architect and the client, and it is up to the contractor to develop a separate construction model for the purpose of coordination and documentation. The other option would be a partially detailed model that can be transferred to the contractor as a starting model, and after being detailed and elaborated, used for construction, coordination and fabrication. The first option has been widely accepted and practiced by designers today to minimize or eliminate liability for arising construction issues (Eastman et al., 2007). The assumption is that the second approach might be better in the future if the potential impediments are resolved. This issue was addressed in the expert interviews for their views on the topic and possible remedies of the situation in the future.

The NIST's study "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" (Gallaher et al., 2004) estimated the efficiency losses in the U.S. capital facilities industry to be approximately $15.8 billion per year (based on 2002 data) due to inadequate interoperability. Interoperability was defined in this study as "the ability to manage and communicate electronic product and project data between collaborating firms and within individual companies' design, construction, maintenance, and business process systems" (NBIMS, 2007).

This brings us to the point that a change in project delivery is necessary. The construction industry goal should be "better, faster, more capable project delivery created by fully integrated, collaborative project teams. Owners must be the ones to drive this change, by leading the creation of collaborative, cross-functional teams comprised of design, construction and facility management professionals" (CURT, 2004). A good way to accomplish this goal is an integrated project delivery approach where construction and operations knowledge and experience is brought early in the design decision making process. The integrated project delivery process was further explained in *Optimizing the Construction Process: An Implementation Strategy* by CURT (2006) and in *The Contractor's Guide to BIM* (AGC, 2006), and can be seen, compared to the traditional design process, as a preferred design process, showing that if the decisions are made early in the design process, cost of design change can be avoided.

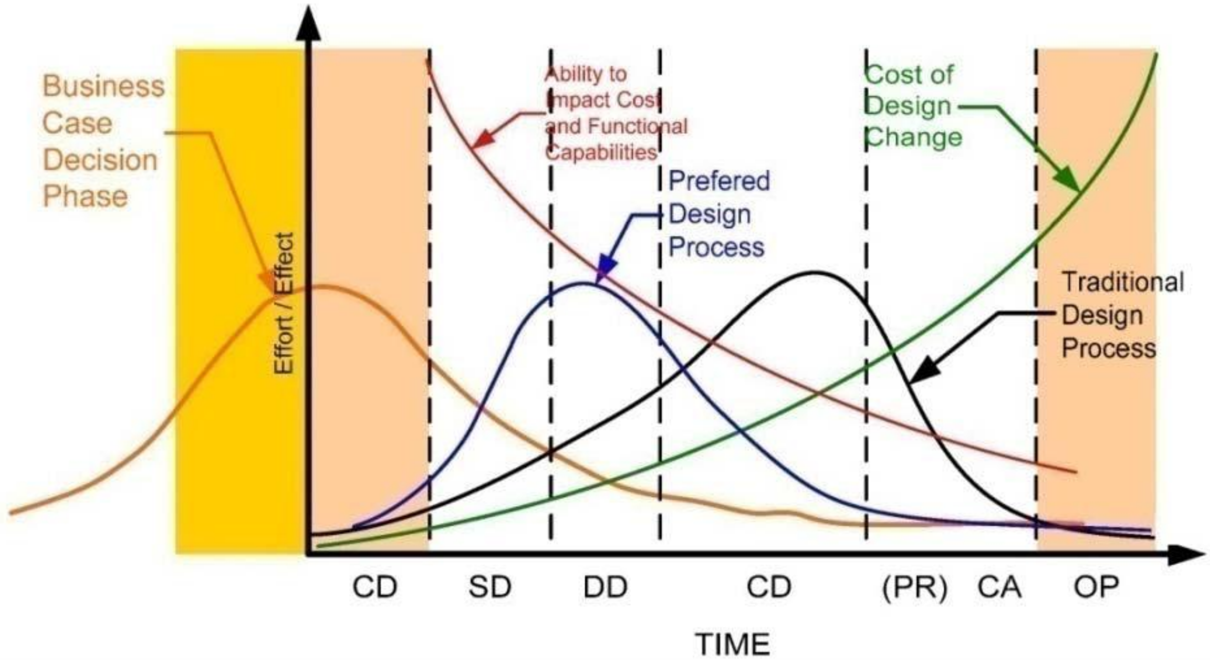


Figure 3.2: Integrated Project Delivery vs. Traditional Design Process (Source: buildingSMART conference presentation "The Strategic Process Behind BIM Enabled Decision Processes" by David M. Hammond, RLA, APA, Office of Civil Engineering, U.S. Coast Guard)

Three new phases emerge in this integrated delivery approach: Design Optimization, Construction Optimization, and Construction Orchestration. Design Optimization involves using advanced analysis software in all areas (structure, energy consumption, lighting, daylighting, air flow (CFD)) to decide what should be built, leading to an intelligent building model and optimized design solution. 3D visualization is one of the most important aspects of the design optimization because it improves communication with all stakeholders and speeds up design decisions. The information transmitted to the contractor can be an intelligent model or a series of discipline specific models. The next phase of Construction Optimization involves contractors, subcontractors and fabricators performing a 3D review process and electronic submittals. The geometry of the discipline specific models is merged and interferences or conflicts are resolved. Schedule added to the 3D model of the facility resolves the construction interferences using 4D techniques, and the construction can begin. The information handed over is a detailed 3D model of the building with the components defined to the level that they can be fabricated from the model. The final phase is Construction Orchestration, involving fabrication of the components in a controlled environment resulting in less waste, less number of hours on the site, less laydown space needed and improved safety overall. The necessary factor for integrated project delivery is technology or Building Information Modeling (NBIMS, 2007). As a conclusion, several authors have strongly supported the need to use integrated delivery method for achieving better results with BIM.

Some guidelines developed by Campbell (2006) and M. A. Mortenson Company to facilitate integrated practice are:

1. *Model, do not draft.* A complete BIM model needs to be developed and coordinated to discover and resolve conflicts early.

2. *Model your own scope of work.* Every designer, engineer, and subcontractor is responsible for modeling his own scope of work in BIM.
3. *Model it at true size.* Everything must be represented at its true size and in the right location. Incorrectly modeled data should not be concealed by disclaimers and dimension overrides.
4. *Be data agnostic.* There are too many file formats and specialized software applications available, therefore standards like IFC, VRML and X3D should be adopted.
5. *Share your information* . Address questions about intellectual property and liability early in the project with adequate legal and contract language.
6. *Manage change.* Develop standards to manage and track design revisions in design and construction.

3.1.5 BIM Benefits and Challenges

Benefits and challenges perceived are critical for future adoption of BIM, especially from the owners' point of view. The connection established between benefits and results is crucial for potential new users to decide to implement BIM on their projects. The scorings in the survey of the owners (FMI/CMAA Eight Annual Survey of Owners) were differentiated between non-BIM users and BIM users, but the total score was given as well. Rankings are as expected higher for BIM users since they are certain they are receiving or would receive these benefits. Highest ranked were improved communication and higher quality project execution and decision-making.

Table 3.1: BIM Benefits and BIM Hurdles (Source: FMI/CMAA Eight Annual Survey of Owners)

BIM Benefits			BIM Hurdles		
Rate benefits that BIM solutions provide on capital construction projects (Scale: 1=strongly disagree; 5=strongly agree)	All responses		Rate hurdles that slow or prevent adoption of BIM solutions on capital construction projects (Scale: 1=strongly disagree; 5=strongly agree)	All responses	
	Score	Rank		Score	Rank
Improved Communication and Collaboration Among Project Participants	4.22	1	Lack of Expertise	4.09	1
Higher Quality Execution and Decision-Making	4.09	2	Greater System Complexity	3.92	2
Greater Assurance of Project Archival	3.98	3	Lack of Industry Standards	3.92	3
More Comprehensive Planning and Scheduling	3.97	4	Poor Integration with Existing Systems	3.79	4
Higher Quality Construction Results	3.90	5	Different Needs Across Stakeholders	3.72	5
Easier to Achieve Process Standardization	3.89	6	Training Burden	3.66	6
More Reliable Compliance with Regulations	3.73	7	Unclear Business Value and ROI	3.62	7
Greater Productivity from Labor and Assets	3.71	8	Lack of Executive Buy-in	3.57	8
More Consistent Performance Against Budget	3.68	9	Vague Cost Estimates	3.32	9
Significantly Reduced Change Orders/Claims	3.64	10	Legal/Contractual Concerns	3.23	10
Broader Strategic Perspective and Innovation	3.63	11	Security Risks	3.03	11
Decreased Labor Costs	3.52	12			
Measurably Reduced Contingencies	3.49	13			
Improved Safety Performance	3.44	14			
Competitive Advantage in Recruiting and Staffing	3.39	15			

The scoring of all hurdles or challenges is much lower by BIM users since they are more confident they can or would be overcome. Non-users rank a lack of executive buy-in as more significant, while BIM users rank higher the challenges that arise from different needs across different stakeholders. Not expected, security risks and legal/contractual concerns were ranked low (D'Agostino et al., 2007).

Based on the experience of the design and engineering firms who already adopted BIM, the following benefits were recognized (Staub-French and Khanzode, 2007):

1. Most design conflicts are identified prior to construction,
2. Productivity is significantly improved,
3. Less rework,
4. Increased opportunity for pre-fabrication,
5. Fewer Requests for Information (RFIs),
6. Fewer Change Orders,
7. Design errors can be identified prior to construction,
8. Ability to build the system with a less skilled labor force,
9. Improved safety performance,
10. Better cost control.

To realize these benefits some compromises had to be made. Productivity was improved, but design time increased. Rework was avoided, but design coordination time increased. The project team made more informal decisions, but the time it took to design, plan and estimate the project increased. The efficiency of the installation process increased, but the design cost and time increased as well (Staub-French and Khanzode, 2007).

To take advantage of these benefits, owners need to bring a project team together early in the project, designers need to work more on the overall design and its coordination and less on detailed design; contractors need to be skillful at manipulating and managing the 3D model, work closely with designers, and provide their input early in the design; and subcontractors need to be able to do more detailed design, work closely with the designers and engineers, and help coordinate designs early in the process (Staub-French and Khanzode, 2007).

Benefits of implementing BIM are evident, but they have to be justified considering additional costs involved, training staff and introducing new procedures. Fee for design services is either calculated as a percentage of construction cost or an hourly rate. For designers to offset their costs, a solution would be to start offering new services that can be added to their fee. Some of the possible services can include: performance-based design using analysis applications and simulations, integrating design with construction leading to faster construction, facilitating offsite fabrication of assemblies, and reducing field work (Eastman et al., 2007).

3.1.6 BIM Productivity Benefits

To justify the additional cost involved with implementing BIM, the production benefits need to be assessed. One way is to track the reduction of errors by the lowered number of Requests for Information (RFIs) and Change Orders (COs) on a project. Another way would be to assess the increase in labor productivity, measured as the total cost of labor hours and salaries, to realize a certain task. The return on the investment can be determined by comparing the investment in BIM required with the reduction in labor costs. Few firms keep track of the unit costs based on floor area or facade area during design phases, like design development and construction documents, but these metrics can be very valuable in performing cost-benefit analysis of BIM implementation (Thomas et al., 1999). Little research data has been published on productivity gains and this can be one of the greatest challenges for the design firms to track their costs and time and money savings (Sacks and Barak, 2006). The annual return on investment and the time needed to regain the cost can be determined by dividing the total annual benefit by the total cost including labor training cost, learning curve cost and hardware and software costs (Eastman et al., 2007).

Though the key application of BIM is currently in the design and construction field, there are other creative applications that can lead to production benefits (Birx, 2006):

1. Visualization. Model renderings are done as package services and add to the design fees.
2. Fabrication and shop drawings. The BIM model if properly set up from the beginning can be fully used for fabrication and construction purposes.
3. Code reviews. Code officials find BIM models as a great tool for the project code reviews.
4. Forensic analysis. BIM model can be used in multiple ways to analyze the building, its evacuation plans and potential failures and leaks.
5. Facilities management. BIM model can be also used for further renovations, space planning and maintenance of the building.
6. Construction information database. Single source of information is aiding everyone involved with the process of constructing a building.
7. Cost estimating. Material quantities are easily extracted from the BIM model and can be automatically adjusted with changes made in the model.
8. Construction sequencing. Ordering, fabrication and delivery schedules for building materials and systems are easily created from the BIM model.

At present time, most design firms and construction companies are not keeping track of the cost involved with BIM implementation, and the cost gains due to improved productivity and technology. These metrics need to start being collected in order to quantify precisely the cost-benefit ratio of BIM. Also an understanding must be reached of what information precisely is crucial for each business activity in construction (NBIMS, 2007).

Key success factors were also identified:

1. Strong leadership by the client or executive leadership within the company,
2. The team buy-in and BIM skilled personnel in the team,
3. Transparency and accessibility of electronic information,
4. Ability to use the information across the design/construction team,
5. Appropriate quality assurance methods and procedures,
6. Collaboration that includes the trades,
7. Recognition of new project roles, i.e. information manager,
8. Mutual trust.

3.1.7 New and Changed Staffing within Firms

One of the main challenges in implementing BIM is the transition that needs to be made in adopting new practices, methods of working, and documenting work. Another challenge that firms face when it comes to staff and training are new roles that arise with the new technology: Model Manager maintaining model's data integrity and Systems Integrator setting up exchange methods for BIM data with consultants (Eastman et al., 2007).

BIM is changing the way the project needs to be staffed. In a traditional approach the project staff would include a principal, a part-time project manager, a project architect, a full time architect 1 and full time intern. With BIM, more senior staff needs to be involved early in the project, the average hourly rate has increased, and less man-hours are needed to finish the project. Working in BIM requires more experience, which would mean that the principal is involved the same as before, the project manager and architect need to put in more hours, while the architect 1 and intern would work less hours due to the process automation. This also means that young architects starting their career would spend less time learning drafting and more time designing (Birx, 2005). This analysis is represented in Table 3.2, but can be considered an educated guess on how the new hours would look like in the changed scenario with BIM.

New technology requires team members in charge of managing the model, training the staff and providing IT support. Staff needs to be aware of the purpose and use of the information involved, life cycle aspect of information, quality assurance issues, how to create and use the information, and security issues such as confidentiality, virus checking and backup (NBIMS, 2007).

Table 3.2: Pre-BIM and Post-BIM Man-hours Needed to Finish the Project (Source: Birx, G. W. (2005). BIM Evokes Revolutionary Changes to Architecture Practice at Ayers/Saint/Gross.

Pre-BIM										Post-BIM									
Week No	1	2	3	4	5	6	7	8	Total	Week No	1	2	3	4	5	6	7	8	Total
Principal	4	4	4	4	4	4	4	4	32	Principal	4	4	4	4	4	4	4	4	32
Project Mngr	16	16	16	16	16	16	16	16	128	Project Mngr	24	24	24	24	24	24	24	24	192
Project Arch	24	24	24	24	24	24	24	24	192	Project Arch	40	40	40	40	40	40	40	40	320
Architect 1	40	40	40	40	40	40	40	40	320	Architect 1	24	24	24	24	24	24	24	24	192
Intern Arch	40	40	40	40	40	40	40	40	320	Intern Arch	0	0	0	0	24	24	24	24	96
Total Hours	124	124	124	124	124	124	124	124	992	Total Hours	92	92	92	92	116	116	116	116	832
Average Rate									$92.25	Average Rate									$110.25
Fee Required									$91,520	Fee Required									$91,520

3.1.8 BIM Contractual Terms

Since the 2D information on paper is replaced by 3D intelligent models, questions of contracts, liability, risk management and insurability need to be addressed. The general consensus is that the model needs to be accurate at all times to be used as intended. Due to the transitional period, most contracts still include the need for paper copies of all the construction documents. Standard contract language in case of sole usage of BIM model needs to be changed or special contract clauses should be added to assure adequate allocation of responsibility in creating, maintaining and handing over the model (NBIMS, 2007).

Recently new documents have been released on how to change contractual terms if using BIM or sharing the model in a traditional, design build or integrated project delivery. More information can be found in the following published documents: the AIA E202 document, the AGC Consensus Docs BIM Addendum and the AIA IPD Documents.

3.2 Lack of a Taxonomy of BIM Uses

While there are various reports and papers on Building Information Modeling in design and construction, there are few sources that provide specific data on implementation of BIM in practice. Furthermore, currently there are no guidelines to lead the project team members in how to develop an execution plan for BIM in design and construction. This research is being done with the intention to provide a taxonomy of BIM uses and informed guidelines for the early project participants that would assist in preparing a customized project execution plan for BIM. New contract language on BIM implementation identifies the need for a BIM execution plan, but no detailed method for developing this plan is yet available.

3.3 THE NEED FOR BIM PROCESS INTEGRATION

To develop a BIM Process Mapping Procedure, it was necessary to look at the current efforts on BIM implementation in the industry. It was important to review the existing literature in several domains: the intra-organizational aspect of BIM and how organizations utilize this technology within the company; the future potential of BIM and where the industry is heading; and the inter-organizational use of BIM. The literature establishes the need for BIM process integration to address the challenges of the inter-organizational use of BIM; and also identifies the current efforts by the NBIMS to establish the exchange of product data.

The need to transfer data between engineering applications has existed before the development of the first CAD systems. It arises due to the collaborative nature of design. While the non –BIM environment does not facilitate efficient transfer of information during the critical phases of the facilities lifecycle (Eastman et al. 2008; Teicholz 2004), the utilization of BIM technology requires dramatic changes in the current business practices (Derrick and Mei Kuen 2008; Mihindu and Arayici 2008; Sidwell 1990). The acceptance of BIM has been a challenge requiring a steep learning curve and a paradigm shift in the business models of Architecture Engineering Construction/ Facility Management (AEC/FM) organizations. Laiserin (2007) has pointed out some potential areas of improvement:

- Accuracy: Complete, correct communication between AEC/FM project participants; for example, owner requirements to designer (program/brief), designer feedback to owner (visualization/simulation), design intent to construction documents (CDs), and CDs to constructors/bidders;
- Consistency: Uniformity within a representation; for example, within a set of drawings or specs;
- Integration: Linkage between related representations; for example, between drawings and specifications or between models and sequencing/schedules;
- Coordination: Interference checking among disciplines; for example, between building and site or between structural and mechanical/electrical/plumbing (MEP);
- Synchronization: Achieving comparable levels of detail/resolution over time; for example, drawings/specifications versus cost.

Additionally, several researchers have recognized the problems caused by the fragmentation of the industry (National Institute of Building Sciences 2007); and the lost opportunity costs caused by inadequate interoperability (Gallaher et al. 2004); and inconsistent technology adoption among stakeholders (Wix 2007).

Fox and Hietanen (2007) have reported several challenges to the inter-organizational use of BIM including: management challenges; shortcomings of IFC; lack of cross trained staff with both construction and IT skills; archiving of information; and multiple design perspectives. Architects tend to perceive buildings as systems of spaces, while HVAC engineers see buildings as systems of thermal zones is just one example of the multiple design perspectives. Therefore, the creation of a model is fit for the purposes of several different types of analyses throughout the building lifecycle. As a result, the transition between multiple parties requires a lot of thought and execution (Fox and Hietanen 2007).

Fox and Hietanen (2007) have also reported the results of interviews from several organizations regarding the existing and planned use of BIM. A number of participants mentioned 'inconsistencies in the ways in which BIM models were being created' as a major technological challenge that they faced. Some individuals had the opinion that these inconsistencies can be overcome by establishing inter-organizational guidelines for the creation of BIM models. This establishes a need to create standardized information exchanges (IEs) that are required to define facility projects.

The latest effort is the development of an integrated building model supports data exchange using the Industry Foundation Classes (IFC) of the International Alliance of Interoperability (IAI) (Eastman 1999). The intent of the IAI, now functioning under a new brand called buildingSMART, is to provide means of passing a complete and accurate BIM model from the computer application used by one party to computer application used by other parties without any loss of information (IAI 2008). To maintain industry enthusiasm for the benefits of integration, the IAI has sought to define and release a new version of the IFC every year, encouraging quick and incremental development (Eastman 1999).

Eastman (1999) has argued that as 'the general flow of work has become more distributed; the tacit process knowledge embedded in the workflow needs to become more explicit.' This is due to the fact that the process operating on some data and the data exchange carrying that information are interdependent. This justifies a need for not only a standard and consistent data exchange, but also, a detailed and parallel commitment of defining and modeling processes supporting the data exchange.

3.3.1 Process Mapping

Process maps (PMs) are a visual aid for organizing work processes with links between inputs, outputs, and tasks (buildingSMART International Ltd. 2008). It describes the flow of activities within the boundary of a particular topic. The concept of process, however, lacks a commonly agreed definition. A typical definition for process is: *a set of partially ordered steps intended to reach a goal* (Feiler and Humphrey 1992).

- A process map is used to understand (buildingSMART International Ltd. 2008):
- The tasks (activities) performed within a business process,
- The sequence in which they are carried out,
- The actors (people/organizations) involved in the process, and
- The information that is exchanged between actors as a result of activity completion.

3.3.2 Purpose of Process Maps

The purpose of a process map is to assist in understanding how work is undertaken in achieving a well-defined objective (Wix 2007). A process map usually:

- Has a goal;
- Has specific inputs (typically from other exchange requirements and from other data
- sources);
- Has specific outputs (typically to other exchange requirements);
- Uses resources;

- Has a number of activities that are performed in some order;
- May affect more than one organizational unit; and
- Creates value of some kind for the customer.

For the planning process in this research, the principal roles of the process map will be to:

- Establish the logical sequence of the activities within a process;
- Identify the inputs, i.e., the Reference Information and BIM deliverables that support the activities within the process;
- Establish the BIM outputs and the Information Exchanges between processes; and
- Identify the team participants or the agents responsible for a particular BIM task.

3.3.3 Perspectives in Process Representation

Curtis et al. (1992) reported that many forms of information must be integrated to adequately describe processes. Among the forms of information that people ordinarily want to extract from a process model are: what is going to be done; who is going to do it; when and where will it be done; how and why will it be done; and who is dependent on it being done (Curtis et al. 1992). Four common perspectives in process representations are:

- *Functional:* represents what process elements are being performed, and what flows of informational entities (e.g., data, artifacts, products) are relevant to these elements. In this view processes consist of activities that together achieve the goal. In addition, supplementary concepts such as data exchanges can enhance the process representation;
- *Behavioral*: represents when process elements are performed and how they are performed through feedback loops, iteration, decision- making conditions, entry and exit criteria, etc.;
- *Organizational*: represents where and by whom (which agents) process elements are performed, the physical communication mechanisms used for transfer of entities, and the physical media and locations used for storing entities;
- *Informational*: represents the informational entities produced or manipulated by a process; these entities include data, artifacts, products (intermediate and end), and objects; this perspective includes both the structure of informational entities and the relationships among them.

Hypothetically, a combination of all these perspectives would provide a relatively complete process. I n the current practice of process modeling, however, the functional perspective is most often used (Cutting-Decelle et al. 2000) as provided by the Structured Analysis and Design Technique (SADT) and the closely related Integrated Definition Language (IDEF0) technique (Yusuf and Smith 1996). This is because the focus is on the modeling of project activities in a logical and causal relationship, with the activity as the basic construct and the process concept achieves only one goal – "*How to obtain the result*"(Cutting-Decelle et al. 2000). Of course, this provides an area for improvement. There are three other relevant goals: *how not to consume unnecessary resources, who is responsible for the various tasks*, and *how to ensure that the results correspond to the requirements*.

3.3.4 Process Modeling in the Construction Industry

Several different types of process models have been used in the construction industry to analyze processes. The process models relevant to the study are presented in this section. The review presented is representative and not comprehensive, since there are many ongoing research efforts in the field of construction process modeling.

Sanvido et al. (1990) developed the Integrated Business Process Model (IBPM) as a generic model which establishes the processes required to provide a facility. The 'provide facility' process, refer to Figure 3.3, was subdivided into managing, planning, design, construction and operations of a facility.

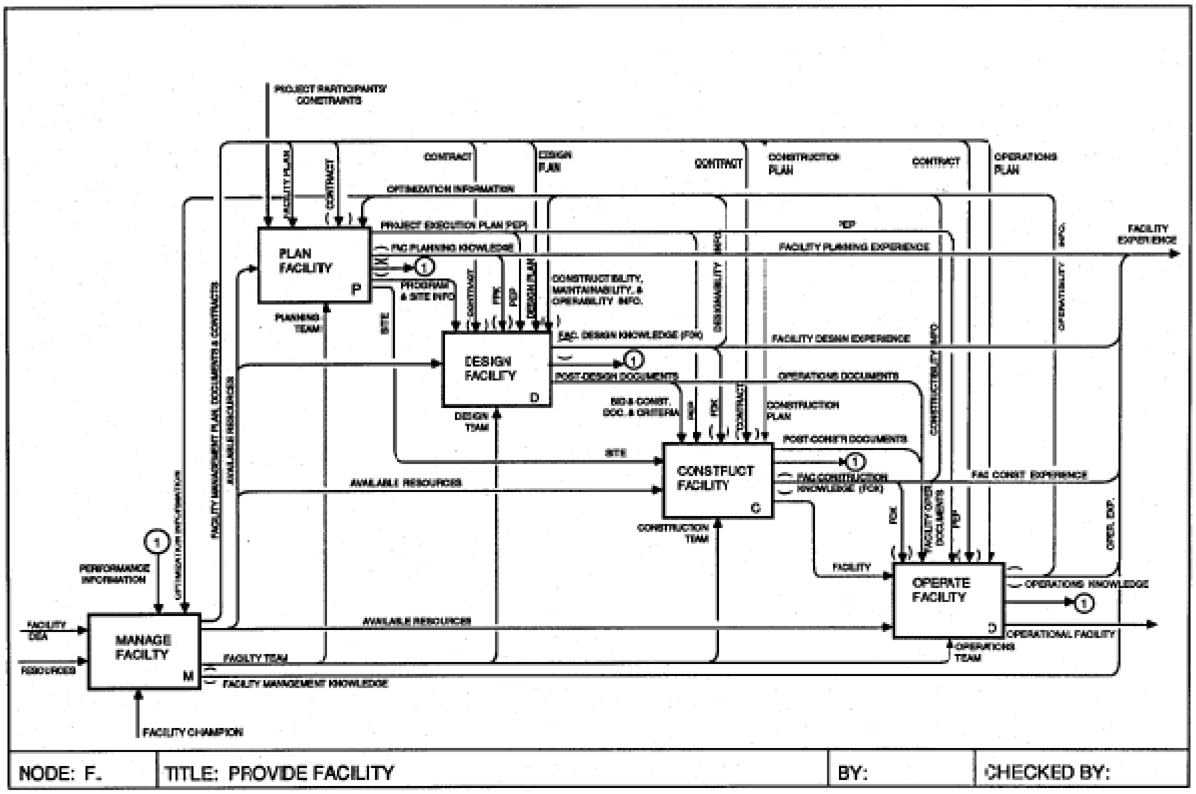


Figure 3.3: Provide Facility (Sanvido et al. 1990)

This particular model used the IDEF0 modeling methodology and identifies the inputs, outputs, constraints and mechanisms associated for each function. The basic concept of the IDEF0 syntax, refer to Figure 3.4, consists of boxes and arrows with the activity represented by a rectangular box and the flow of a process with arrows.

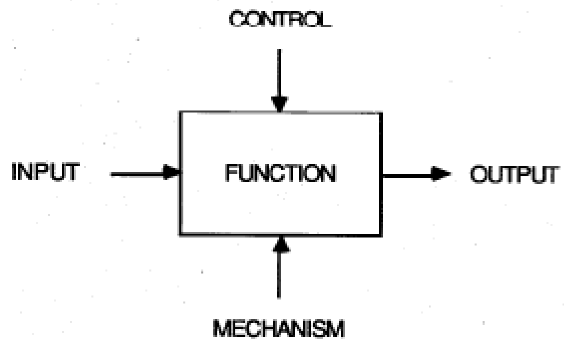


Figure 3.4: IDEF0 box and arrow graphics (Sanvido et al. 1990)

Another attempt by a research team at the University of Salford in the UK, in conjunction with nine collaborating companies, was the Generic Design and Construction Process Protocol, or the Process Protocol[1]. The Generic Design and Construction Process Protocol essentially breaks down the design and construction process into 10 distinct phases, shown in Figure 3.5. These 10 phases are grouped into 4 broad stages, namely Pre-Project, Pre-Construction, Construction and Post-Construction. These phases cover aspects of a project lifecycle from the demonstration and conception of need to the operation and maintenance of the constructed and/or refurbished facilities.

The map draws from principles developed within the manufacturing industry that include stakeholder involvement, teamwork and feedback, and reconstructs the design and construction teams to create multi-functional group of participants called the ‘Activity Zones’. These activity zones are represented on the Y-axis of the process protocol and represent the structured set of tasks and processes which guide and support work towards a common objective (Kagioglou et al. 2000).

[1] For more information, visit the website: www.processprotocol.com

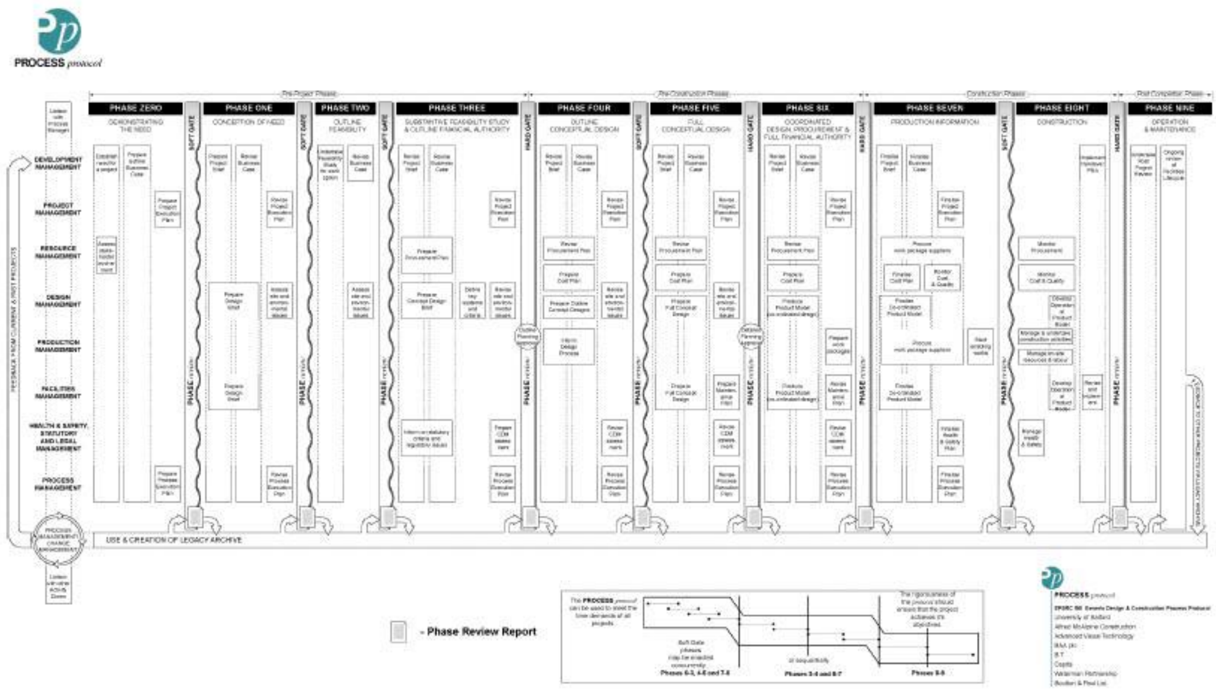


Figure 3.5: The Generic Design and Construction Process Protocol model (Kagioglou et al.)

In a continued attempt by the same group, with additional expertise from Loughborough University, the Process Protocol Level II was created. The primary deliverable was to create sub process maps of the eight Activity Zones that exist within the original Generic Design and Construction Process Protocol model (Fleming et al. 2000).

The Process Protocol is not mapped using a standardized format. Visio was used as a diagramming tool and an original process map template was developed depicting the ownership of a process, the process name, and the participants involved. This was necessary for the successful completion of a project as shown in the Figure 3.6.

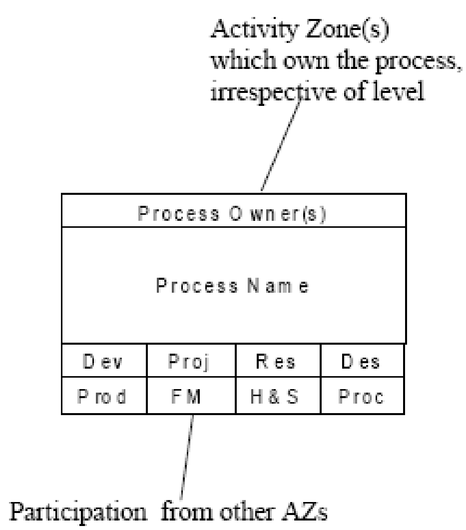


Figure 3.6: Process map template for the Process Protocol (Fleming et al. 2000)

None of the process maps discussed specifically focus on the tasks that a project team must perform to effectively implement BIM on a project level. The existing models are also not adequate for supporting the strategic decisions to be made by a construction team since an information handover is required encompassing many specific BIM tasks, company information and other external information. Therefore, a project specific approach is needed to assist the project teams in successfully analyzing the strategic decisions and implementing BIM.

3.3.5 Basic Components of a Model

Several process models have been developed in the construction domain. A synthesis of the common features of these process models as described by Bjork (1992) is based on three main categories: activities, results, and resources. An *activity* uses *resources* to produce *results*. Traditional construction classification systems often tend to equate *result* to building and their parts. Other important sub-types of results are information, mostly delivered as documents, and services.

The construction process entity can be divided into a number of subtypes, refer to Figure 3.7 (Bjork 1992).

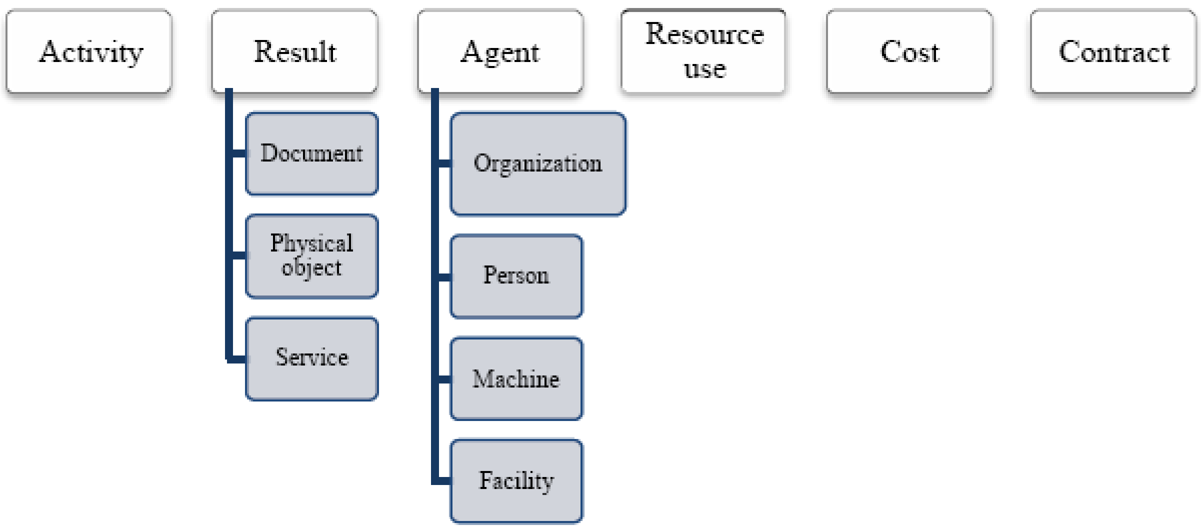


Figure 3.7: Subtypes of the construction process entity (Bjork 1992)

Bjork (1995) also provided an EXPRESS-G representation of some of these objects in a generic construction process, as shown in Figure 3.8.

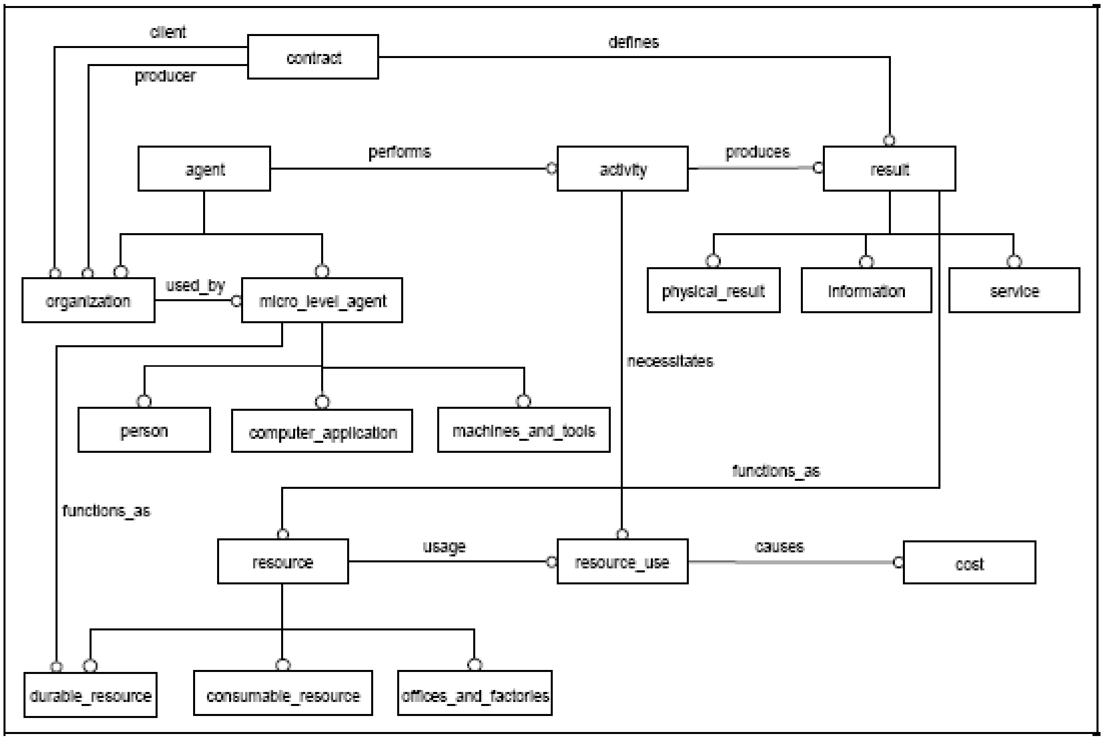


Figure 3.8: A model of generic construction categories, showing some of their internal

3.3.6 Business Process Modeling Notation (BPMN)

A BIM Process Mapping Procedure has been developed using the BPMN modeling methodology. The reasons for adopting this notation over other methods such as IDEF0 are:

- BPMN provides businesses with the capability of defining and understanding their internal and external business procedures through a Business Process Diagram, which will give organizations the ability to communicate these procedures in a standard manner. It is a standard maintained by the Object Management Group (OMG) with a richer set of capabilities for modeling business process than IDEF0 (buildingSMART International Ltd. 2009)**;**
- It has a better capability to express business process. In particular, it uses 'swimlanes' to enable communication between actors to be visualized. This is not easy to do with IDEF0 but is critical to seeing where exchange requirements are needed in IDM (Wix 2007);
- There are several available software tools that range from fairly simple, free benefits to extensive industrial strength solutions. For the purpose of demonstrating the use in this research, the TIBCO and Microsoft Visio software application will be used to create PMs;
- The notation has a conversion method to the Business Process Execution Language for Web Services which is emerging as a standard XML based approach for workflow control (Wix 2007); and
- There is a possibility to better integrate with the detailed information exchange mapping initiatives used in the IDMs currently being developed for the NBIMS as well as BIM Standards in other countries.

3.4 INFORMATION EXCHANGE OF PROJECT DATA

The exchange of information between various project participants has always been very important, but at the same time, a very difficult task. Recently, with considerable number of software implementations, the Industry Foundation Classes (IFC) has turned out to be a leader in establishing an interoperable standard for the exchange of building product information. The IFC specifications, developed by the International Alliance of Interoperability[2] (IAI), has been promoting its vision of a STEP based integrated product model which would cover all vital information about the building in its life cycle. The alliance aims at developing an object oriented data model to allow different disciplines to accurately share technical information with IFC compliant tools (International Alliance for Interoperability 2001). However, since the start of its first industrial pilot application with the HUT-600 project (Fischer and Kam 2002), there are still many shortcomings which undermine the reliability of data exchange (Pazlar and Turk 2008). The shortcomings include geometric misrepresentation, loss of object information, confusion in interdisciplinary revisions, large file size, and specific application requirements. However, as IFC's continue to evolve, some of these challenges have been addressed in more recent releases of IFC (e.g., IFC 2x3).

While this approach has progressively satisfied the requirements for a complete schema; it is not able to capture the business process and its various developments which a user may later need (Wix 2007). Similarly, it also does not account for the ways in which information is created and shared by the practitioners which justifies the need for Model View Definitions (MVD) and the Information Delivery Manuals (IDM).

In spite of this development in the technology, there are several obstacles in completing the model and consequently establishing an integrated design and construction process (Bazjanac 2002; Pazlar and Turk 2008):

- The extent of fragmentation in the AEC industry;
- Unique software products;
- Growing requirements of the AEC industry; and
- Traditional working methods.

To combat these general obstacles and complementing the above efforts, a refined procedure for BIM Project Mapping Planning is developed in this research.

3.4.1 INFORMATION DELIVERY MANUAL (IDM)

Wix (2007) argues that the IFCs provide a comprehensive reference to the totality of information within the lifecycle of a constructed facility; however, it does not incorporate a comprehensive reference to the individual processes within building construction. The Information Delivery Manual (IDM) aims to "provide the integrated reference for process and data required by BIM by identifying the discrete processes undertaken within building construction; the information required for their execution; and the results of that activity" (Wix 2007). It will specify:

[2] For more information on IAI visit: http://www.iai-tech.org/products/ifc_specification/

- Where a process fits and why it is relevant;
- Who are the actors creating, consuming and benefitting from the information;
- What is the information created and consumed; and
- How the information should be supported by software solutions.

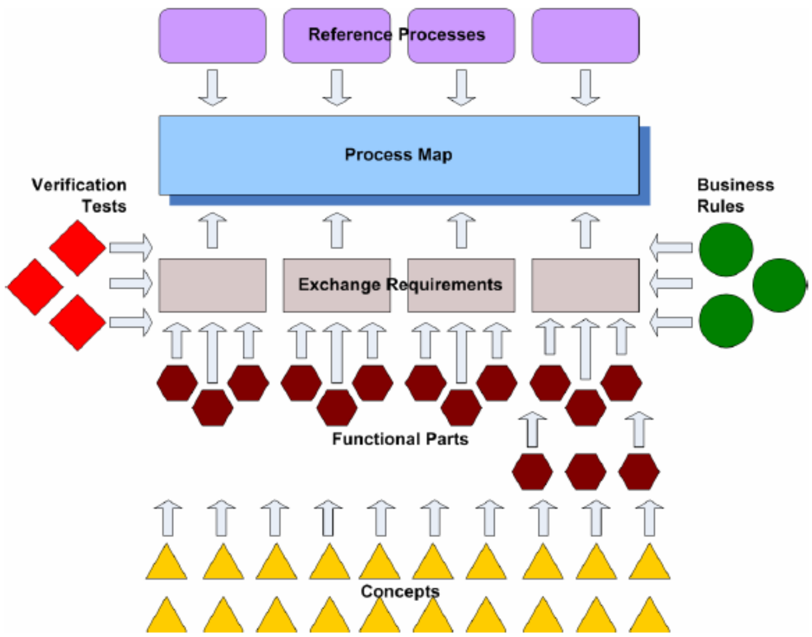


Figure 3.9: IDM technical architecture (Wix 2007)

The three main components of an IDM are Process Map (PM), Exchange Requirements (ER) and Functional Parts (FP), refer to Figure 3.9. Through these components business processes are identified, described and specified in order to meet the needs from participants in the AEC/FM project lifecycle (buildingSMART International Ltd. 2006). Wix (2007) explains the logical sequence of creating an IDM. Typically, it should start by defining a PM, then specify the defined ER's and the belonging FP's.

The main goal for the PM is to (buildingSMART International Ltd. 2006):

- Identify in which project stages (e.g. outline design, full conceptual design, coordinated design etc) of the process there are exchange of information for this business process;
- Identify all the ER's for this business process. ER's can also be independent of IFC (e.g. local/national standards, building regulations etc). This will typically be *input* to the process;
- Identify the purpose of the business process and sub-processes; and
- Identify the result of execution of the processes – *output.*

Refer to Figure 3.10 for a sample PM for Electrical Engineering.

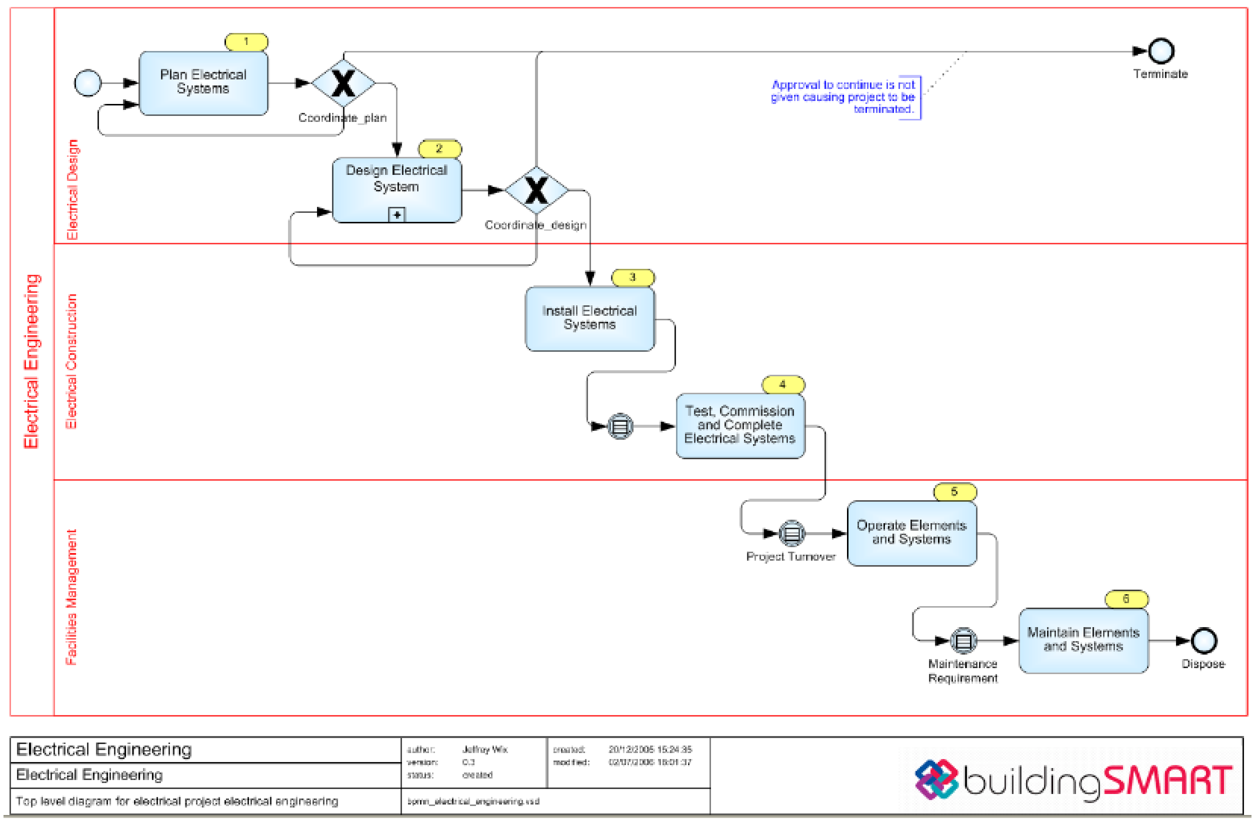


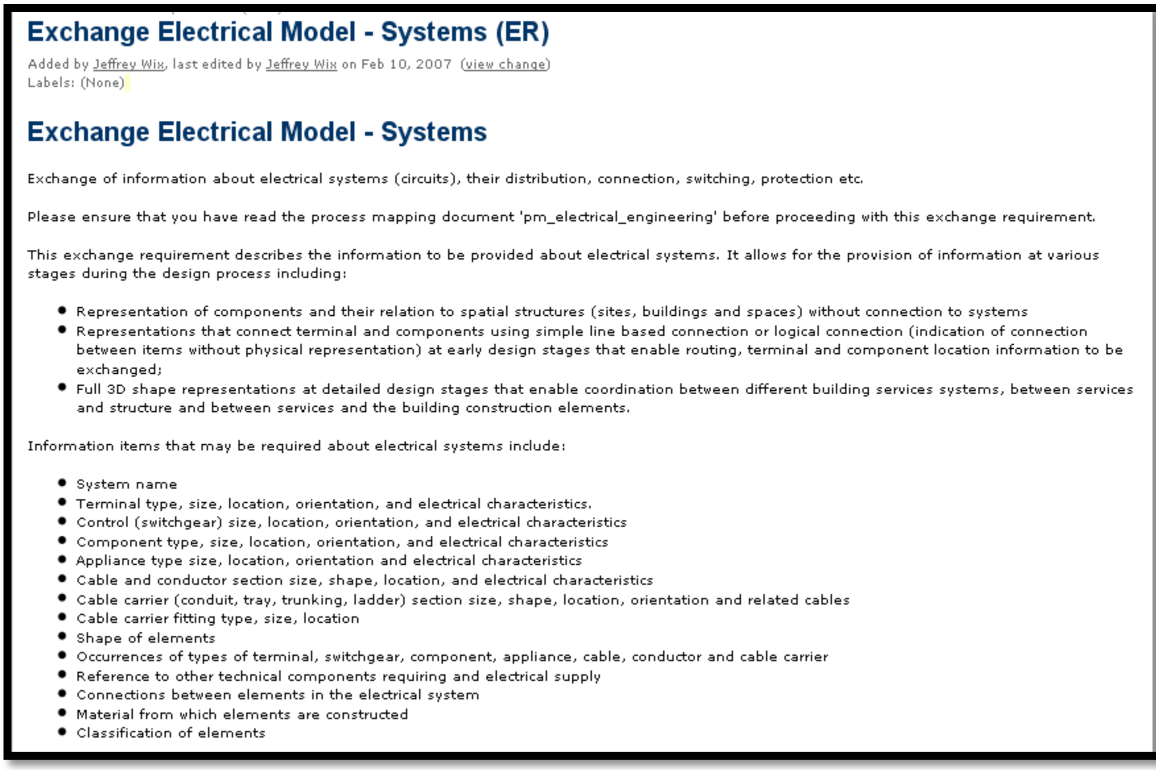
Figure 3.10: PM for the business process: Electrical Engineering[3].

An ER is typically unique within a project stage. However in many cases the business process has a cyclical sequence between project stages. Essentially, it is the degree of detail of information and the decomposition of elements from speculative into more specific types that changes from stage to stage. The main goals for ER's are to (buildingSMART International Ltd. 2006):

- Identify what information a specific business process needs;
- Describes the information that must be passed from a business process to enable another to happen;
- Identify the actors sending and receiving information within the process by role;
- Identify when information exchange must happen;
- Identify a table of information units needed to satisfy the requirement (other ER's and FP's); and
- Specify the functional part that satisfies the information unit.

A snapshot of ER for the Electrical Model Exchange is shown in Figure 3.11.

[3] For a complete reference to the available PMs within the IDM, please refer to http://idm.buildingsmart.no/confluence/dashboard.action



Exchange Electrical Model - Systems (ER)

Added by Jeffrey Wix, last edited by Jeffrey Wix on Feb 10, 2007 (view change)
Labels: (None)

Exchange Electrical Model - Systems

Exchange of information about electrical systems (circuits), their distribution, connection, switching, protection etc.

Please ensure that you have read the process mapping document 'pm_electrical_engineering' before proceeding with this exchange requirement.

This exchange requirement describes the information to be provided about electrical systems. It allows for the provision of information at various stages during the design process including:

- Representation of components and their relation to spatial structures (sites, buildings and spaces) without connection to systems
- Representations that connect terminal and components using simple line based connection or logical connection (indication of connection between items without physical representation) at early design stages that enable routing, terminal and component location information to be exchanged;
- Full 3D shape representations at detailed design stages that enable coordination between different building services systems, between services and structure and between services and the building construction elements.

Information items that may be required about electrical systems include:

- System name
- Terminal type, size, location, orientation, and electrical characteristics.
- Control (switchgear) size, location, orientation, and electrical characteristics
- Component type, size, location, orientation, and electrical characteristics
- Appliance type size, location, orientation and electrical characteristics
- Cable and conductor section size, shape, location, and electrical characteristics
- Cable carrier (conduit, tray, trunking, ladder) section size, shape, location, orientation and related cables
- Cable carrier fitting type, size, location
- Shape of elements
- Occurrences of types of terminal, switchgear, component, appliance, cable, conductor and cable carrier
- Reference to other technical components requiring and electrical supply
- Connections between elements in the electrical system
- Material from which elements are constructed
- Classification of elements

Figure 3.11: Snapshot of the ER for the Electrical Model

ER's and PM's are not independent of each other. It is therefore essential that they are coordinated to serve the complete project. The main goals of the FP's are to (buildingSMART International Ltd. 2006):

- Describe the actions that are carried out within a business process to provide the resulting output information;
- Be reusable or may be used by many exchange requirements;
- Ability to be broken down into other functional parts;
- Specify other functional parts that are used; and
- Identify IFC entities, attributes, property sets and properties required.

3.4.2 Model View Definition (MVD)

The MVD format was adopted by the IAI in 2005 as a format for defining views for IFC. Software that claims to be IFC compliant is certified against these views or subsets of the complete IFC specification (Wix 2007). The goal of MVD is to provide information for software users about IFC based solutions, and to help software developers add meaningful IFC support to software[4].

[4] For more information, refer to the MVD View Definitions Website: http://blis-project.org/IAI-MVD/

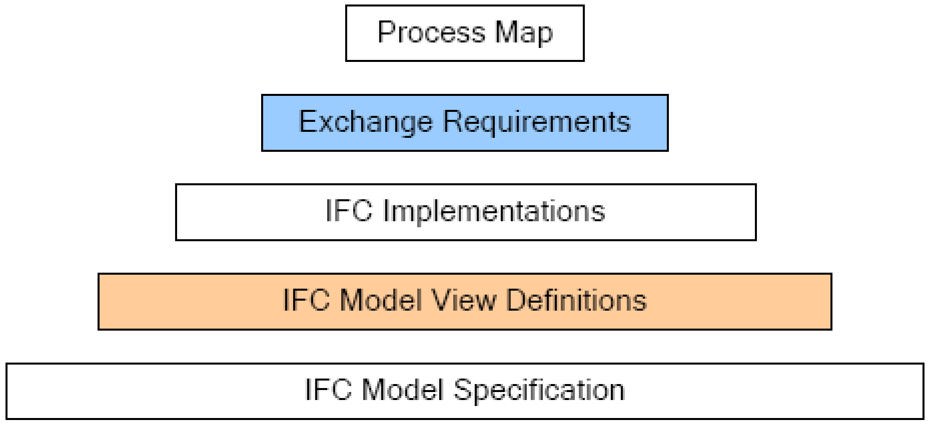


Figure 3.12: IDM/MVD interoperability frame (Hietanen 2006).

Figure 3.12 shows the different steps that are needed for creating IFC based interoperable solutions. One of the main responsibilities if the IAI is to ensure that the development of MVD and IDM occur in parallel (Hietanen 2006). The MVD format is divided into two main parts, (1) the generic part and (2) the IFC release specific part. Both parts enable to bridge the gap between the Exchange Requirements and the IFC specification as the business language is translated to the IFC data structure (Weise et al. 2008).

There are a couple of view definitions that are discussed within the MVD. At the moment the most important one is the Coordination View that is the basis for available CAD implementations (Weise et al. 2008). The MVD format is used for new developments such as the "Structural design to structural analysis" (www.blisproject. org/IAI-MVD).

Though the approach to standardize and create consistent information by the IAI has been enormous, it has yet to be tested, integrated and used on a broad scale. Currently, the PM and ER of the IDM are under development, and the software vendors and users are struggling with the interoperability issues. The BIM Process Mapping Procedure has been created for a project team as a standardized approach to establish a BIM plan with consistent information which can be used on the projects today. As the information exchanges become standard throughout the industry, the team can reference the standard exchanges, instead of providing a custom information exchange requirement for a task.

3.5 Developing the Need for Information Exchange Requirements

The following summary was performed to reveal problems associated with the implementation of BIM in the AEC industry. Also, previous work was reviewed to determine how the information exchange process is linked to successful execution of BIM in construction. Finally, lean theory is introduced as a way to identify waste inside an information exchange process. The following literature review contains information in regards to the latest state of knowledge for the following areas: Cost of Interoperability in the AEC Industry, Benefits and Challenges of BIM Implementation, the Information Exchange Process including Information Delivery Manuals (IDM), the Philosophy of Lean Thinking including the Eighth Form of Waste: Intellect, and Value Stream Mapping including the potential for Discrete Event Simulation.

3.5.1 Cost of Interoperability in the AEC Industry

As stated in the introduction, the annual cost of inadequate interoperability was quantified as approximately 15.8 billion dollars for the U.S. AEC industry in 2002 (Gallihar et al. 2004). Two-thirds of this cost is attributed to owners and operators due to operation and maintenance of a facility. Therefore, approximately 5.3 billion dollars of waste can be attributed to the design and construction of a facility. It is important to note that this study developed by the National Institute of Standards and Technology (NIST) was calculated through counterfactual analysis in which a hypothetical scenario is compared to actual activities (Fogel, 1979). In this study the hypothetical situation used is based on the concept of a "fluid and seamless" data management system that includes the transformation of data throughout the lifecycle of a facility. Therefore, the information is entered only once, and is completely transparent, available to all team members when it was needed. For the context of this analysis, three general cost categories were used to characterize inadequate interoperability: avoidance costs, mitigation costs, and delay costs, which are described below (Gallihar et al. 2004). Additional, Table 3.3**: Costs of Inadequate Interoperability by Cost Category (in $Millions)**depicts the total cost of interoperability for each cost category.

Avoidance Costs – preventative costs aimed to prevent technical interoperable cost before they occur:

- Cost of purchasing, maintaining, and training for redundant CAD/CAE systems;
- Cost of maintaining redundant paper systems for exchanging information;
- Outsourcing translation services to third parties;
- Investments in in-house programs, such as point-to-point translators and neutral file format translators to address interoperability issues; and
- Cost of participating in industry consortia activities aimed at improving interoperability.

Mitigation Costs – repair costs of interoperable problems after they occur:

- Cost of design and construction rework due to interoperability problems,
- Cost of manually reentering data when electronic data exchange is unavailable or when errors were made in the exchange, and
- Cost of verifying information when original sources cannot be accessed.

Delay Costs – cost of time associated with activity delays

- Idle resources as construction activities are delayed,
- Profits lost due to delay of revenues (discounts the value of future profits),
- Losses to customers and consumers due to delay in the availability of products and services, and
- Idle resources when a facility is not in normal operation.

Table 3.3: Costs of Inadequate Interoperability by Cost Category (in $Millions)

Cost Category	Architects and Engineers	General Contractors	Specialty Fabricators and Suppliers	Owners and Operators	Total
Avoidance Costs	485.3	1,095.4	1,908.4	3,120.0	**6,609.1**
Mitigation Costs	684.5	693.3	296.1	6,028.2	**7,702.0**
Delay Costs	—	13.0	—	1,499.8	**1,512.8**

Source: RTI estimates, totals may not sum correctly due to rounding.

During the data collection portion of this analysis, a total of one hundred and five industry members were surveyed with 21 Architects and Engineers, 11 General Contractors, 5 Specialty Fabricators, and the remainder Owner, Operators, Software Vendors, and Research Personnel. The survey results were used to determine a cost per SF of interoperability for each stakeholder for each phase of the project lifecycle: Plan and Design, Construction and Commission, Operation and Maintenance, and Decommission Phase. The cost estimate was quantified by comparing the actual survey results to the hypothetical counterfactual scenario as described above. The difference between the actual and counterfactual scenario represented the cost of interoperability. To determine the total economic loss of inadequate interoperability per year, the cost per square foot was multiplied by the total capital facility square footage under construction. Simplified algebraically, the total interoperability costs in a single year can be expressed as:

Equation 3.1: Total Cost of Interoperability in a Fiscal Year

$$\text{Cost} = \sum ij\ (DEP_{ij} {}^{*} Qg) + \sum i\ (C_{ij} {}^{*} Qg) + \sum i\ (OM_{ij} {}^{*} Qs) + \sum i\ (D_{ij} {}^{*} Qd),$$

where

i	=	the stakeholder group subscript;
j	=	the activity category subscript;
DEPij	=	annual design, engineering, and planning interoperability cost per square foot or capacity for stakeholder *i* for activity *j*;
Cij	=	annual construction interoperability cost per square foot or capacity for stakeholder *i* for activity *j*;
OMij	=	annual operations and maintenance interoperability cost per square foot or capacity for stakeholder *i* for activity *j*;
Dij	=	annual decommissioning interoperability cost per square foot or capacity for stakeholder *i* for activity *j*;
Qg	=	total capital facility square footage under construction in a given year;
Qs	=	total capital facility existing stock in terms of square footage; and
Qd	=	total capital facility

Another interesting note of the study on the cost of interoperability is the breakdown for general contractors. Table 3.4: **Costs of Inadequate Interoperability for General Contractors**Table 3.4 is a summary of the cost of interoperability for general contractors totaling approximately $1.8 billion dollars.

Table 3.4: Costs of Inadequate Interoperability for General Contractors

Life-Cycle Phase	Cost Category	Cost Component	Average Cost per Square Foot	Average Cost per Square Meter	Inadequate Interoperability Cost Estimate ($Thousands)
Planning, Engineering, and Design	Avoidance Costs	Inefficient business process management costs	0.14	1.55	163,674
		Redundant CAx systems costs	—	—	—
		Productivity losses and training costs for redundant CAx systems	—	—	—
		Redundant IT support staffing for CAx systems	—	—	—
		Data translation costs	—	—	—
		Interoperability research and development expenditures	0.0006	0.006	630
	Mitigation Costs	Manual reentry costs	0.16	1.74	184,028
		Design and construction information verification costs	0.006	0.06	6,302
		RFI management costs	0.12	1.24	131,299
	Subtotal	Avoidance costs	0.14	1.55	164,304
		Mitigation costs	0.28	3.05	321,629
		Subtotal	**0.43**	**4.59**	**485,933**
Construction	Avoidance Costs	Inefficient business process management costs	0.82	8.78	927,487
		Redundant CAx systems costs	—	—	—
		Productivity losses and training costs for redundant CAx systems	—	—	—
		Redundant IT support staffing for CAx systems	—	—	—
		Data translation costs	—	—	—
		Interoperability research and development expenditures	0.003	0.03	3,571
	Mitigation Costs	Manual reentry costs	0.11	1.19	126,047
		Design and construction information verification costs	—	—	—
		RFI management costs	0.16	1.74	183,818
		Construction site rework costs	0.01	0.11	11,356
	Delay Costs	Idle employees costs	0.01	0.12	12,988
	Subtotal	Avoidance costs	0.82	8.78	931,059
		Mitigation costs	0.28	3.04	321,221
		Delay costs	0.01	0.12	12,988
		Subtotal	**1.11**	**11.94**	**1,265,268**
Operations and Maintenance	Mitigation Costs	Post construction redundant information transfer costs	**0.04**	**0.48**	**50,419**
Total Cost					**1,801,620**

In this report, the general contractor is responsible for all construction activities. This includes construction managers, general contractors and consultants. The majority of the waste, $1.27 billion, occurred during the construction phase. Not included in this result are the specialty subcontractors, which are referred to as specialty fabricators and suppliers by NIST. The total cost of interoperability for specialty fabricators and suppliers is estimated at $2.2 billion with approximately $1.76 billion occuring during the construction phase. When comparing the cost of interoperability to the establishment of revenue developed in 1997, the cost of interoperability accounts for 0.86% of the total revenue by general contractors, non-residential building construction [$1.8 billion (cost of interoperability, 2002) / $209.3 billion (U.S. Census Bureau, 1997)], and 1.24% for specialty fabricators and suppliers. If compared to the U.S. Census in 2002 for non-residential building construction, the total revenue increased to $259 billion, therefore the actual percentage is around 0.70% for genral contractors, non-residential building contruction and 0.95% for specialy fabricators and suppliers. If we assume this percentage, the cost of waste in 2007 is approximately $2.4 billion for general contractors.

3.5.2 Information Exchange Waste

In general, information exchange waste can be considered to include the additional activities and any inactivity that arise as a consequence of not providing the information for immediate consumer access to an adequate amount of appropriate, accurate and up-to-date information. This concept is again analogous to the principles of lean thinking in a manufacturing context and is depicted in Figure 3.13. Value is in the eyes of the customer, therefore the received information is only valuable if the downstream customer can use the data. In a production / manufacturing system, this concept is easily understood because goods are mainly produced inside one company. Since the AEC Industry is project centric, information is handed from company to company without understanding the end use. Therefore, the design of a project specific information management system is a key to successful interoperability.

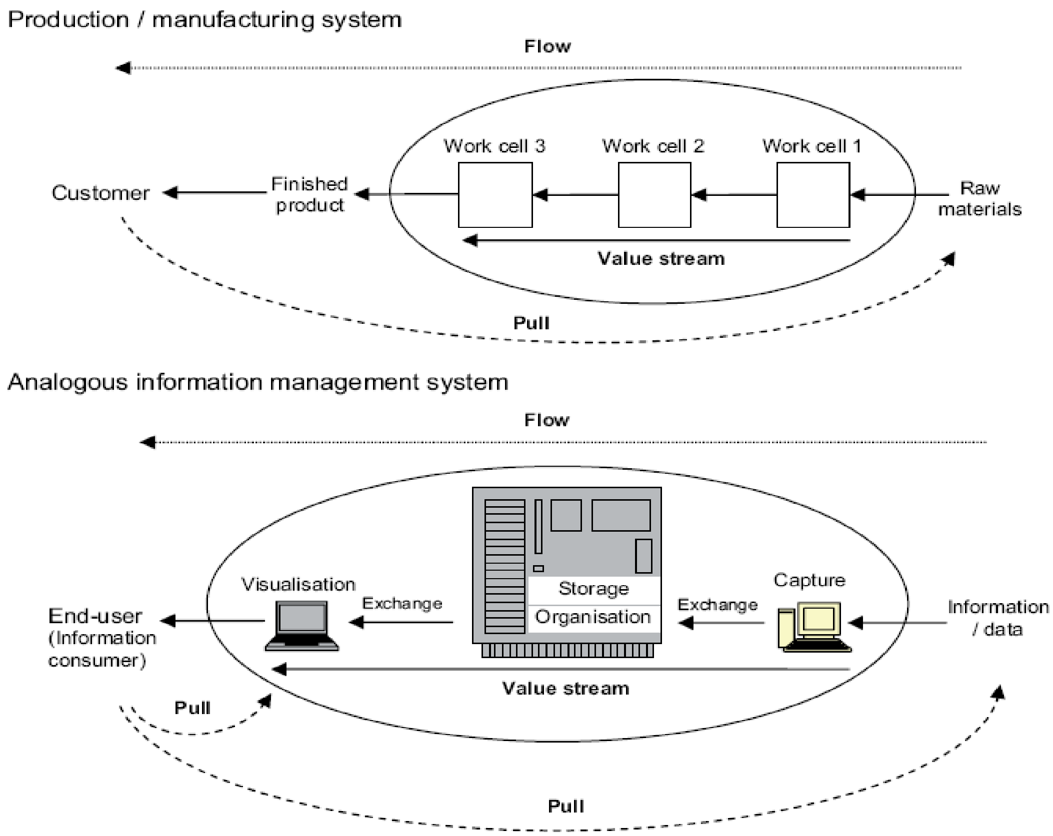


Figure 3.13: The value-flow model as applied to information management (Hicks, 2007)

3.5.3 Information Delivery Manuals

One of the largest challenges of implementing Building Information Modeling on a project is the transfer of information between disciplines (buidlingSMART Norway, 2009). To improve the effectiveness of BIM, information required should be both accessible and usable when needed. This is the goal of the Information Delivery Manuals (IDMs) being produced by the buildingSMART International Alliance for Interoperability (IAI). The components of an Information Delivery Manual are:

- Process maps that describe the evolution of information for key topics throughout the project lifecycle.
- Each process map identifies the requirements for information exchange and the roles within the project from which the information is received or to which it is provided.

- Each requirement for information exchange is described individually in the IDM.
- Each description is in two parts, the first targeted at the BIM user and the second at the BIM solution provider.
- For the BIM user, information is described in non-technical terms that do not need knowledge of the IFC schema.
- For BIM solution providers, descriptions break down the IFC schema into reusable "functional parts" (commonly occurring sets of data that may be used by any number of processes)

According to the IAI, an IDM will specify:

- Where a process fits and why it is relevant
- Who are the actors creating, consuming, and benefitting from the information
- What is the information created and consumed
- How is the information should be supported by software solutions

Although the concept of the IDMs will greatly benefit BIM software developers and ultimately project team members, it is difficult to standardize the information exchange process for unique project implementation processes at the project level. Each project team member uses different means and methods when implementing BIM. The goal of the BIM Project Execution Plan is for the information exchange process to be tailored to fit each project team member's needs and capabilities. Therefore, the development of the information exchange process should focus on the value stream associated with the transfer of models.

In summary, the construction industry is in the middle of a vast transition to improve project efficiency. The total cost of interoperability accounts for approximately 0.70% of the total revenue by general contracors and 0.95% for specialty fabricators and suppliers. These figures are quite staggering and have led to many studies on the effectiveness of Building Information Modeling increasing process efficiency. However, these studies are mostly qualitative, and provide little evidence of the total value of BIM. There are still many challenges that firms face regarding the success of BIM in the AEC Industry. One of the largest challenges of implementing BIM on a project is the transfer of information between disciplines.

In an ideal situation, information required should be both accessible and usable when needed. This is the goal of lean thinking, which aims to improve process speed and reduce cost by eliminating waste. Because the AEC industry is not seamless, the rules with lean must be slightly modified to fit within the building project system. This research has yet to be undertaken. Also, there is a gap in regards to how to assess the value of early planning for Building Information Exchanges on a facility project. Surprisingly, the concept of intellect waste has yet to be examined, which will fit nicely into the evaluation of the information exchange process on building projects. Value stream mapping has proven as an effective means for identifying waste, and will be utilized during the data collection portion of this research. Finally, discrete event simulation was outlined as a potential method for analyzing value stream maps for information exchanges, but further investigation needs to occur before this technology can be deemed valuable to the research project.

3.6 Execution Guide for BIM and Defining Supporting Infrastructure

Several types of execution plans are currently being used in the construction industry to implement BIM in an organization or to facilitate the adoption of BIM in the industry. The execution guides relevant to the study are presented in this section.

3.6.1 Consensus Documents BIM Execution Plan

ConsensusDOCS™ has recently released a BIM Addendum which marks a significant step forward in utilizing BIM as a collaborative tool. The ConsensusDOCS 301 BIM Addendum is an industry standard document to globally address the legal uncertainties associated with utilizing BIM. The BIM Addendum is the first addition to the ConsensusDOCS' comprehensive catalog of contracts and forms.

Additionally, the BIM Addendum requires all project participants "meet, confer and use their best efforts to agree upon the terms of or modifications to the BIM Execution Plan." The BIM Execution Plan or BEP is a detailed checklist for project participants to consider as they map out responsibilities, requirements and processes in greater detail for execution on a project (Lowe nd Muncey 2008).

3.6.2 AIA Document E202-2008: BIM Protocol Exhibit

AIA E202 establishes the procedures and protocols the parties agree to follow with respect to the development and management of a Building Information Model throughout the course of a project. E202–2008 is not a stand-alone document, but is intended to be attached as an exhibit to an existing agreement for design services or construction on a project where the parties intend to utilize BIM. It has been primarily written to support a project using Integrated Project Delivery (IPD). However, it can be attached to more traditional agreements (American Institute of Architects 2008).

There are 5 basic Levels of Development (LOD) which reflect a generic definition of model content and, more importantly, there is a column to add the MEA's (Model Element Author's) which specifies who is responsible for authoring each element of the model at each project phase, so no major design elements are missed or left unaddressed (American Institute of Architects 2008). The Model Elements follow the CSI UniFormat ™ II classification system to divide the Building Information Model into component parts which defines the model progression specification for information exchange. Figure 3.14 shows the model element table of the E202 document comprising 3 essential columns of model elements, LOD and MEA.

§ 4.3 Model Element Table

Identify (1) the LOD required for each Model Element at the end of each phase, and (2) the Model Element Author (MEA) responsible for developing the Model Element to the LOD identified.

Insert abbreviations for each MEA identified in the table below, such as "A – Architect," or "C – Contractor."

NOTE: LODs must be adapted for the unique characteristics of each Project.

Model Elements Utilizing CSI UniFormat™								LOD	MEA	LOD	MEA	LOD	MEA
A	SUBSTRUCTURE	A10	Foundations	A1010	Standard Foundations								
				A1020	Special Foundations								
				A1030	Slab on Grade								
		A20	Basement Construction	A2010	Basement Excavation								
				A2020	Basement Walls								
B	SHELL	B10	Superstructure	B1010	Floor Construction								
				B1020	Roof Construction								
		B20	Exterior Enclosure	B2010	Exterior Walls								
				B2020	Exterior Windows								
				B2030	Exterior Doors								
		B30	Roofing	B3010	Roof Coverings								
				B3020	Roof Openings								

Figure 3.14: Model Element Table (American Institute of Architects 2008).

3.6.3 BIM Roadmap by US Army Corps of Engineers

The BIM Roadmap by the US Army Corps of Engineers (USACE) outlines both the strategic and implementation plans for using BIM technology to improve USACE planning, design, and construction processes. With the adoption of BIM, the Design-Build model request for proposal template includes language to encourage contractors to use BIM as part of their responses. A phased set of strategic goals was developed by USACE to derive the greatest benefit from the industry move towards BIM while also managing technology and business process risk (Brucker et al. 2006).

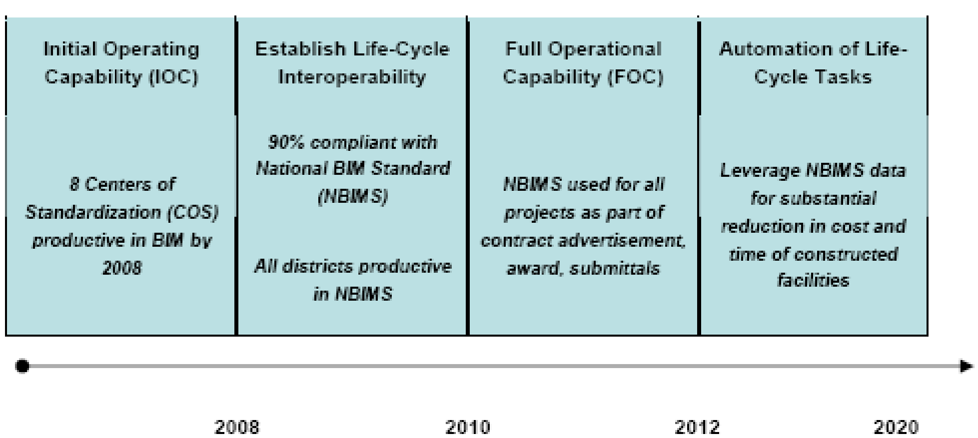


Figure 3.15: Long term strategic goals for BIM (Brucker et al. 2006).

This document includes the USACE strategic goals and objectives, BIM implementation plan, BIM design team work instructions, contract language and the implementation guidance (refer to Figure 3.15). However, the aggressive road map for the adoption of BIM has caused much confusion and forced many firms to rethink their own BIM adoption (Edwards 2009). The language of the roadmap claims to be "BIM neutral"; the realities, nevertheless, constrain the required files to be fully compatible with the USACE Bentley BIM v8 Workspace (Edwards 2009). The challenge is that the USACE needs the required files to be compatible with their chosen BIM application; but currently there is no workable translation process to convert files from other vendor applications to this format.

3.7 Chapter Summary

By reviewing the literature available, one can see that there is a need to develop a consistent procedure to assist project teams when planning the application of BIM on a project. Further, Fox and Hietenan (2007) have reported numerous potential barriers to the inter-organizational use of BIM models. It is an established fact that the potential of BIM is best utilized in an environment where all the project participants adopt and implement BIM on a project. Fox and Hietenan (2007) have documented that one of the challenges in implementing BIM is the inconsistency among processes which leads to variations in which BIM models are created.

The BIM Process Mapping Procedure aims to create a standardized procedure for planning the BIM execution on projects. It encourages the organizations to create their typical company workflows. Each of the responsible parties can then compile these different work processes from the various team members to evaluate the various exchanges. Once the information exchanges are identified, custom information exchange requirements for a task can be developed suiting the project needs and organizational capabilities.

Existing literature provides insights about the need for data exchange and the future potential of BIM in the construction industry. Literature review shows that the IFC standards are agreed and accepted by the industry and is widely implemented in software applications. However, the certification process still has some gaps and challenges which has rendered the certified software useless for practical applications of IFC. As for IDM/MVD, the standards are still under development and are not yet ready for implementation in the industry.

There are several available documents that discuss the elements that should be contained in a project execution plan. It is necessary to digest those documents into something that is straightforward for project team to use to document the process they will implement to successful apply BIM during a facilities' lifecycle. This chapter demonstrates the need to establish standard BIM Uses, a BIM Process Mapping Procedure, and Information exchange procedure and a supporting infrastructure procedure.

CHAPTER 4: BIM PROJECT EXECUTION PLANNING PROCEDURE

4.1 THE BIM PROJECT EXECUTION PLANNING PROCEDURE DEVELOPED

The research project is focused on designing a method to create a BIM Project Execution Plan. After research steps were completed, the research team developed a four-step BIM Project Execution Procedure, refer to

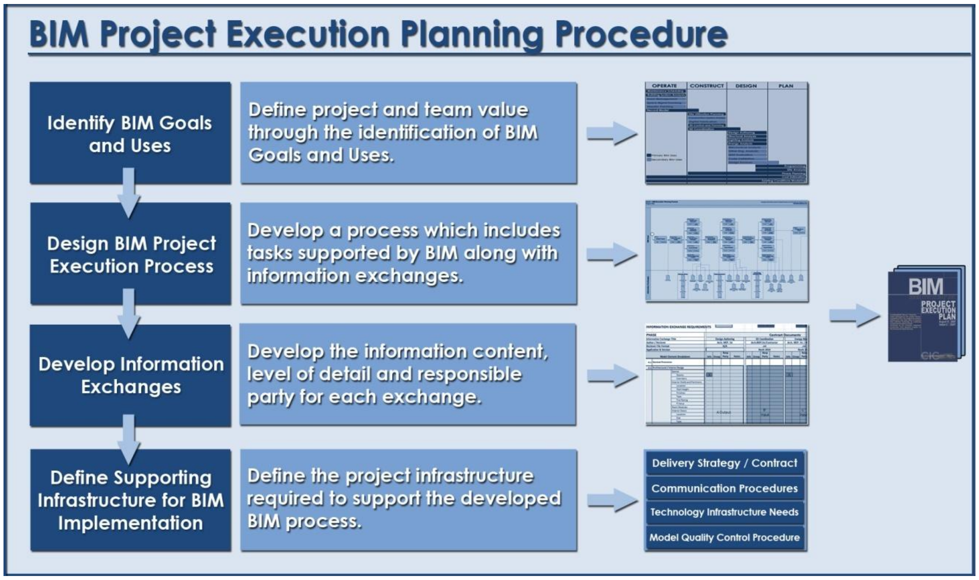


Figure 4.1, which includes:

1. **Identify BIM Goals and Uses:** The first step in the planning process is to clearly define the overall goals for BIM implementation. Once the team has defined their goals then the specific BIM uses on the project can be identified. This includes a review of BIM uses, starting from the operations phase of the project. Several examples of BIM Uses include design authoring, 4D Modeling, cost estimating, and record modeling. The team should identify and prioritize the appropriate uses for BIM they would like to perform on the project.
2. **Design the BIM Execution Process:** Once the team has identified the BIM Uses, Process Maps (PM) must be created for planning the implementation of the selected uses. This allows all team members to clearly understand how their work processes interact with the processes performed by other team members.
3. **Define the Information Exchanges:** After developing the appropriate BIM PM, the information exchanges which occur between the project participants need to be clearly identified. The information content for the exchange can be defined in the Information Exchange (IE) worksheet.
4. **Define the Infrastructure Required to Support the Process:** After identifying the BIM Uses; defining the PMs and developing the IEs; the team can then develop a detailed BIM Implementation Plan. It is important to include all project information relevant and supportive to BIM. Some of these categories include communication procedures, technology infrastructure needs, model structure and quality control procedures.

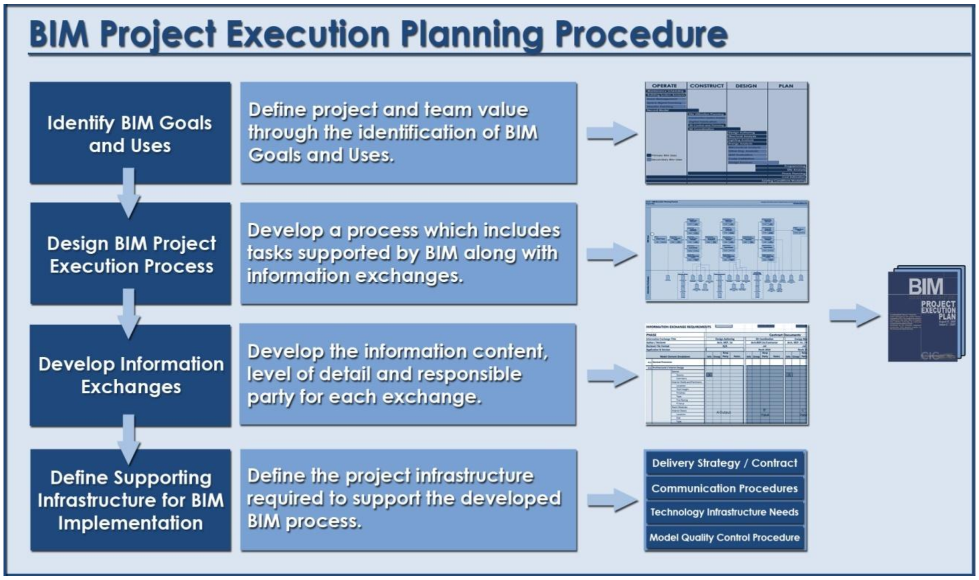


Figure 4.1: The BIM Project Execution Planning Procedure

Please refer to the BIM Project Execution Planning Guide for a detailed explanation of each step in the procedure.

CHAPTER 5: BIM GOALS AND USES

After the procedure was defined, each step needed to be further developed. The first step of the BIM Project Execution Planning Procedure was originally just to define BIM Uses. It was decided that this should also include establishing BIM Goals. To assist in project teams in defining why they are using BIM, a BIM Goal worksheet was created.

Furthermore the applications of BIM (BIM Uses) throughout the lifecycle of a facility were defined. To accomplish this interview questions were developed to identify current and future uses of BIM from industry experts. The interviews were then conducted and analyzed through detailed content analysis, resulting in a list of BIM uses along with preliminary information for each. The Uses were then organized into the different phases (plan, design, construct, and operate) of facilities lifecycle with multiple Uses spanning several phases. After an initial definition of the Use was defined by the research team, a graduate student was given each use for further definition as part of a graduate course on BIM. For each BIM Use, the student was to document a description, the potential values, the resources required, and the team competencies required. The student accomplished this through additional interviews and literature review. Each Use was compiled into a one-page description and later included in the guide and on the research project website. Additionally these Uses have been and continue to be further defined as the project proceeds.

A BIM Uses analysis worksheet was created to assist teams when selecting which BIM Uses will be utilized on the project. The worksheet guides the team through considerations of each BIM Use such as the value to the project, the responsible parties, the value to responsible party, the resources required, competencies required, and the experience required.

5.1 BIM GOALS

It is important for project teams to determine the reason for that they are using BIM in the first place. What goal will be accomplished by using BIM? The team should outline these goals prior to selecting what BIM Uses they will use on the project. To assist project teams when determining their goals for the Use of BIM on the project team created a simple BIM Goal Worksheet. See Figure 5.1 for a sample goal worksheet. A complete version of the worksheet can be located in the appendix.

Priority (1-3)	Goal Description	Potential BIM Uses
1 - Most Important	Value added objectives	
2	Increase Field Productivity	Design Reviews, 3D Coordination
3	Increase effectiveness of Design	Design Authoring, Design Reviews, 3D Coordination
1	Accurate 3D Record Model for FM Team	Record Model, 3D Coordination
1	Increase effectiveness of Sustainable Goals	Engineering Analysis, LEED Evaluation
2	Track progress during construction	4D Modeling
3	Identify concerns accosiated with phasing on campus	4D Modeling
1	Review Design progress	Design Reviews
1	Quickly Asses cost associated with design changes	Cost Estimation
2	Eliminate field conflicts	3D Coordination

Figure 5.1: Sample BIM Goal Worksheet

5.2 BIM USES[5]

A taxonomy of BIM Uses was created based on the literature review and the results from the expert interviews, and it identifies approximately 25 BIM uses, see Figure 5.2. After the taxonomy was produced, each BIM use was investigated in more detail for the BIM Execution Planning Guide.

[5] This section discusses various items associated with BIM uses. It starts with the identification of BIM uses that were developed from this research. Then it covers the topics of model content and level of detail, modeling process and software applications, team competencies, and legal, insurance and contractual considerations. The BIM Uses are outlined along with interview comments regarding the uses. The information obtained from the interviewees is reported and indicated with the designation of "[I-#]" to indicate the number of the interviewee that made the statement. Not all statements have been validated through research so the reader should only evaluate these statements as one opinion from an experienced person.

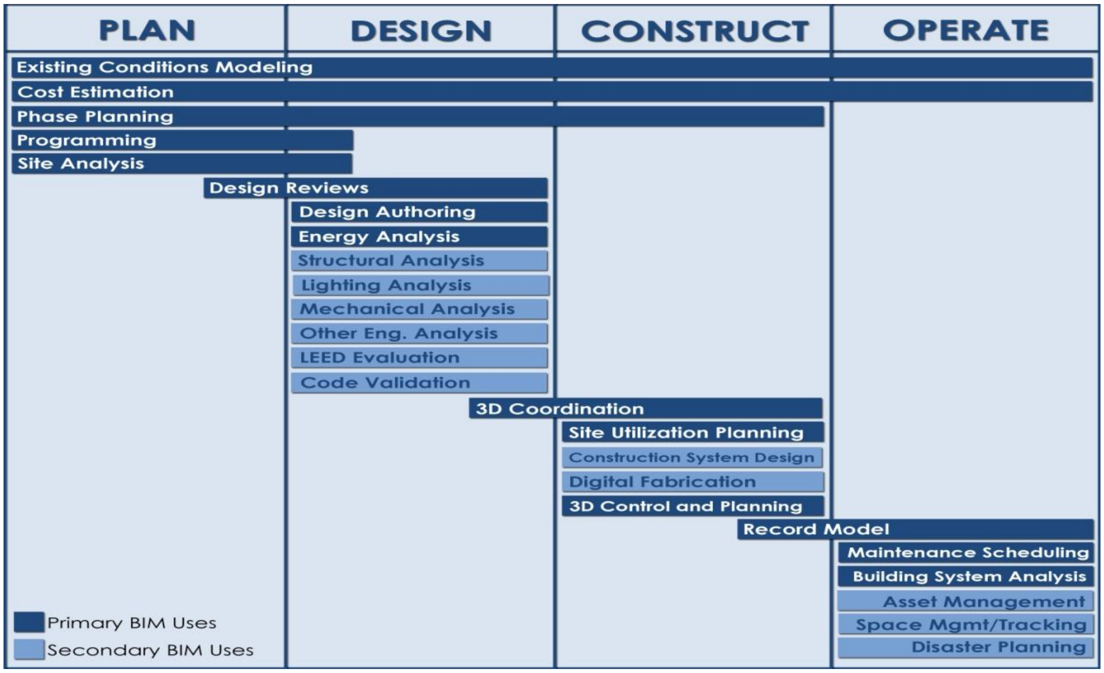


Figure 5.2: BIM Uses through the lifecycle of a Project

5.2.1 Design Authoring

Design Authoring is defined as a basic BIM use in which 3D software is used to create and develop a BIM model based on criteria that is important to the translation of the building's design (CIC, 2009). There are two types of applications at the core of a BIM-based design process (Tardif, 2008):

- Design Authoring tools and
- Audit and Analysis tools.

Authoring tools create models while audit and analysis tools analyze or add to the richness of information in a model. Design authoring tools are a first step towards BIM and the key is connecting 3D model with powerful database of properties, quantities, means and methods, costs and schedules (Tardif, 2008). Once created, a BIM model greatly enables communication of design intent to the client, consultants and other stakeholders. Most of audit and analysis tools, on the other hand, can be used for Design Review and Engineering Analysis BIM uses.

5.2.2 Programming

Programming is defined as a process in which a spatial program is utilized to efficiently and accurately assess design performance in regard to spatial requirements (CIC, 2009). It can also be defined as design discovery and definition [I-5]. Eleven design offices explained how they use BIM for programming purposes (61%). It is considered to be a very important part of architectural practice, since a design program is necessary and very valuable to develop while making critical decisions in this phase.

Programming brings most value to the project when needs and options are discussed with the client and the best approach is analyzed. Clients would rather not compensate designers for this service, but this mindset needs to be changed. Most benefits can already be reaped from BIM, since preliminary model is started at this point and it becomes schematic design, design development and finally construction documents. There is a lot of preliminary information and visual data offered to the client and all stakeholders at this point early in design development.

A good number of design firms still do programming in the traditional way with hand sketching, graphic blocks and elements, or using Sketchup for initial ideas, but this approach has no continuum with a BIM authoring tool [I-7]. Some of the available applications aid with blocking and stacking of programming relationships (OPS and Trelligence). During programming a lot of design analyses are done, and hundreds of schemes and different possibilities are generated. Then they are filtered out based on appropriateness, context, and performance, and presented to the client. The project team, by doing these initial design analyses, can be confident that the design is progressing in the right direction. Clients are usually impressed by the use of BIM in even the earliest phases of design [I-9].

BIM programming tools can present a tremendous labor saving device in ruling out bad design ideas early on. Presenting programming options and design visualization often help clients obtain funding for their projects and communicate their vision to the stakeholders [I-12]. Animated renditions and massing representations at the early stage of the project are always included in the proposal phase [I-14]. A few design offices have their own "home grown" programming tools and databases. These tools analyze space requirements and are automating the programming process based on little input, like number of employees, and build a program based on rules of thumb. OPS is one of the widely available BIM programming tools that is web based. It takes programming data, does number crunching, and produces utilization of spaces, special arrangements, as well as blocking and stacking of spaces. The software can then export the created information into the desired file format and to BIM authoring tool for further analysis and improvement [I-16].

5.2.3 Existing Conditions Modeling

Existing Conditions Modeling is defined as a process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility (CIC, 2009). One good example for this BIM use would be historic preservation of theatres which include complex interior spaces and many details. It is very expensive, labor intensive and time consuming to document existing conditions manually. 3D laser scanning, though pricey, is still far less expensive than sending design staff to remote job sites to document and manually enter data into CAD. Measuring existing conditions has little value for these specialized firms, so the business decision is to outsource existing condition modeling with 3D laser scanning and devote designers' time to high value adding tasks. Profit increases since no low-value work is done; cost decreases but not as much as time which leads to delivering projects months earlier [I-3].

5.2.4 Design Reviews

Design Reviews are a group of BIM uses. Design Review is defined as a process in which design is reviewed for constructability, coordination of systems and visualization of spaces and building details (CIC, 2009). They were covered in three categories: Constructability, 3D Design Coordination and Virtual Mockups. Majority of interviewed design offices use BIM for constructability and 3D design coordination purposes. A significant percentage mentioned they had used some form of virtual mockups for the clients, either for specific spaces or the building details. Value engineering in the traditional approach happens when the design is complete, while 80% of the cost of the building is determined in the first 20% of the design stage. The ability to affect cost is very limited to the last 20% of design; however value engineering is much more effective in the BIM environment. Design reviews early in design lead to fewer questions and less miscommunication between the design team members [I-17].

5.2.4.1 Constructability

Constructability is defined as a review of the building model along with plans and specification to determine constructability of the project and coordinate with other project participants (CIC, 2009). As part of design reviews, constructability is one of the most frequent BIM uses implemented by all the interviewed participants, since it is much easier to communicate construction details in 3D [I-5]. The contractor reviews the model and drawings in a back and forth process, trying to understand the design and distinguish different aspects and problems. The project team also runs clash detection and evaluates the design. In this process, a number of compromises need to be made to be able to hand off drawings fully coordinated [I-7]. This is one of the biggest benefits of BIM: eliminating tedious manual design review in exchange for more precise, fast, and visual review of building constructability.

5.2.4.2 3D Coordination

3D coordination is defined as a process in which 3D software is used to model the detailed designed building components, followed by automated identification of spatial conflicts between components through a collision detection algorithm. The conflicts can then be resolved by relocating building components (CIC, 2009). 3D coordination is currently used frequently, as well as constructability review done in collaboration with the contractor. In this case, it is up to the designer and consultants to resolve coordination issues on the design level. Software is also readily available to ease this 3D coordination effort like Autodesk Revit, Navisworks, Bentley Navigator, and Solibri Model Checker. Some comments from interviews included that BIM increases communicability with structural engineers and other consultants when used for coordination purposes. Instead of communicating every other day or weekly, some designers talk to consultants twice a day, since every design change has a lot of consequences in the model and usually needs to be discussed immediately [I-4]. The BIM model has a strong potential to illuminate a lot of errors that would occur in 2D drafting solely, and helps designers to stay on top of everything given that they are instantly notified of any changes. 3D coordination is easily the biggest bonus of BIM, with so many demands in place to coordinate different trades [I-6]. This primary use of BIM for error checking and conflict avoidance and resolution leads to developing better and more coordinated documents, fewer change orders, and better designed buildings overall [I-7].

5.2.4.3 Virtual Mock-up

A Virtual Mock-up is defined as a review of the building model used to showcase the design to the stakeholders and evaluate meeting the program and set criteria (CIC, 2009). It is mostly done either in complicated projects for construction details like wall sections or ceilings, or for certain chosen spaces in the project that would benefit greatly from building the virtual mock-up. Examples for those chosen spaces can be courtrooms, operating rooms, patient rooms, auditoriums, concert halls, or any space that would benefit from review and testing by its future end users and clients making the investment. Other software, not necessarily BIM, can be also used for visualization like Autodesk Impression, 3D Studio Max and Sketchup. However, visualization is not the ultimate goal since it is as well part of the architectural design [I-4]. Mock-ups can be also done of a whole campus, a few buildings, or typical spaces to communicate to the client what the next project could be [I-6].

Most important, mockups are usually done in healthcare facilities to test operating rooms, patient rooms and nurses' stations and ensure all equipment, medical gas delivery, and utilities can properly reach and take care of patients. Digital simulations are usually very valuable to check that relationships are proper and to get the approval from the end users: doctors and nurses. For example, the sightlines are crucial in visualizing the patients from the nursing stations. User group meetings occur early in schematic design phase to discuss sightlines and position of medical equipment in interactive work sessions with architects, engineers and medical equipment manufacturers [I-9].

Engineers can also benefit from virtual mock-ups if this technique is used to mock-up some unusual geometry and analyze how building components fit together in space [I-11]. Marketing aspect for clients is also important especially in high end projects where taking a virtual walking tour of building with various interior schemes can yield better sales in the end for the investor [I-16]. At the same time, it is good to keep in mind that full size mockups cannot sometimes be simulated realistically on computer, and the software and hardware might need to advance for virtual mockups to be a full success [I-15].

5.2.5 Site Analysis

Site Analysis is defined as a process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project. The site data collected is used to first select the site, and then position the building based on engineering criteria (CIC, 2009). Only five design offices mentioned potential usage of BIM for the purpose of site analysis (27%), and a large number of interviewees were not even sure exactly how to use BIM for this type of analysis. However, they perceive tremendous potential in doing calculations, orientation studies, topography, modeling existent and future underground utilities, etc. Sometimes site analysis is more part of environmental or civil engineering and not performed by architectural designers but outsourced to consultants [I-10]. Available software that can take part in site analysis is: Google Earth Pro, Geographic Information System (GIS) [I-12], Ecotech, Sketchup, Geopack Bentley, and Autodesk Civil 3D [I-18].

5.2.6 Engineering Analyses

Engineering Analysis is defined as a process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications. Development of this information is the base for what is passed on to the owner and/or operator for use in the building's systems (CIC, 2009).

BIM model as a virtual representation of a facility with its digital database enables various engineering analyses. These analyses and performance simulations can significantly improve the design of the facility and the energy consumption during its lifecycle in the future. Audit and analysis tools (Tardif, 2008) play a key role in analyzing building information models or adding to the richness of information in a model. Applications typically focus on one analysis area such as structural analysis, energy modeling or mechanical analysis.

5.2.6.1 Structural Analysis

Structural Analysis is defined as a process to develop analytical structural representation of a building model, document the information needed for the third party analysis application and integrate it with the structural design model (CIC, 2009). This BIM use, as part of various engineering analyses, was mentioned mostly by AE firms or specialized structural engineering firms. Usually, this service is outsourced from architects to consultants. Currently structural analysis cannot be done directly in the BIM authoring software, but by using some of the external applications or a 3rd party software since there is no direct way to do analysis and make changes in the authoring software [I-15].

There are several software applications that support BIM for structural analysis: ETABS/SAP, RAM Structural System/RAM Advanse, RISA, STAAD, ROBOT, etc (Khemlani, 2007). With BIM, the analytical and the building models are created simultaneously, thereby improving workflow and reducing the chances of error. Without BIM, individual models must be produced to initiate each type of structural analysis. A common complaint of structural firms is that their highly educated staff spends too much time transcribing information from one software package to another, configuring various analytical models for input into different analysis software applications, and then manually coordinating the analysis and design results with documentation (Autodesk, 2008). Integration of structural analysis with BIM can drastically improve documentation of design information and facilitate the collaboration between the architects and the structural engineers.

5.2.6.2 Energy Analysis

Energy Analysis is defined as a process to predict energy loads and usage in a building and to provide multiple alternatives and strategies for better energy performance (CIC, 2009). This type of analysis was done even before BIM emerged in the AEC industry, but usually too late in the design process to incorporate the results of the analysis for life cycle cost evaluations and value engineering. There is an abundance of energy modeling and analysis software. An extensive list of available applications can be found online in the Building Energy Software Tools Directory (see References). The software most frequently mentioned and used by the interviewees was: Ecotech, IES, and Green Building Studio. These tools try out different design scenarios and examine the energy model change [I-7] while decisions about shape, orientation and fenestration pattern are made to fine tune the design. Ideally, the energy modeling tools should be in hands of designer, since often decisions are made quickly in design before energy analysis results can be even brought on board [I-16]. Climate Control software is another application offering basic energy modeling information for site conditions with option to download all wind, rain and sun information for the site. Adding those tools to the BIM model, as the design progresses, aids tremendously site analysis and sustainability efforts [I-18].

5.2.6.3 Lighting Analysis

Lighting Analysis is defined as a process in which various lighting scenarios are explored to determine efficient use of daylight and reduce lighting energy use for the optimal building performance (CIC, 2009). This analysis is considered to be part of engineering analysis and can be also part of sustainability evaluation: however it was not further elaborated on by the interviewees or part of their expertise. Some BIM tools for lighting analysis are still very rudimentary, but when they become more integrated in one database, more rich capabilities will be extracted out of them [I-7]. This sort of analysis in done independently by lighting designers and consultants, but can be also part of sustainability criteria analysis in order to achieve the Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ points.

5.2.6.4 *Mechanical Analysis*

Mechanical Analysis is defined as a process in which various scenarios are explored to determine efficient use of mechanical systems (Heating, Ventilating, and Air-Conditioning – HVAC) for the optimal building performance (CIC, 2009). This analysis is not fully developed since mechanical BIM tools are lagging behind the architectural and structural ones. Most consultants choose not to use these tools yet, though they might be experimenting with them. Some interviewees felt that existing mechanical BIM software is not set up yet to work with large projects and it will take 3-5 years for a more integrated design solution to emerge and to build confidence in this software to be used on more complex projects [I-7].

5.2.6.5 *Other Engineering Analyses*

Many engineering analyses which can be performed might have not been mentioned in the expert interviews, since they were rarely done, still not well developed, unknown to the interviewees or maybe just done by their consultants depending on the project requirements (i.e., acoustical analysis, etc). For these analyses, a category "Others" is added to the taxonomy of BIM uses in design. Please refer to Figure 7-2 for more details. Some of the possible other analyses that can be done which have been referenced in literature include:

- Earthquake Analysis,
- Fire Protection Analysis,
- Acoustical Analysis,
- Forensic Building Analysis,
- Moisture Intrusion Analysis,
- Microbial Investigations, and
- Infrared Analysis.

5.2.7 Sustainability Criteria Analysis

Sustainability Criteria Analysis is defined as a process in which all sustainable aspects and features of a building are tracked in order to obtain the desired sustainable certification by condensing various criteria analyses into a single database (CIC, 2009). This analysis is done by almost all interviewed design offices and it is part of their everyday practice, but most are doing the evaluation the traditional way and have no full BIM capabilities yet in this area [I-4]. Energy and lighting analyses are mostly used to complement sustainability evaluation and secure the Leadership in Energy and Environmental Design (LEED) points [I-7]. Though sustainability and energy modeling start to be core beliefs of the interviewed companies, with all projects turning green or having a sustainable component to them, software is still disconnected from the rating system and reporting points. One interviewee stated that no sustainability evaluation can be done in one model nor can all the points be recorded from one model. Some of the obvious obstacles are how o do innovation points or thermal comfort points when survey results are needed for these [I-8]. Autodesk is currently working with the U.S. Green Building Council (USGBC) on unique software to track all the sustainability points [I-10].

Another interviewee stated that since the technology does not have the capability to do the environmental analysis for the sustainability efforts, design offices combine available software capabilities with spreadsheets to keep track of the achieved points. For example, a tracking sheet in Autodesk Revit can be used for certain points while Ecotech is utilized to confirm rules of thumb, building orientation, do comparative cost studies, thermal analysis, etc [I-15]. Also, an external database can be used from which designers can pull pertinent information about systems and products into the BIM model. Instead of building the information into the content, designers can outsource the sustainable evaluation to an external database for analysis [I- 16]. This type of evaluation usually requires an internally developed score card; time dedicated to research and deciding with the clients what level of sustainability is desired; design elements that can be achieved; and how sustainability affects the program set from the beginning of the design process [I-18].

5.2.8 Code Validation

Code Validation is defined as a process to check the building design for compliance with project specific codes by using the 3D BIM model (CIC, 2009). This analysis was identified as another important BIM use from the literature, but the majority of the interviewees responded that they are still manually checking codes. Several design offices are trying to move forward in this direction (16% of interviewed firms), but the software is not readily available or trusted for this purpose yet. Solibri Model Checker is software that can be used for checking the project design for code compliance as well as checking General Services Administration (GSA), National Standard and military requirements (calculate egress, circulation paths, etc). The International Code Council (ICC) project Smart Codes can also perform code checking and validation [I-3]. Site and code restrictions should be investigated first and then generate design solutions, but it is important to note that codes are very open to local interpretation [I-5].

Code checking for structural design can be done only in design analysis software such as RAM for steel and ADAPT for concrete, and then the design can be imported back into the BIM authoring tool [I-11]. Egress paths, fire rated walls, ADA requirements, turning radiuses can all be checked or highlighted as they relate to the local codes and help designers to facilitate data evaluation [I-14]. But code officials have not yet been able to use electronic data for code review, though this might be possible in the near future [I-18].

Two more BIM uses were identified from the literature under Code Validation, though not being as frequent or utilized by the interviewees: Emergency Evacuation Planning and Security Validation. These two BIM uses are not further elaborated, but their definitions are as follows. Emergency Evacuation Planning is defined as a process to plan an emergency evacuation strategy using 3D BIM model navigation and simulation, and have it evaluated, improved and communicated to the client, end users or interested parties (CIC, 2009). Security Validation is defined as a process to analyze building security by using 3D BIM model navigation and simulation and provide better understanding of the security system vulnerabilities (CIC, 2009).

5.2.9 Cost Estimating

Cost Estimating is defined as a process in which a BIM model can offer a reasonably accurate quantity take-off and cost estimate early in the design process and provide cost effects of additions and modifications with potential to save time and money and avoid budget overruns (CIC, 2009). It is one of the unusual BIM uses in the design phase, since it is traditionally done by the contractor or a hired cost estimator, but it is very useful at this stage of the process. A significant number of the interviewees responded that they might be able to provide quantity takeoffs from the BIM model and possibly even cost estimating, however they have not been asked to provide those services yet. At this time, it is difficult to suggest new services, since clients are not willing to pay more and the construction market is down [I-4].

One of the questions to be addressed is who is responsible for the data in the model used for quantity take-offs and if contractors would accept the responsibility, since designers provided the information and the BIM model [I-5]. The contractor would still need to do detailed costing, but some tasks which overlap with budgeting and scheduling between design and construction might exist [I-7]. The early cost estimating by designers can be used to back check certain suspicious aspects and offer early estimates of costly items, intended for value engineering efforts. BIM models need to be very accurate to do take-offs, and mutual agreement between designer, consultants and contractor has to be achieved on which building components can be modeled or drafted in more informal fashion. If the BIM model is not intended to be handed off to the contractor, it may not be acceptable later to be used as an estimating, fabricating and contracting tool. This leads to a cultural shift in how we approach the model in terms of the level of seriousness, because contractors have expectations that need to be better understood in order for the model to be shared. At the same time, the legal structure needs to catch up so handoffs can be more smooth in the future. Also, one interviewee felt that the issue of added value of the correctly built model needs to be addressed as added service and fee for the designer, if the model is being built from the beginning for the purpose of being used in construction and operations [I-9].

When estimates are performed faster and earlier in design, the clients can make easier decisions in which direction to go since they are more aware of the ramifications of chosen materials [I-10]. Half of the battle is to get accurate material quantities, which the BIM model can provide. This leads to a better understanding of construction cost during preliminary stages of design [I-11]. Even basic comparative studies can be very useful, like comparing metal panel vs. glass vs. brick.

One of the available software applications, US Cost Success Estimator, establishes the link between the BIM model and the RS Means database. Anytime a change is made and exported to the ODBC database, the calculations can be quickly run again and give the designer a fairly accurate estimate of the cost fluctuations [I-15]. Another approach would be to extract the information from the BIM model and connect it to cost estimating sources externally, and not bring cost data to the model.

Cost estimating gives designers more power and control over value engineering exercises. The estimator usually has no association with visual ramifications of the decisions and focuses on cost of materials only. Designers understand the problem visually and spatially, and can make decisions about cost more effectively, understanding the impact on the environment [I-16].

5.2.10 Phase Planning (4D Modeling)

Phase Planning (4D Modeling) is defined as a process in which a 4D model (3D model with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit or addition, or to show the construction sequence and space requirements on a building site (CIC, 2009). 4D modeling is usually associated with adding time or schedule to the BIM model and used for construction and trade coordination purposes on the job site. Phase planning can be used to understand better phases of a project and their demarcation when moving people from one to another building in case of renovations [I-7]. Projects can be phased as well by cost loaded schedule, by construction, by occupancy, etc. If a project is fast tracked, then adequate management is needed for architectural scheduling and phasing in case the phasing affects what the space will be at any given time (occupied but needs to be phased in, swing space to move people around, etc) [I-8].

4D modeling can also help the client in interviewing the construction managers on how the project will be phased [I-9]. Phase planning can be done for space utilization when the model is phased to illustrate graphically people moving through the space due to renovations or tenant fit-out [I-12]. This can also be part of the service market for architects, though sequencing is traditionally done by the contractor. Understanding durations of tenant fit-out activities and having additional information can lead to more intelligent decisions in the end [I-10].

Considering space utilization and planning, building managers are always trying to understand the spaces in the building better and how they are being used, but tools at their disposal are typically completely separate from the design information and never up to date and accurate. If space utilization information is part of the BIM model, it can be used for complete analysis of building spaces and the design documentation would continuously be updated. On the other hand, if information can be pulled into external database, then it can be used in the operations or facilities management and portfolio management system [I-16].

5.2.11 Construction System Design

A process in which 3D System Design Software is utilized to design and analyze the construction of a complex building system (e.g. form work, glazing, tie-backs, etc.) in order to increase planning (CIC, 2009).

5.2.12 Site Utilization Planning

A process in which a 4D model is used to graphically represent both permanent and temporary facilities on site, with the construction activity schedule. Additional information incorporated into the model can include labor resources, materials and associated deliveries, and equipment location. Because the 3D model components are directly linked to the schedule, site management functions such as visualized planning, short-term re-planning, and resources can be analyzed over different spatial and temporal data. (CIC, 2009).

5.2.13 Digital Fabrication

A process that utilizes machine technology to prefabricate objects directly from a 3D Model. The 3D Model is spooled into appropriate sections and inputted into fabrication equipment for production of system assemblies (CIC, 2009).

5.2.14 3D Control and Planning

A process that utilizes a model to layout the building assemblies and produce lift drawings. Lift drawings are 2D/3D component drawings used by foremen during on site construction (CIC, 2009).

5.2.15 Record Model

A process used to depict an accurate representation of the physical conditions, environment, and assets of a facility. The record model should, as a minimum, contain information relating to the main architectural and MEP elements. Additional information including equipment and space planning systems may be necessary if the owner intends to utilize the information. Furthermore, with the continuous updating and improvement of the record model and the capability to store more information, the model contains a true depiction of space with a link to information such as serial codes, warranties and maintenance history of all the components in the building. The record model also contains information linking pre-build specification to as-built specifications. This allows the owner to monitor the project relative to the specifications provided (CIC, 2009).

5.2.16 Building Maintenance Scheduling

A process in which the functionality of the building structure (walls, floors, roof, etc) and equipment serving the building (mechanical, electrical, plumbing, etc) are maintained over the operational life of a facility. A successful maintenance program will improve building performance, reduce repairs, and reduce overall maintenance costs (CIC, 2009).

5.2.17 Building System Analysis

A process that measures how a building's performance compares to the specified design. This includes an analysis of the mechanical system operational characteristics including the energy use of a building. Other aspects of this analysis could include, but are not limited to, ventilated facade studies, lighting analysis, internal and external CFD airflow, and solar analysis (CIC, 2009)

5.2.18 Asset Management

A process in which an organized management system will efficiently aid in the maintenance and operation of a facility and its assets. These assets, consisting of the physical building, systems, surrounding environment, and equipment, must be maintained, operated, and upgraded at an efficiency which will satisfy both the owner and users at the lowest appropriate cost. It assists in financial decision-making, as well as short-term and long-term planning. Asset Management utilizes the data contained in a record model to determine cost implications of changing or upgrading building assets, segregate costs of assets for financial tax purposes, and maintain a current comprehensive database that can produce the value of a company's assets (CIC, 2009).

5.2.19 Space Management and Tracking

A process in which BIM is utilized to effectively allocate, manage, and track assigned workspaces and related resources. A BIM model will allow the facility management team to analyze the existing use of the space and appropriately manage changes in clientele, use of space, and future changes throughout the facility's life. Space management and tracking is an application of the record model (CIC, 2009).

5.2.20 Disaster Planning

A process in which emergency responders would have access to critical building information in the form of a model and information system. The BIM would provide critical building information to the responders that would improve the efficiency of the response and minimize the safety risks. The dynamic building information would be provided by a building automation system (BAS), while the static building information, such as floor plans and equipment schematics, would reside in a BIM model. These two systems would be integrated via a wireless connection and emergency responders would be linked to an overall system. The BIM coupled with the BAS would be able to clearly display where the emergency was located within the building, possible routes to the area, and any other harmful locations within the building (CIC, 2009).

5.3 BIM USE ANALYSIS WORKSHEET

To assist project teams when determining what BIM Uses they should apply during the project's lifecycle, the research team developed an excel spreadsheet to guide the team through the process. The worksheet, (see Figure 5.3) includes:

- Each BIM Use
- The value to the project of that BIM Use
- The Party Responsible for performing that BIM Use if pursued
- The Value to the responsible party (note that a use may not be of high value to the person performing the BIM Use but may still be very beneficial to the project)
- A capability rating for teams to determine if they have the resources, competency and experience to perform the BIM Use
- Additional Resources / Competencies Required to Implement the BIM Use
- General Notes about the BIM Use
- A place to note whether or not the project team has decide to proceed with the BIM Use

BIM Use*	Value to Project	Responsible Party	Value to Resp Party	Capability Rating			Additional Resources / Competencies Required to Implement	Notes	Proceed with Use
	High / Med / Low		High / Med / Low	Scale 1-3 (1 = Low)					YES / NO / MAYBE
				Resources	Competency	Experience			
Record Modeling	HIGH	Contractor	MED	2	2	2	Requires training and software		YES
		Facility Manager	HIGH	1	2	1	Requires training and software		
		Designer	MED	3	3	3			
Cost Estimation	MED	Contractor	HIGH	2	1	1			NO
4D Modeling	HIGH	Contractor	HIGH	3	2	2	Need training on latest software	High value to owner due to	YES
							Infrastructure needs	phasing complications	
								Use for Phasing & Construction	
3D Coordination (Construction)	HIGH	Contractor	HIGH	3	3	3			YES
		Subcontractors	HIGH	1	3	3	conversion to Digital Fab required	Modeling learning curve possible	
		Designer	MED	2	3	3			
Engineering Analysis	HIGH	MEP Engineer	HIGH	2	2	2			MAYBE
		Architect	MED	2	2	2			
Design Reviews	MED	Arch	LOW	1	2	1		Reviews to be from design model	NO
								no additioanl detail required	
3D Coordination (Design)	HIGH	Architect	HIGH	2	2	2	Coordination software required	Contractor to facilitate Coord.	YES
		MEP Engineer	MED	2	2	1			
		Structural Engine	HIGH	2	2	1			
Design Authoring	HIGH	Architect	HIGH	3	3	3			YES
		MEP Engineer	MED	3	3	3			
		Structural Engine	HIGH	3	3	3			
		Civil Engineer	LOW	2	1	1	Large learning curve	Civil not required	
Programming	MED							Planning Phase Complete	NO

* Additional BIM Uses as well as information on each Use can be found at http://www.engr.psu.edu/ae/cic/bimex/

Figure 5.3: A Portion of the BIM Use Analysis Worksheet

5.4 MODEL CONTENT AND LEVEL OF DETAIL

Model content and level of detail are very important questions to address when building a model, since BIM software applications have the ability to embody a tremendous amount of detail. All the information usually never gets added due to this process being very time consuming, laborious, and typically not the responsibility of the designer [I-3]. That is the main reason why owners and designers are struggling on how to define the best level of detail and extensive but limited list of model contents.

One of the next steps in the BIM revolution would be manufacturers providing designers with their product data, moving BIM to a new level. Currently model content carries geometry and some limited information, but few elements have finishes, pricing, specifications, etc. A few manufacturers offered libraries of their products with all selections, but now they are hesitant to share this information due to liability for misrepresentation and outdated pricing. This is one of the biggest roadblocks to implementing product selection in Building Information Modeling [I-5]. Best practices need to be established for using BIM in design offices. Currently, the size of the model can easily become an issue due to the amount of information that can be embedded. To resolve this, components are sometimes simplified, grouped and even drafted with 2D lines and planes. Standards need to be created so that a model component can be detailed for rendering purposes at one instance, but not copied in that complex form thousands of times throughout the project decreasing model manageability [I-6].

One of the design offices suggests the approach of model granularity, which is decided per project by a design team in collaboration with all project participants considering future information needs. Model contents depend on the contract and if the client has a level of detail or granularity requirements. If a greater level of model granularity is agreed upon, more work and coordination efforts are needed. For example, guidelines for modeling the building elements suggested by one design firm: mechanical ducts 10” or more, electrical conduits 2.5” or more, slab penetrations over 6x6”, etc. They made these suggestions since small pipe is rarely a conflict or reason for change order, but ductwork conflicting with the beam is frequently a problem. The contractor would be able to decide on the best place for pipe less than 2” that is economical and works well, or route it differently based on cost. BIM modeling guidelines can be even more rigorous with modeling pipes less than 2”, but it all depends on the contract and agreement with the contractor and owner on the best value approach [I-7].

Another option would be to outsource the creation of the library and model components, and instead of spending internal human resources, spend financial resources [I-8]. The winning combination of the model components and level of detail still needs to be developed. For an example, if a healthcare facility model is loaded with medical equipment components, the BIM model gets very cumbersome. It is important to be mindful of how the model is built, so that a minimal amount of remedial work needs to be done when it is handed off to the contractor, owner or facility manager [I-9]. Another thing to keep in sight is the Construction Operations Building Information Exchange (COBIE) standard and how to enter the data as it is created during design construction, and commissioning, and collect it later on from the model for facility management.

Setting BIM standards is an ongoing and very important endeavor. As owners get more sophisticated and project requirements increase, the future might bring even more detailed BIM models than today. Since the ultimate goal would be to have one model started by a designer and shared along the way, the model needs to be setup properly from the beginning and be more robust if serving more groups (architects, consultants, contractor, subcontractors, fabricators, manufacturers, facilities managers, etc). Currently designers and contractors rarely share the model or have handoffs. Therefore, designers may take shortcuts while modeling because of time constraints and less requirements in place [I-10]. For example, structural BIM model contents would depend on the objective. If a model is used for conflict avoidance, only major structural members defining the geometry of the structure would be included. No mesh or rebar in the concrete would be modeled in this case, since it does not affect the geometry. If the model is developed for construction purposes, then it may have every piece of rebar and all these elements need to be smart and carry properties or information. The model in this case would be much more complex, and the level of detail and the file size would increase dramatically. But these more comprehensive BIM models are currently hard to find. It is in the owner's best interest, however, to invest in this new BIM technology. If a very precise model is provided, everyone would have the same information, and the bids on the bid day would be much tighter [I-11].

The BIM applications are setup in a way that more information is required than the client actually needs or the designer is eager to share. The decision of when to stop modeling has to be seriously considered to avoid more exploration and technical development, getting lost in details, and doing more work than is required for a successful project. This is one of the initial struggles of designers when a project is started in BIM [I-14]. One of the design offices interviewed supports a common sense approach and has a rule of thumb about what to model and what to draft instead. They previously aimed to model everything, but the BIM model got too complicated, slowed down and had performance issues. If the manufacturer's components are used, caution should be taken since the abundance of information provided and very precise modeling can slow down the model and decrease its manageability [I-15].

Another approach would be to have a central library built with generic content, not manufacturer specific. Each project would track more specific information at a project level and not a master central library level. A special group can be formed to create content only based on the staff feedback and project needs. An interesting solution has been developed by McGraw Hill and launched in May 2008: Architect's Design Studio tool (www.architectsdesignstudio.com). This BIM application contains external manufacturers' database with product information, not a library of objects. The BIM model is queried, exported to Architect's Design Studio online, and all the building components are organized in a search for a good product match. At this instance, a designer can explore all manufacturers who can provide that product as part of the database, including the cost data. When the products are chosen, their attributes and information can be easily taken back to the model (depending on the application). This seems to be a very good solution to model content when you start generic, explore, make decisions, and add information back to the model to continue with design development [I-16].

5.5 MODELING PROCESS AND SOFTWARE APPLICATIONS

The process used to create a model was described briefly by each interviewee. Software applications were also mentioned and commented on, however, an extensive list of currently available BIM software can be found online under specific vendor names.

Design office No.1 [I-1] decided to cross train its staff on both major BIM platforms now available (Bentley and Autodesk), which gives them more leverage between these two software providers. The staff can move laterally between the two and play out the strengths and weaknesses of both. So far this design office has been sharing the model in a design-build project delivery, though the model is strictly marked for informational use only. BIM model uses, type and quantity of information included, are tracked when it goes into construction [I-1]. In order to share models, a unified approach is recommended due to interoperability issues [I-2].

Some of the most frequent software applications used are: Triforma, Microstation (Bentley), AutoCAD, Architectural Desktop (ADT), Autodesk Building Systems (ABS), Revit, Navisworks (Autodesk), Archicad (Graphisoft), Gehry Technologies Digital Projects, Integrated Environmental Solution (IES), Ecotect, Green Building Studio, etc [I-7 and 8]. A good portion of design offices have built templates from which they start their projects in a form of customizing a standard BIM file with certain wall types and materials uploaded, and have the other ones erased [I-12]. Design offices make a distinction between full BIM (social BIM) implementation when the model is shared with the contractor, and BIM light (lonely BIM) when the model is used just for conflict resolution. The contractor in this case never sees this model or benefits from it, but possibly is constructing his own model for coordinating the trades [I-11]. The AEC industry is slowly moving towards a social BIM concept in which models are shared and handed off from designers and consultants, to contractors and facility managers at the end covering the whole lifecycle of the building.

5.6 **TEAM COMPETENCIES**

Various team competencies were listed as important by the interviewees. Solid BIM training is considered to be one of the crucial competencies to be successful in BIM implementation. Senior designers have the design and construction knowledge, but might not know the software, while the young staff is comfortable using the software, but seriously lacks the building experience. Synergy of the team in this time of change is very important [I-7]. No designer can operate by himself since teamwork is essential and everyone becomes connected with the rest of the team [I-6]. People need to be brought together and start team building from day one, since decisions made would impact everyone down the line, internally and externally [I-10].

Company management needs to understand BIM on both a corporate and strategic level. Project management and senior staff need to make a cultural shift from drafting to modeling. More collaboration, verbal and digital communication, is happening in the same database at the same time, so there is a necessity for everyone to be a team player [I-8]. Database management is offering a different approach to design. The project is structured using worksets, and a designer is having other coworkers locked out of his workset when modifying the project database [I-9].

Team composition also changes, given that a smaller number of more experienced people is more effective on a BIM project. A number of interviewees agreed that more senior staff is needed up front to get the model setup, get going in the right direction, and make serious decisions early on in the schematic stage of design. Staffing level, then again, is more of a horizontal line, there is no more adding staff later on since the staffing is much more uniform [I-11].

Some of the listed skills are: problem solving, positive attitude, flexibility, collaboration, communication, coordination, and knowledge of design disciplines and design tools [I-12]. Everyone needs to be trained in BIM software, have a consistent understanding of the technology and apply it in equal fashion throughout the team [I-14]. Agreement on how much to model and how much to draft along with model setup, and a concept of work sharing are crucial after proper training. Every change made can and will affect the entire team, which raises the question about liability [I-15].

BIM gives the opportunity to better manage the project team and a better way to mentor,since senior staff is spending more time with junior staff as the model is progressing [I-16]. Due to the change in practice, it is imperative for senior people to lead the building technology effort. In order to build a model, construction knowledge is a must, and nothing can be hidden in the model like in 2D drawings. Building the model virtually is like building the project and the knowledge of building technology is required. Most design offices stressed the importance of a senior designer sitting with junior staff, and while they are running the model, the senior person's input moves modeling faster, making quick decisions about products, coordination and model contents. To achieve a smooth transition from college to the working environment, it is up to higher education institutions to teach young designers building technology and not just design [I-18].

5.7 Legal, Insurance and Contractual Considerations

Legal, insurance and contractual considerations were identified by the interviewees as one of the most important issues to address with the implementation of new technology. Many design offices are adding some BIM contract language to limit their liability, to start by using the BIM model for information only. In that case, after the model is handed off, if anyone is making changes or modifying the design somehow, the design office is not responsible for those changes [I-1].

One interviewee stated that sharing drawings in the form of AutoCAD files (DWGs) usually went along with a disclaimer, electronic paralegal agreement, or the drawings were delivered in read only (DWF) format where the original can be altered, but the file cannot be saved. BIM needs to have a similar approach with a disclaimer on how to share the model. However, many clients are not requiring BIM models yet, and so there is no urgency to deliver and protect the model. However, if everyone is sharing the benefits, everyone needs to share the risk together [I-4]. Responsibility has to be allocated when models, information, and data are shared. Until this is resolved, BIM model will not be shared with the contractor, facility manager or owner unless the barriers are removed. Nowadays, owners mostly are still not using the data provided in the model, and since software and file formats become out of date fast, migration policies for data received need to be in place to handle this transition [I-5].

The American Institute of Architects (AIA) offers a contract for sharing the electronic model, but there are no precedents available yet. BIM contract language started to appear, but most of it is untested so far. The legal system has not fully reacted yet, given that case law drives contracts and someone has to be on trial first for contracts to fully develop [I-7].

Contractual relationships are needed for teaming and collaboration. If the contractual relationship exists with the owner only, then not everyone is on the same team at the end of the day. Handing the model over is still considered high risk, because responsibility for the data is not defined yet, which is against open standards, collaboration and communication. A better environment is created in design-build relationship, when the designer and contractor are working together before construction documents are complete. Owners, who have a long term investment in lifecycle maintenance of the building, create requirements knowing that BIM has to be incorporated in contractual relationship [I-8].

One interviewee stated that the AIA has an ongoing effort to utilize integrated project delivery (IPD) and share the profit pool as a way of the future. Using BIM is another vehicle to make this change in project delivery happen. In this case, everyone is on the same team and usual frictions between project participants are not that evident. IPD offers a different legal structure from anything before, in a form of true partnership, and traditional fighting is eliminated or reduced. Early interaction with the contractor, his engagement and intervention are very beneficial. If the designer and contractor work together on constructability and market forces, designing a project that the owner cannot afford can be avoided. The BIM model started by the designer is usually not used for fabrication purposes, since a different level of effort would be needed and more serious approach to building the model. Many of the interviewed designers voiced that if the model is handed off and the owner is getting the benefits of the early intelligence, design offices would like to expect nominal additional fee for the model creation as compensation [I-9].

One interviewee [I-10] stated that there is no case work to show that BIM projects are more or less risky, therefore the insurance rates are not impacted. BIM is actually seen as being less risky down the line, because the conflicts that tend to lead to claims are avoided, and possibly the rates would be reduced for everyone. Though there are no insurance impediments, the questions about model ownership, control, responsibility and defining risk have to be addressed sooner or later [I-11].

Electronic information in a model is authored, signed and sealed, and if changes are made, there are records of them. Designers are still obliged to provide 2D drawings as contractual documents, but for them to be replaced by the model, it is very important for different platforms to be completely compatible, work in any format and export generic BIM that can be imported or exported to any other BIM software [I-12]. Industry Foundation Classes (IFC) might be the answer to bridge this gap, though as the basic bare bones model; it is the lowest common denominator between various BIM software applications [I-15]. New contracts will need to be drafted that are specifically incorporating BIM technologies and the limitations the client would have to adhere to if receiving the model instead of set of construction documents [I-14].

BIM implemented in design offices can lead to less risk since drawings are tighter and analyzed better. However, when the model is being shared, there are a number of unknowns and no strong separation between design and construction. Contractual language should help develop partnerships between design and construction team, and long term business relationships should be built with contractors that have the same mindset and attitude towards new technology implementation [I-15].

To conclude, the general consensus was that traditional processes carry more risk than the added risk of information sharing in BIM. Contractors and owners are starting to realize the value of the BIM model and how it can help them in their everyday practice (reduce the time needed for estimating, help with tight schedule, etc). While the BIM model is strictly used to create a set of 2D construction documents, no special legal or insurance considerations are needed to cover the use of the model except perhaps a supplemental agreement [I-16]. When the model is used to its full capacity, legal and insurance considerations should be changed [I-17].

5.8 QUANTIFYING THE VALUE OF BIM USES

The value of implementing Building Information Modeling (BIM) is challenging to quantify. Few studies illustrate the value of BIM implementation throughout a facility's life; especially studies based on different variables such as implementation methods and workflows. This paper presents results from a survey focused on identifying the perceived benefits and frequency of implementation of twenty-five BIM Uses which are currently being implemented on projects in the industry. The BIM Uses span the lifecycle of a project with primary categories of planning, design, construction and operation uses. The applications definitions of the BIM Uses were adopted from a study of BIM Project Execution Planning which identified and developed the descriptions through literature review, interviews and focus groups with industry experts. The survey results indicate that all twenty-five BIM Uses were perceived as beneficial and are currently being used to some degree on projects. Based on the survey, the BIM Uses of 3D Coordination and Design Reviews were perceived as both the most beneficial and the most frequently used applications of BIM. Some BIM uses seem to be underutilized based on having a low frequency of use relative to a high perception of value. The survey results can assist future teams when prioritizing appropriate uses for BIM on their projects. The results have also identified criteria to classify the level of BIM implementation on a project which can support future research efforts to more accurately study the value of BIM implementation on projects.

CHAPTER 6: DEFINING THE BIM PROCESS MAPPING PROCEDURE

The first section of this chapter defines the two levels of creating a Process Map (PM). The second section identifies a procedure to develop these PMs. This includes the PM components, procedural steps and a process representation in BPMN. The aim of the PM is to provide a visual representation of all the processes that make up a particular BIM use. The third section of this chapter defines a procedure to create the Information Exchange (IE) worksheet identified in the process design.

6.1 DESIGNING A PROCESS MAP FOR A TASK WITH BIM

The creation of a BIM PM allows the team to understand the overall BIM process, identify the IEs that will be shared between various parties, and clearly define the various processes to be performed for the identified BIM Uses. This is accomplished by creating PMs using BPMN. The PMs also serve as the basis for identifying other important implementation topics including contract structure, BIM deliverable requirements, information technology infrastructure, and selection criteria for future team members.

The BIM Process Mapping Procedure includes the creation of PMs on two different levels:

- **Level 1: BIM Overview Map**
  A high level Overview PM should be created to show the relationship of BIM uses which will be employed on the project. This PM shows the information flow throughout the project lifecycle. This emphasizes that the BIM model attained after implementing a BIM Use will be shared with the future BIM Uses in the succeeding phases.
- **Level 2: Detailed BIM Use Process Maps**
  Detailed BIM Use PMs are created for each identified BIM Use on the project to clearly define the sequence of various activities to be performed. These maps should also identify the responsible parties for each activity, reference information content, and the IEs which will be created and shared with future processes.

6.2 PROCEDURE TO DEVELOP PROCESS MAPS FOR BIM PROJECT EXECUTION

For a team to develop a detailed BIM Use Map, template maps have been created which will provide a starting point for the team and aid in identifying discussion areas. This section identifies the process mapping components and a strategy to develop them. The methodology notation used to develop these maps is called Business Process Modeling Notation (BPMN).

6.2.1 KEY PROCESS MAPPING ELEMENTS

The key elements (see Figure 6.1) used to define BIM Process Mapping Procedure (adopted from BPMN) are:

- Pool: This acts as a container of all processes. It represents a BIM Use in the Level 2 PMs.
- Swimlane: Swimlanes segregate information contained in a pool into meaningful representations.
- Activities: A logical sequence of activities defines the process that constitutes a BIM Use.
- Events: Events are points in a process where something notable occurs.

- Gateways: Gateways are decision points. They describe the points where processes may diverge or converge.
- Connecting Objects: A connecting object joins the objects in a PM. They play a major role in determining the flow of a process.
- Data objects: Data objects define the information to be exchanged between activities.

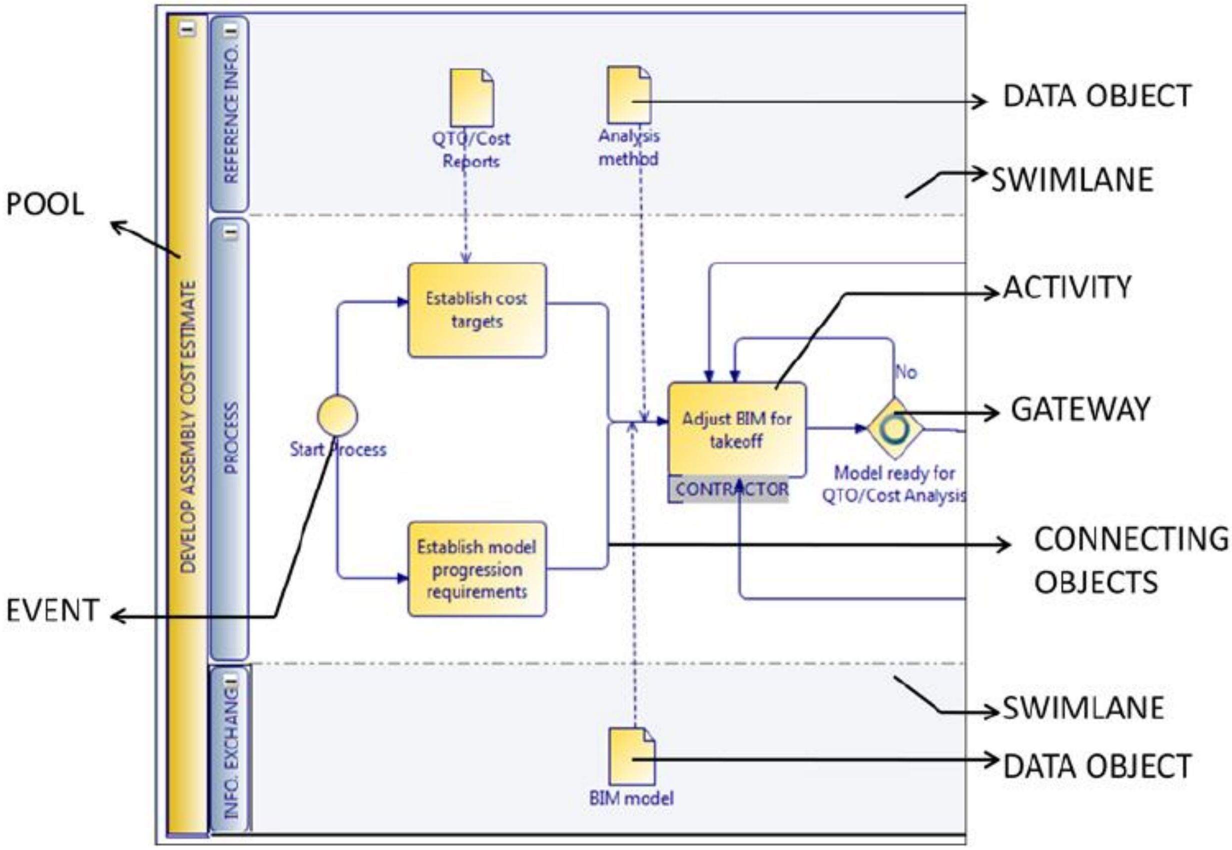


Figure 6.1: Key process mapping objects

6.2.2 BIM Process Mapping Components

Bjork (1992) based the construction process entity on three main categories: activities, results, and resources; reporting that an activity uses resources to produce results. Basing the process planning procedure on a similar premise, the researcher recommends adding a fourth component to the framework: agent. An 'agent' performs an 'activity' using 'resources' to produce 'results'.

The essential components for the BIM process mapping framework are:

- *Activity*: The activities are the kernel of the framework since they are the links between the results that are produced, the resources they use, and the agents that perform them. Also, the activity entity has relationship with other activities in the process.
  In the BPMN representation of the process map, the activities would define how a particular BIM task is delivered and forms the second swimlane termed 'Process'.

- *Result*: A result is defined by the document, BIM model, or service which forms the core of the IE Worksheet. The resulting entity could either be a final or an intermediate product.
  In the BPMN representation of the process map, the results will usually be defined in the third swimlane termed 'Information Exchange'. Information Exchanges are discussed in more detail in Chapter 7.
- *Resource*: A resource is defined as an entity which is consumed or used (Bjork 1992; Cutting-Decelle et al. 2000).
  In the BPMN representation of the process map, this would be defined in the first swimlane termed as 'Reference Information'. The reference information could either be enterprise specific or information from external sources.
- *Agent*: An agent in the process mapping framework is defined as any organization, department or person which participates or is responsible for a particular activity.
  In the BPMN representation of the process map, agents are listed underneath the particular activities that comprise the process.

6.2.3 Strategy to Develop a Process Map for a BIM Use

Based on the process mapping components discussed, four key steps have been identified to develop a procedure to create a PM for a BIM Use:

1. Identify the set of activities that make up a particular task;
2. Identify the agent(s) involved;
3. Identify the intermediate and end result for the task; and
4. Identify what resources will be referred or used for the completion of the task.

Figure 6.2 shows a graphical display of the strategy employed. After the various BIM Uses have been identified for a project, the next step is to develop each BIM Use. This is accomplished by listing the set of activities in a logical order that comprise a task. Additionally, each activity would be defined by a resource, agent and a result, as applicable. The next task is to plan the information requirements of an activity.

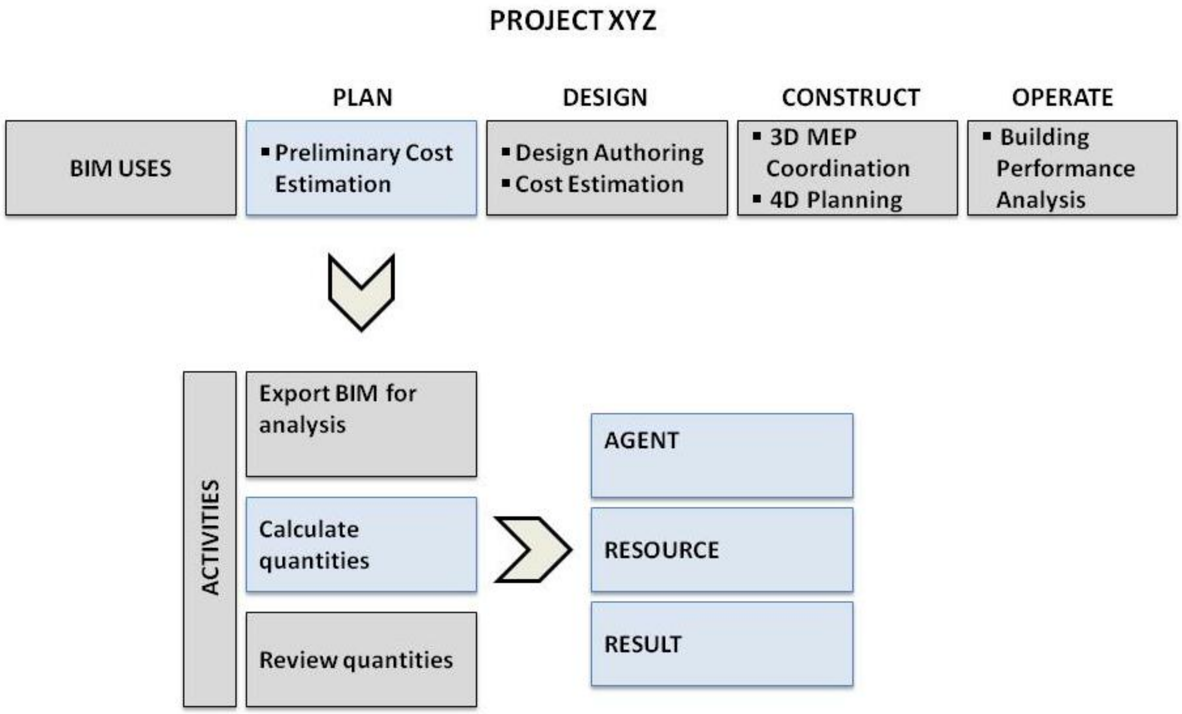


Figure 6.2: Strategy to develop a process map for a BIM Use

6.2.4 Planning the Information Requirements for an Activity

To plan each activity within a BIM Use, the following information is required (refer to Figure 6.3):

- The predecessor and successor of the activity;
- The agent performing the activity;
- The application required;
- The reference information required to accomplish the task;
- The input information content; and
- The output information content.

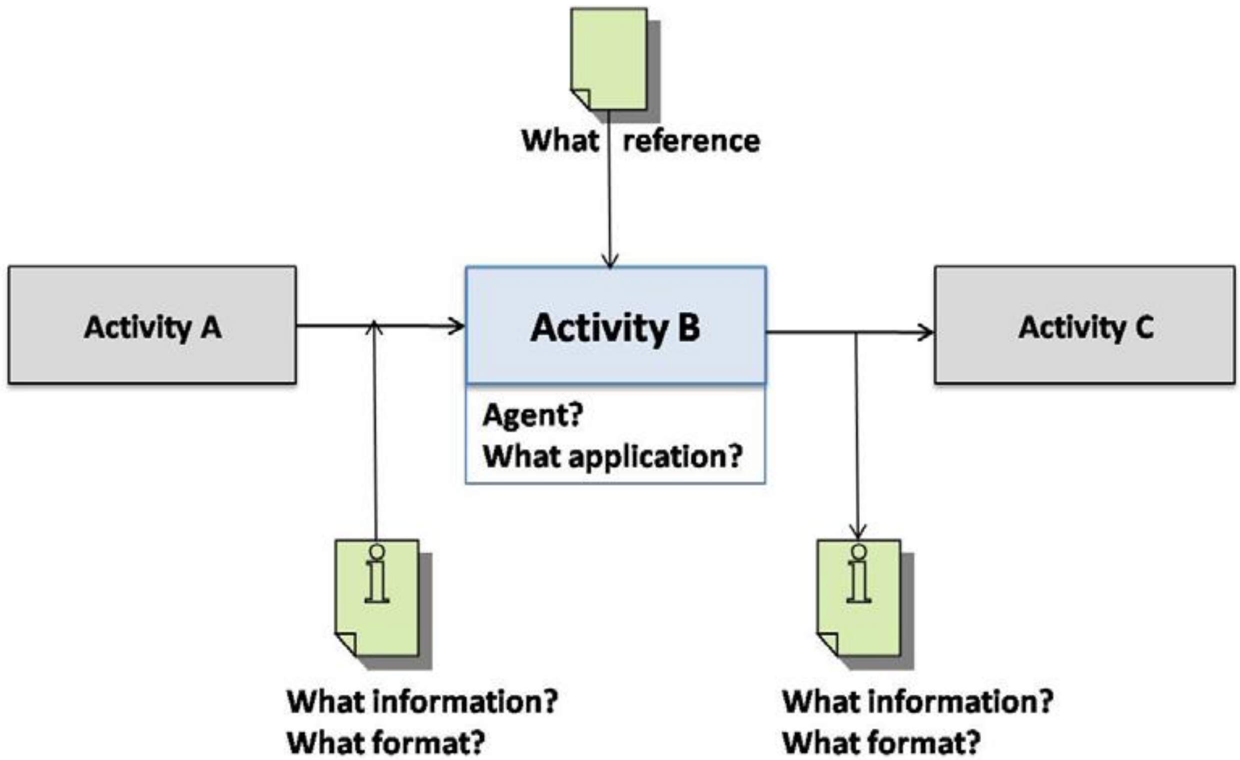


Figure 6.3: Planning the information requirements for an activity

Having established a strategy and the information requirements of planning a BIM Use, the next step is to define a detailed Procedure to create a PM.

6.2.5 Process Mapping Procedure

Procedure is defined as a sequence of steps which include the preparation, conduct and completion of a task. It usually defines the rules that should be followed by an individual or group to carry out a specific task. A procedure is usually required when the task to be performed is complex or routine and is required to be performed consistently (Lee et al. 2000).

With reference to the present work, the Process Mapping Procedure defines the steps which a project team will follow to create PMs for a BIM use. To create a BIM PM, a team must:

1. Hierarchically decompose the chosen BIM Use into a set of activities;
2. Define the dependency between activities;
3. Identify the components to provide more detail to these activities:
   - Resource (identify the resources required to execute the BIM Use);
   - Result (define intermediate and final results in the form of Building Information
   - Model and the IE between two activities or a group of activities); and
   - Agent (identify who is performing the activity).
4. Check if the goals have been met – e.g., decision making loops;
5. Document, review and refine this process for further use.

A graphical representation of a PM is shown in Figure 6.4.

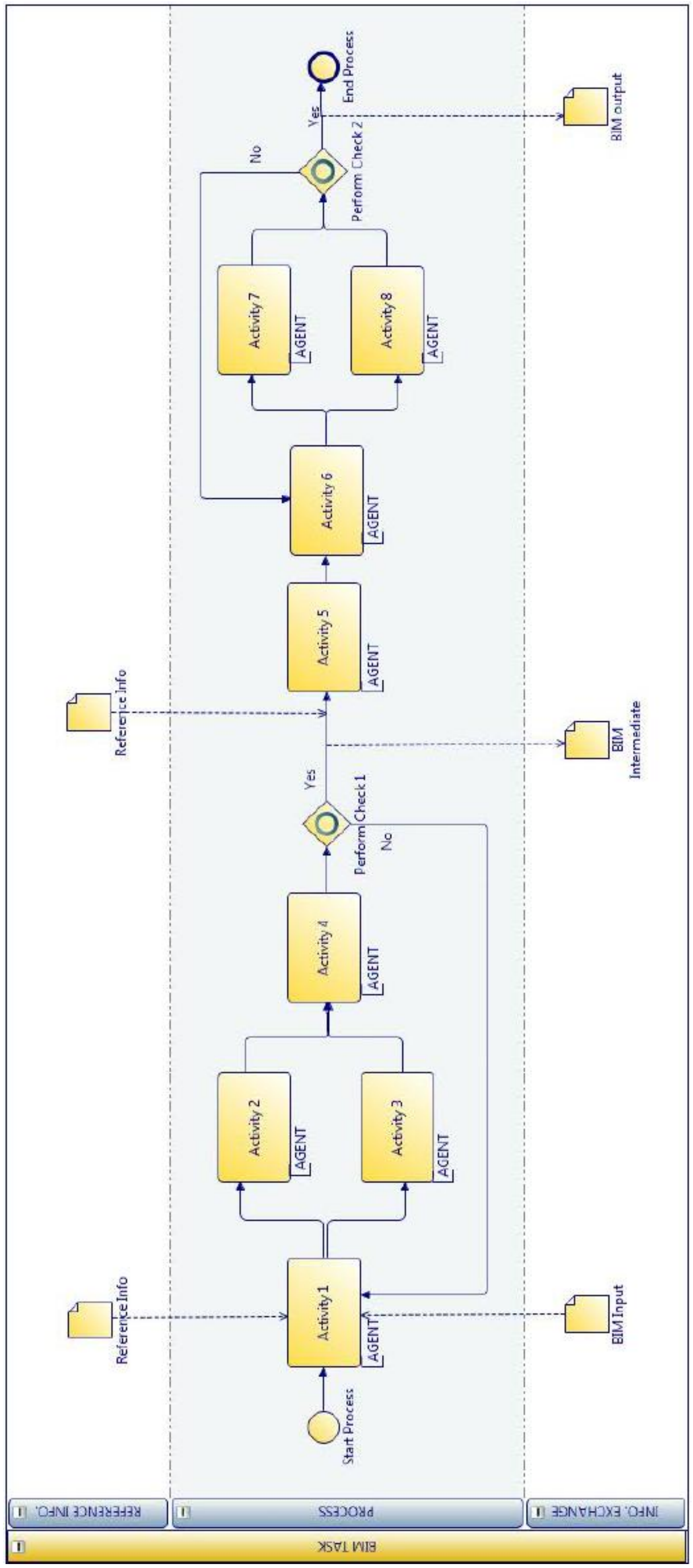


Figure 6.4: Process Mapping Procedure represented in BPMN format.

6.2.6 Process Mapping Representation in BPMN format

A template PM for a BIM Use, as shown in the Figure 6.5, has three swimlanes:

- **Reference Information:** ‘Reference Information’ is the first swimlane in the PM. This contains all information requirements from the enterprise and/or external sources.
- **Process:** ‘Process’ forms the second swimlane. This swimlane comprises of a logical sequence of activities that constitute a particular BIM Use; and
- **Information Exchange:** ‘Information Exchange’ forms the third swimlane. This identifies the BIM deliverables from one process which may be required as a resource for future processes.

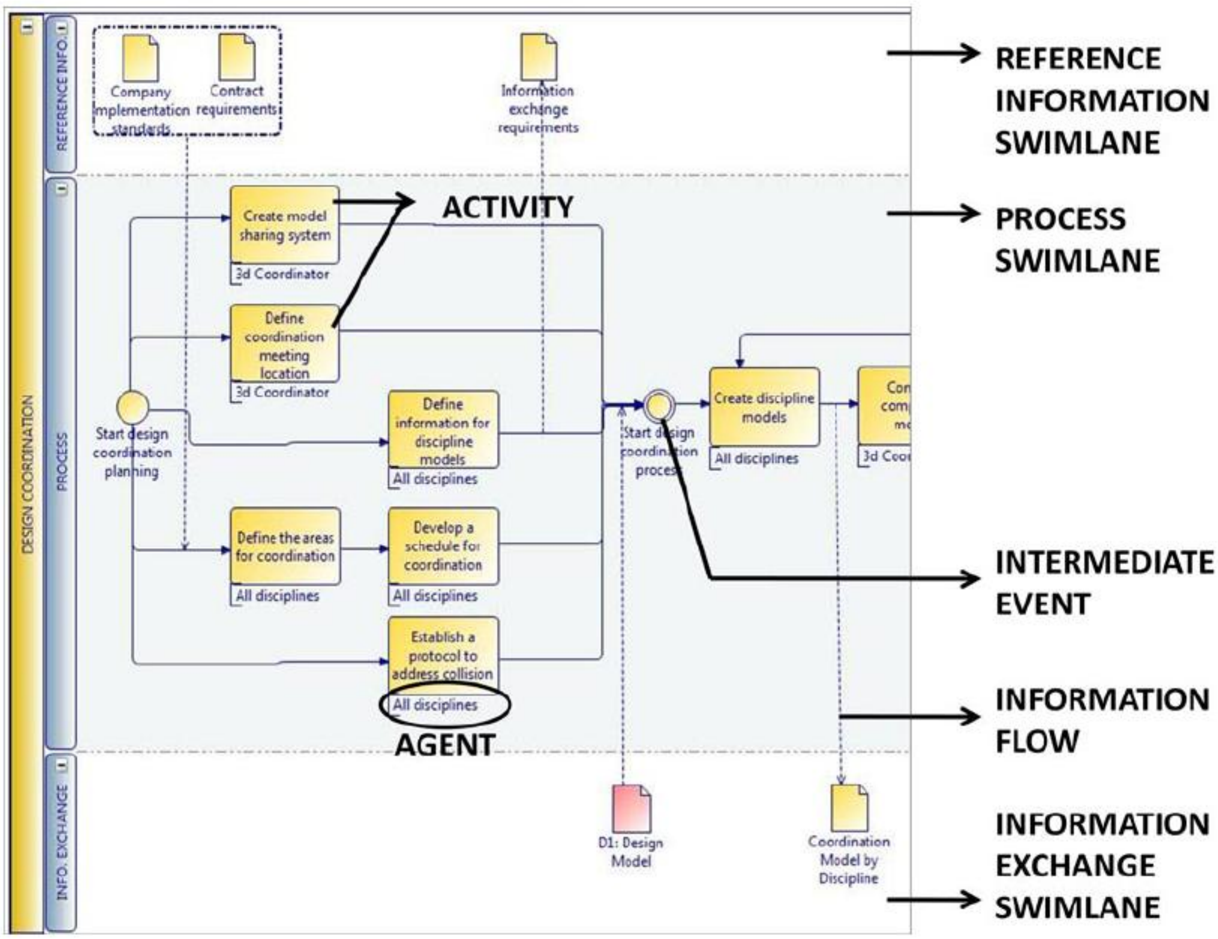


Figure 6.5: Terminology used for BIM process mapping (adopted from BPMN)

The scope of the study identifies the creation of Template PMs for the following BIM uses: Programming, Energy Analysis, 3D Coordination, Record Modeling and Cost Estimation. Template map for Programming is provided in Figure 6.6.

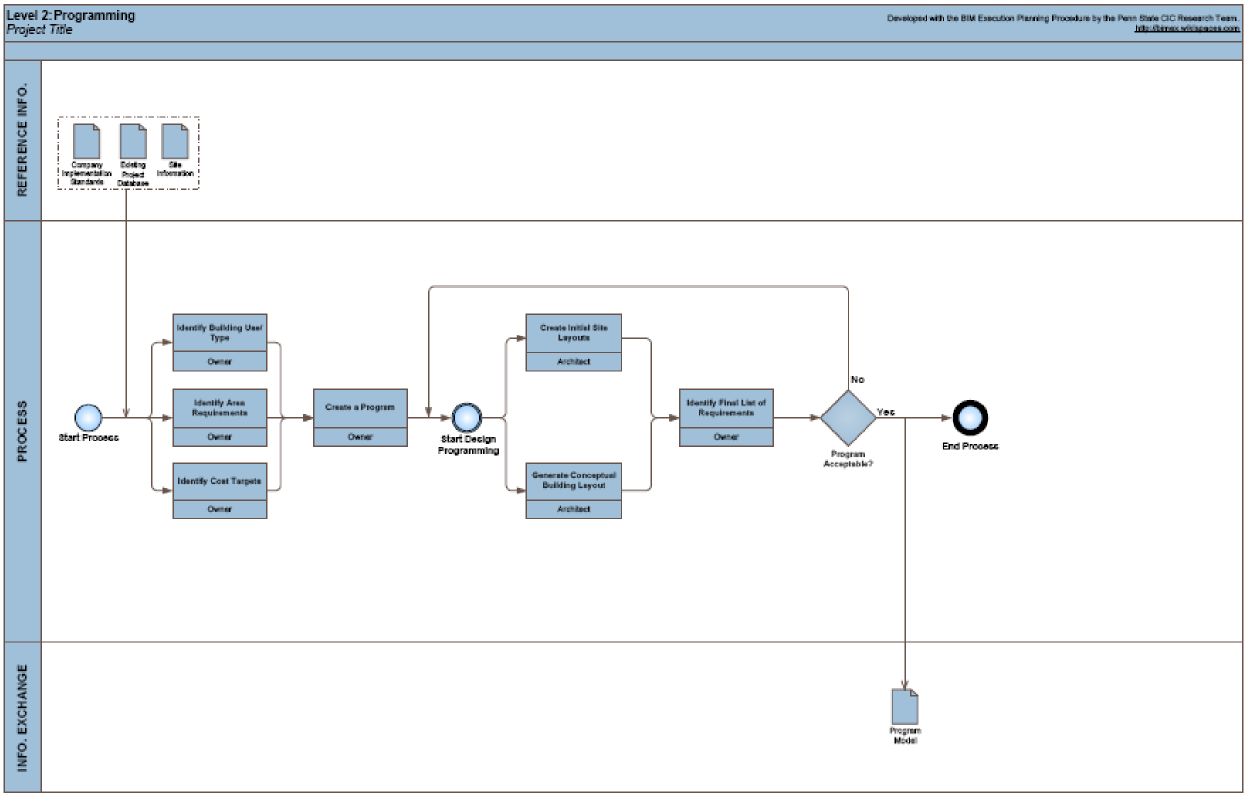


Figure 6.6: Template process map for Programming

6.2.7 Designing the BIM Process Map for a Project

1. **Import potential BIM Uses into BIM Overview Map;**
   Once the project team has identified the BIM Uses for a project, the team can then start a PM by adding each of the BIM Uses as a process within the map.
2. **Arrange uses according to project schedule in the BIM Overview Map;**
   After the project team has established the BIM Uses that will be implemented on the project, it is important to know the order in which each Use will be implemented during the project lifecycle. One of the purposes of the Overview Map is to identify the phase in which the BIM Use will occur (e.g., Schematic Design, Design Development, Construction Documents Phase) and provide the team with an overall picture of the implementation process. For simplicity purposes, the BIM Uses should be aligned with the BIM deliverables schedule.
3. **Determine the responsible parties for each identified BIM Use;**
   Responsible Parties should be identified for each BIM Use. For some uses, this may be an easy task, but for other uses, it may be important to consider which team member is best suited to successfully complete the task. The chosen responsible party will be in charge of identifying the information required to implement the BIM Use as well as the information produced by their process.
   The key information required to complete a BIM Overview Map includes the project phase, process name and the responsible party in the template map, as shown in Figure 6.7.

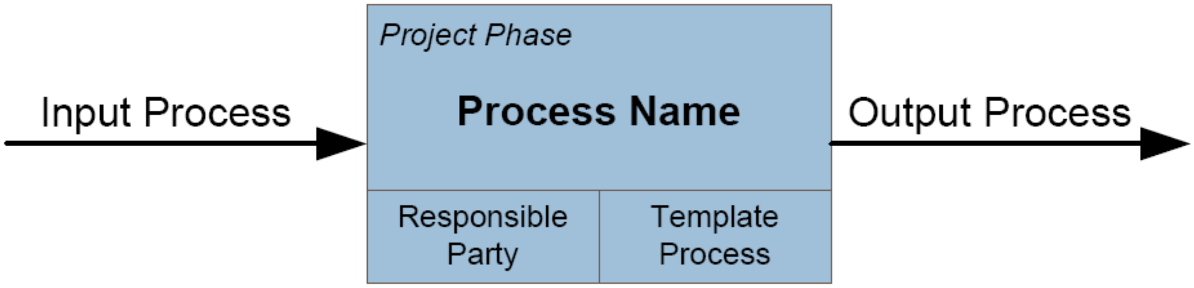


Figure 6.7: Information required to create a BIM Overview Map

4. **Determine the Information Exchanges required to implement each BIM Use;**
   The BIM Overview Map also identifies the key information which must be shared between BIM processes to eliminate the duplication of information.
   To illustrate the results of an overview mapping task, a sample BIM Overview Map can be referenced in Figure 6.8. The map defines the overall BIM Uses that the team has employed for the project which are Design Authoring, 4D Modeling, 3D Coordination, and Record Modeling. It identifies that Design Authoring, 4D Modeling and 3D Coordination will be performed during design development phase. The map also identifies the key IEs that shall be shared between different parties.

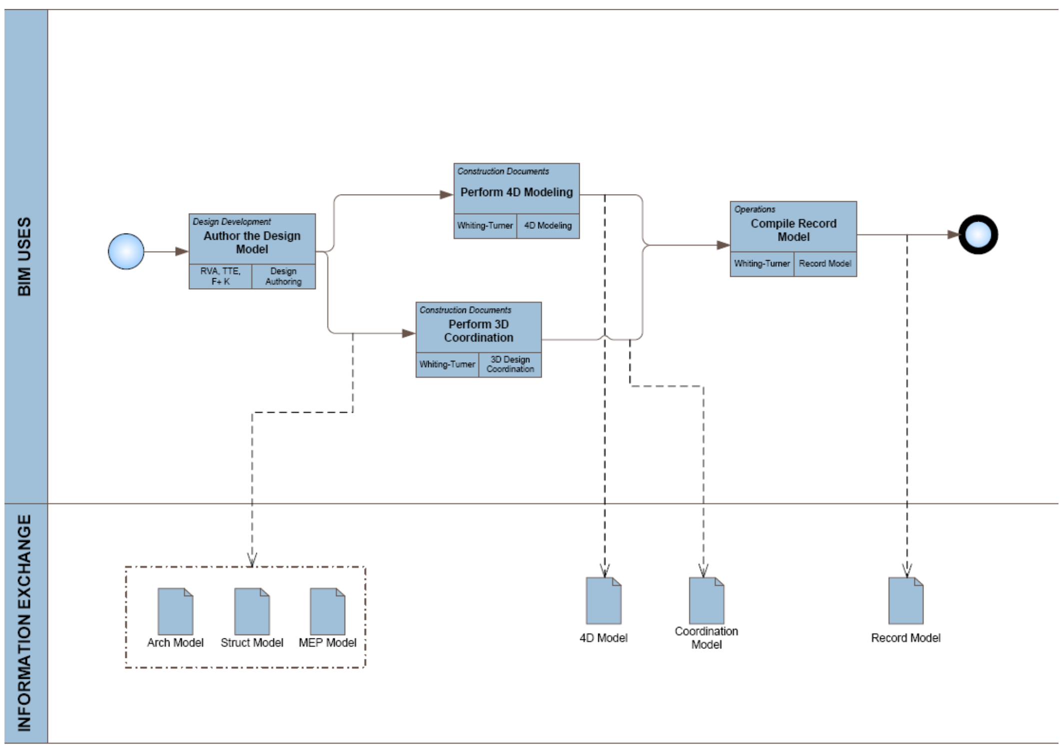


Figure 6.8: Sample BIM Overview Map

5. **Develop a Level 2 – Detailed BIM Use Process Map for each identified BIM Use;**
   After creating an Overview Map, a Detailed BIM Use PM must be created for each identified BIM Use to clearly define the sequence of the various activities to be performed within that Use. Each Level 2 map includes three categories that need to be identified to create a project process

map: Reference Information, Process, and IE. These categories are represented on the left side of the process map and the elements are included in the swimlanes.

6.3 Process Mapping Task Assessments

The quasi-experiment consisted of participants completing a process mapping task for a chosen BIM use at Penn State. The individuals took about one and one half to two hours to complete the task. The PMs which were created were later analyzed to identify possible gaps in the procedure. In addition, a post-test questionnaire was distributed to the individuals to identify the perceptions of the use of process mapping to better communicate the workflow of the BIM use.

6.3.1 Quasi Experiment Design

Quasi-experiments were arranged for eleven participants where they performed the specified task and produced a BIM use PM at the end of the task. The participants of the quasi-experiments were graduate students from the Department of Architectural Engineering and the Department of Architecture at The Pennsylvania State University, all having previous knowledge of BIM. All of the participants have previously taken at least one advanced level course in BIM during their course of study. The participants were required to create a PM for a chosen BIM use, using the established Process Mapping Procedure in a BPMN computer application (TIBCO).

Since this was the first attempt at process mapping, the participants were provided with a task sheet which contained clear direction on what the objective of the task was, and how the task was to be completed. The task was to create a detailed process plan for the BIM Use that would clearly define the different activities to be performed, who will perform them, and what information will be created and shared with future processes to accomplish the BIM Use. TIBCO, a Business Process Management application, was utilized for creating PMs for the purpose of this quasi-experiment. The aim of the activity was to validate if the Process Mapping Procedure and the template procedure map in TIBCO provided to the participants covered all the BIM implementation aspects which would help the participants plan out a BIM use.

Each participant was assigned a laptop for the task. The BIM Use finalized for each individual was not a random selection, rather participants' own preference. However, to avoid multiple people creating a PM for the same BIM Use, some recommendations were suggested to several participants.

At the beginning of the experiment the participants were provided with:

1. A printed copy of the instruction sheet for the task.
2. A printed copy of the Process Mapping Procedure.
3. Procedure in a BPMN format on the assigned laptop. This was suggested to the participants as a starting point for the creation of their individual process maps as it complements the Process Mapping Procedure and is built off the established framework for the study.
4. A printed copy of BPMN guidelines describing the basic symbols and their usage required to create a PM.

Additionally, at the beginning of the experiment the participants were given a 5 minute demonstration on the features they would be using in the TIBCO application.

Two hour time slots were made available to each participant. The researcher was present during these time slots to assist with any application-specific issues which could arise during these sessions. It was also the researcher's responsibility to hand out the perception survey questionnaire at the end of the session.

6.3.2 Questionnaire Design

At the end of the experiment, the participants were asked to complete a questionnaire survey with rating scale type questions to get feedback related to the Process Mapping Procedure as well as their insight on the ease of creating a PM using the Procedure.

The questionnaire consisted of 3 parts: the first part included biographical information questions regarding academic standing and experience level in BIM; the second part contained questions on the comprehensiveness of the Process Mapping Procedure and the template file provided to create a PM; and the third part was a set of four open ended questions to allow respondents to reply in their own terms and opinions on how to improve the Procedure.

The second part of the questionnaire contained questions in a 5-level Likert scale with the participants expressing their level of agreement or disagreement with the statements. The level of agreement varied from 'strongly disagree' to 'strongly agree' with 'disagree', 'neutral', and 'agree' in between.

6.3.3 Process Map Content Analysis

At the end of the quasi-experiment, all the participants had created a PM for their chosen BIM use using the Process Mapping Procedure in TIBCO. For this study, the content produced by the participants was analyzed. These PMs were carefully scrutinized to see if they yielded valid or expected results. The objective of content analysis, in the study, is to verify if the Process Mapping Procedure was followed by the participants or not. Additionally, by providing a starting BPMN template, the goal was to establish a particular format and look to the produced content. To satisfy these objectives, the context of content analysis was defined as:

- Maintaining BPMN rigor in the produced maps;
- Identification of appropriate swimlanes; and
- The PM, on the whole, should have an objective and should be a meaningful representation of the BIM use.

It is important to note that the aim of the quasi-experiment was not to judge the BIM knowledge of the participants, but to establish whether a PM with a defined objective and a particular format could be created using the procedure.

6.4 Process Mapping Outcomes and Analysis

6.4.1 Questionnaire Survey

This section shows a selection of the results of the questionnaire responses to the quasi-experiment performed. The graphs represent the percentage of respondents who gave the particular rating to a Likert item statement. As mentioned before, the scale varied from 'strongly disagree' to 'strongly agree'.

The survey results show that most of the participants had knowledge of the BIM use for which they were creating the PM (Figure 6.9). Also, they seem to agree that the Process Mapping Procedure and the template file provided in TIBCO was adequately defined and it assisted in generating ideas for creating the PMs (Figure 6.10, Figure 6.11, and Figure 6.12). The majority of the participants also seem to agree that the PM will help in communicating the given BIM Use better than traditional means (Figure 6.13). However, some of the students were unsure if the swimlanes helped them in understanding the task (Figure 6.14).

It is expected that creating a PM will require significant effort and BIM implementation knowledge; therefore, it is important to consider that the graduate students have limited industry experience and the time spent completing the task was an average of 1.5 hours per participant.

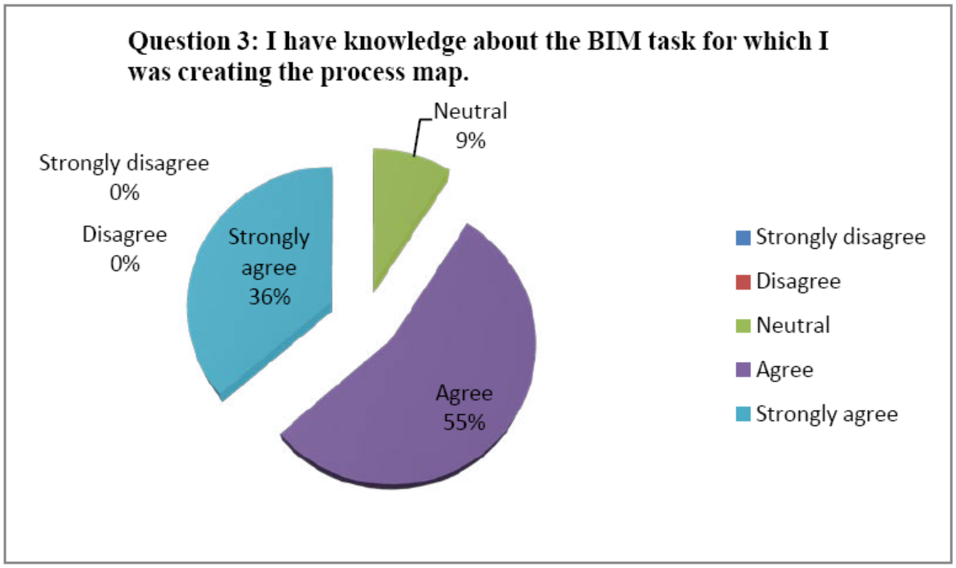


Figure 6.9: Knowledge about the BIM task

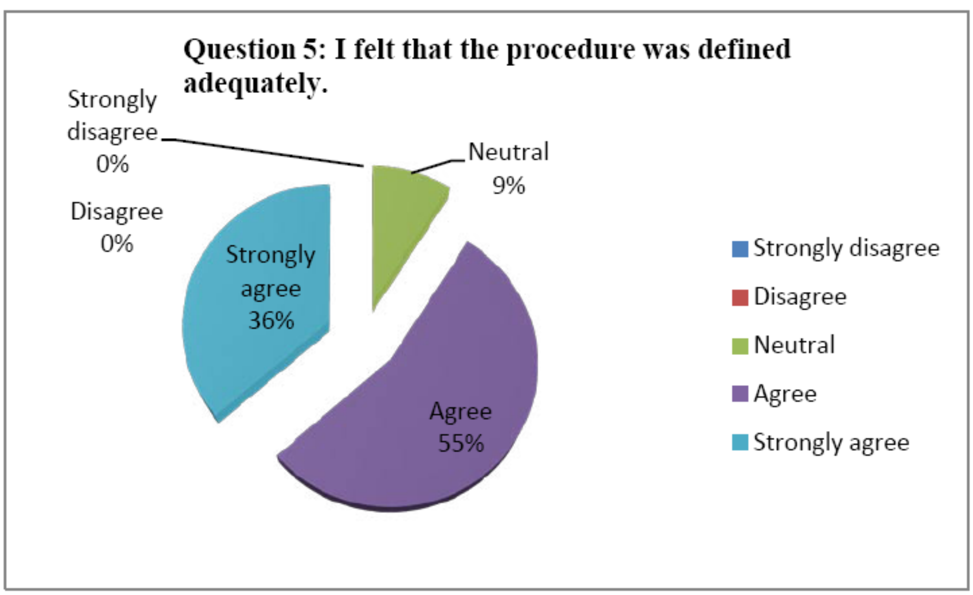


Figure 6.10: Procedure was defined adequately

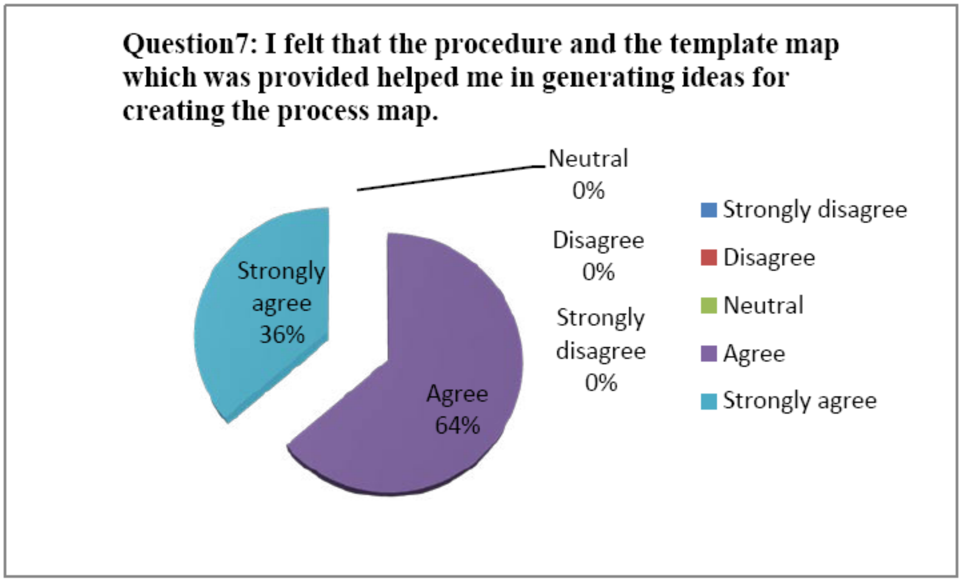


Figure 6.11: Generating ideas for creating a process map

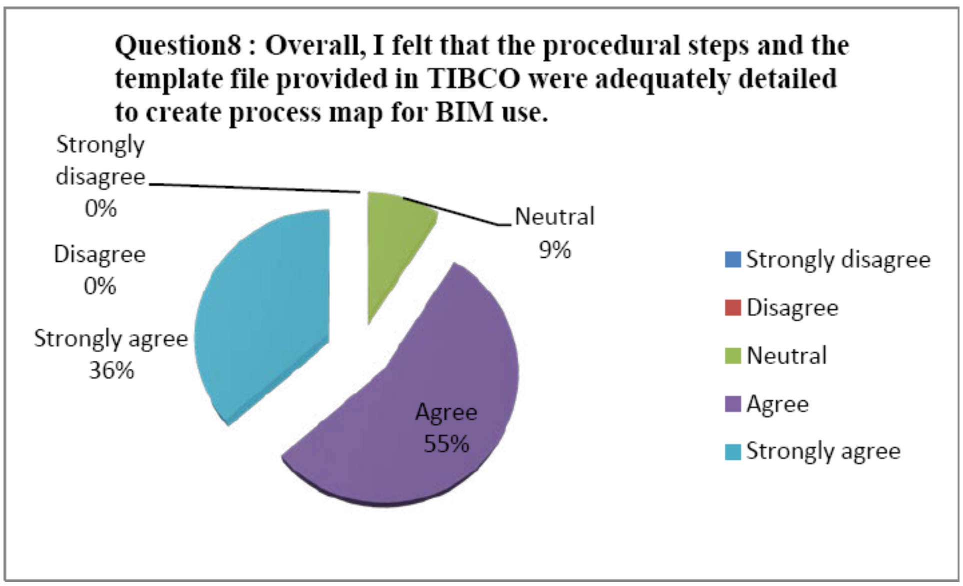


Figure 6.12: Creating a process map from the procedure and the template file

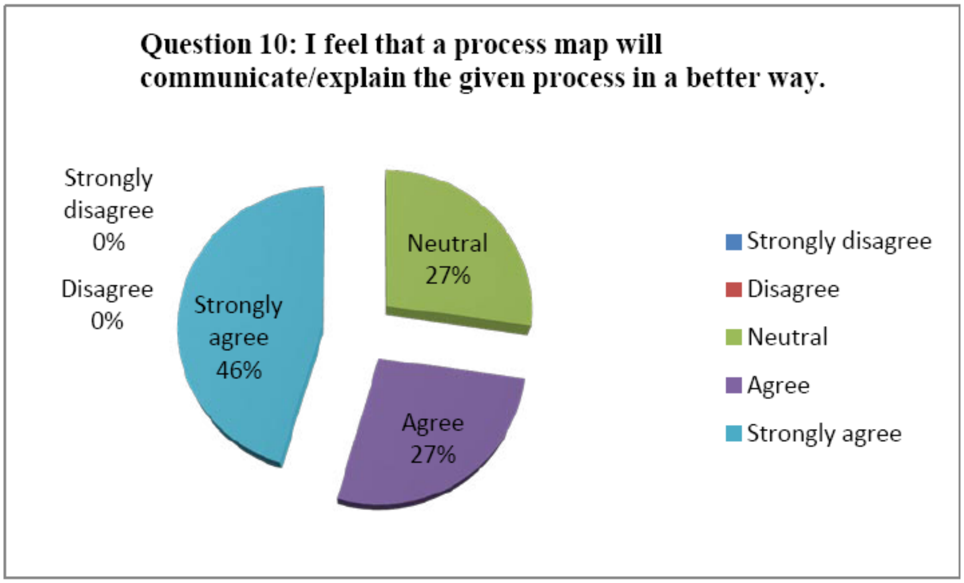


Figure 6.13: Communicate the process

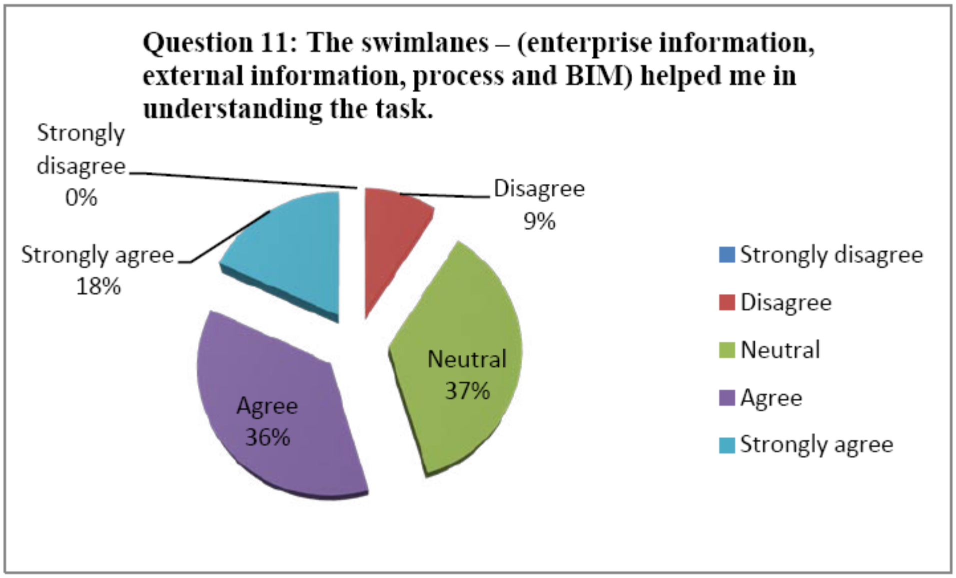


Figure 6.14: Swimlanes

Apart from these rating results, the participants provided feedback on open-ended questions. These questions along with a few student quotes are shown below:

- **What challenges did you face while creating the process map?**
  "The challenge was intellectual – trying to organize/generalize the process."
  "Challenge in determining the level of detail necessary for the map."
  "Relating given palette in TIBCO to thought process."
  "Choosing symbols to define decision making tasks."
- **What additional steps/instructions would you like to see included in the procedure or the template file provided?**

"Provide an example map."
"Define the purpose of swimlanes."
"Swimlanes related to the team members rather than general external input."

- How long did it take you to orient yourself to TIBCO?
  The answers were in the range of 10 to 20 minutes.
- **How long did it take you to develop this map?**
  The answers were in the range of 40 to 90 minutes.
- **Please provide any additional comments.**
  "Good guidelines to follow for any BIM use."
  "A good method to develop and illustrate workflows."
  "Having standard templates with tasks for each BIM activity would likely be helpful to industry."
  "The initial idea development was the biggest challenge."

6.4.2 Process Map Analysis

Content analysis was used to judge if the participants felt comfortable creating a well defined workflow for a BIM Use with which they were most acquainted. The objective of the PM analysis was to check the validity of the produced content, and infer by observing the PMs if the participants understood the general idea of creating a workflow. It was important for the researcher to know if the students would be open to the idea of creating a workflow diagram, and also, understanding the workflow through a PM. The Procedure should be viewed as a tool to aid in the creation of these PMs. It is also important to possess knowledge on the topic for which a PM is being created. With this in mind, the objective was not to judge the completeness of the template map produced, but to document ways which would aid to accomplish this task.

By careful scrutiny, the researcher documented the irregularities observed in the produced PMs, and redefined the Procedure to more clearly define the topic. Some of the common irregularities observed were:

- Incorrect usage of symbols
- Information not placed in the correct swimlane
- The information displayed is not appropriately detailed
- The template maps not having an expected format

In Figure 6.15, the process map does not end with the correct symbol. An End event indicates when the process has completed. The Procedure developed requires a process to contain a Start and an End Event.

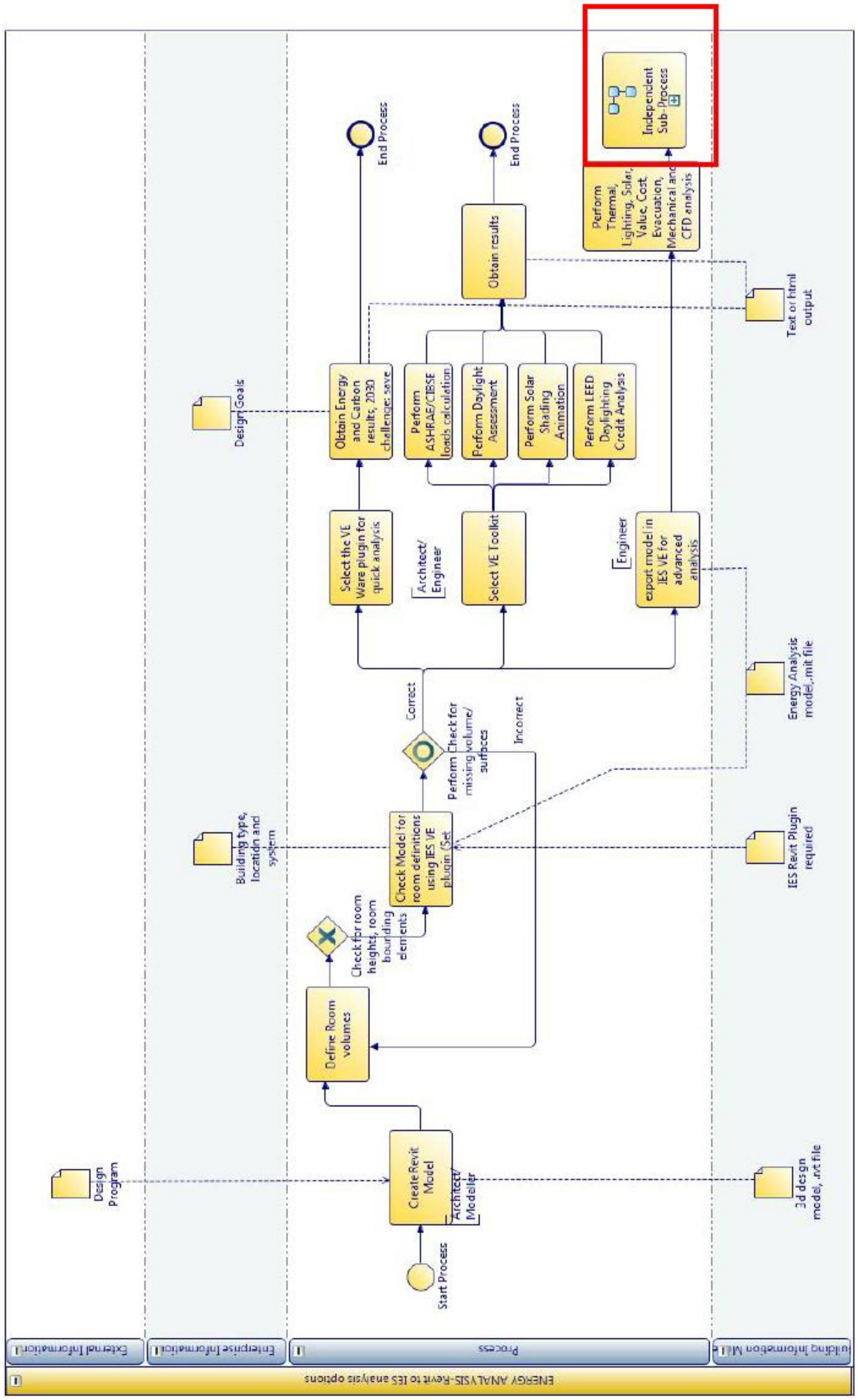


Figure 6.15: The process map must have an end process to symbolize the end event.

Embedded sub-process is not a part of the template map provided (refer to Figure 6.16 and Figure 6.17). If there is information that has to be represented in the process map, it should be included in the 'Reference Information' swimlane.

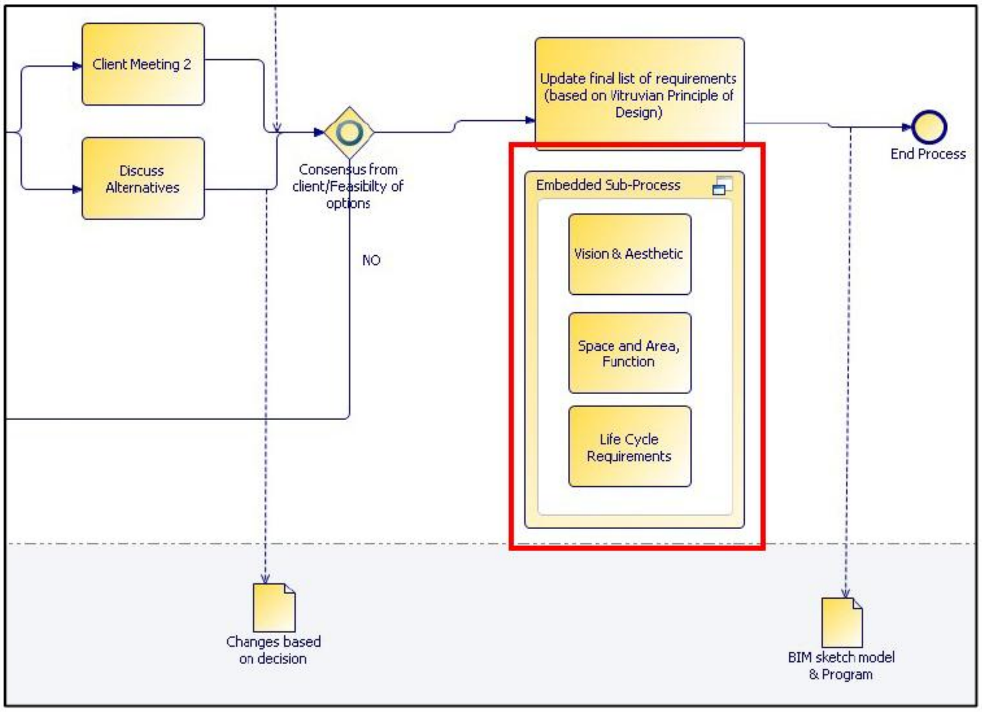


Figure 6.16: Embedded process should not be used as part of template map

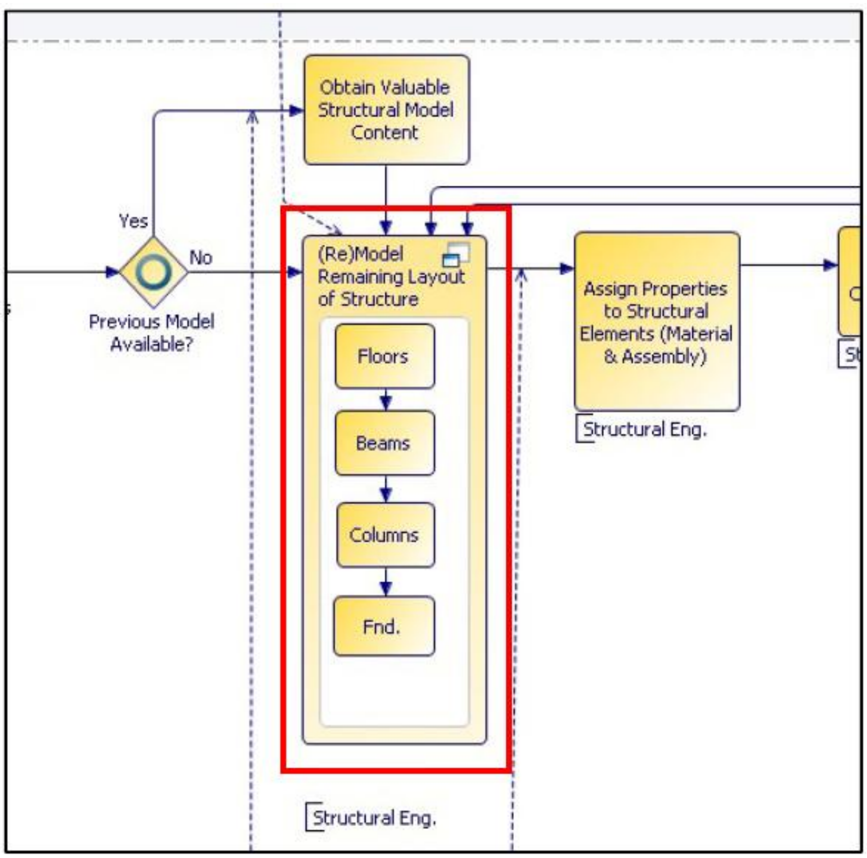


Figure 6.17: Incorrect use of embedded process

In Figure 6.18, ‘Verify tolerances’ is an activity and should be a part of the ‘Process’ swimlane instead of being included in the ‘Reference Information’ swimlane.

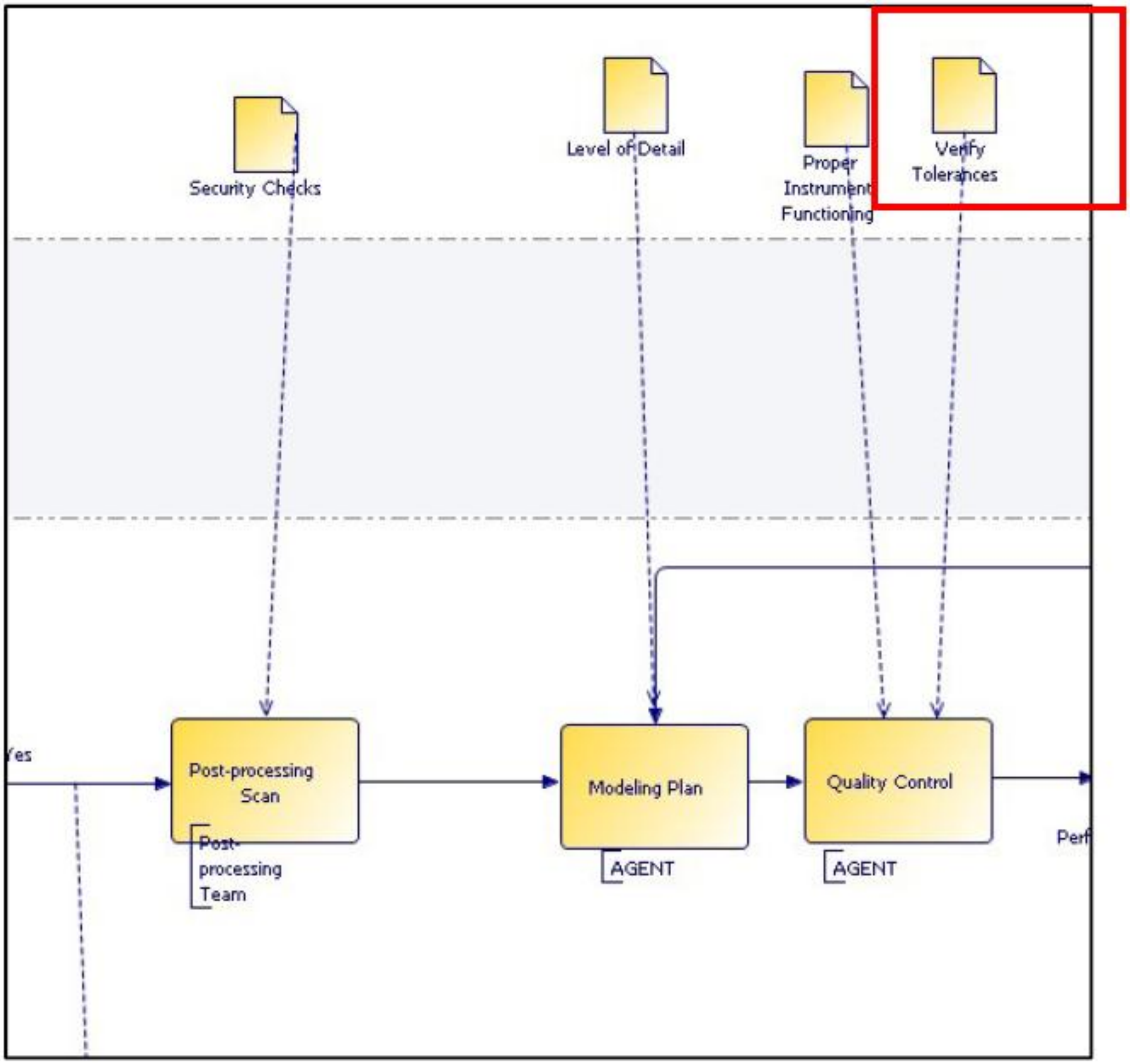


Figure 6.18: Incorrect use of swimlane

The information represented in a PM should be adequately detailed for others to understand. In Figure 6.19, it is challenging to understand what ‘BIM input’ and ‘BIM intermediate’ might contain. ‘BIM input’ should be specified in terms of an Architectural Model, Structural Model or likewise depending on the information exchange. These models should be further detailed using the IE template. As far as possible, vague phrases should be avoided to maintain clarity in the model.

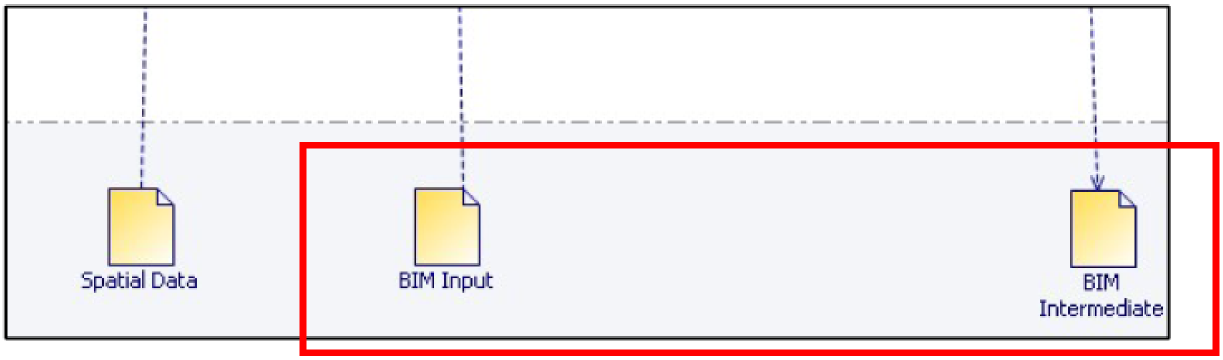


Figure 6.19: The level of detail of the BIM deliverable is not appropriate

In Figure 6.20, it is unclear what information architect or the contractor is providing.

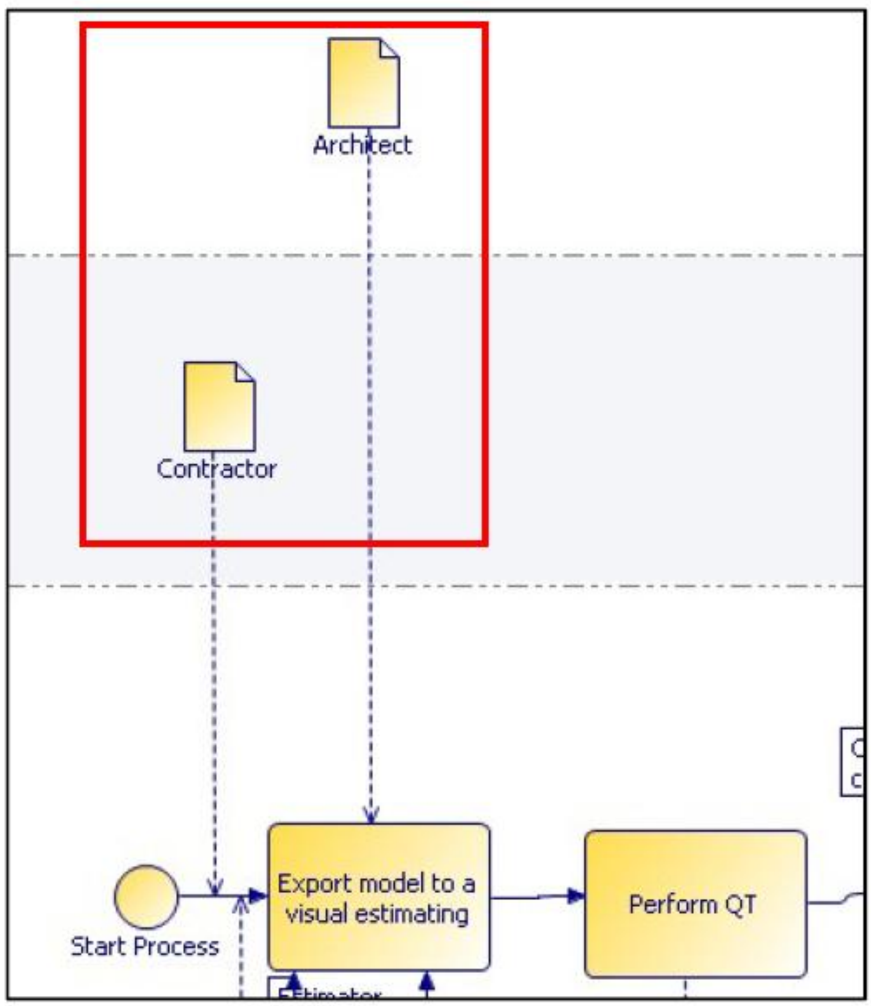


Figure 6.20: The reference information has to be detailed

As seen in Figure 6.21, it is important for information and processes to be linked appropriately with the use of arrows. Here, it is unclear if ‘construction database’ and ‘utility rates’ is an input to the process or an output of the workflow.

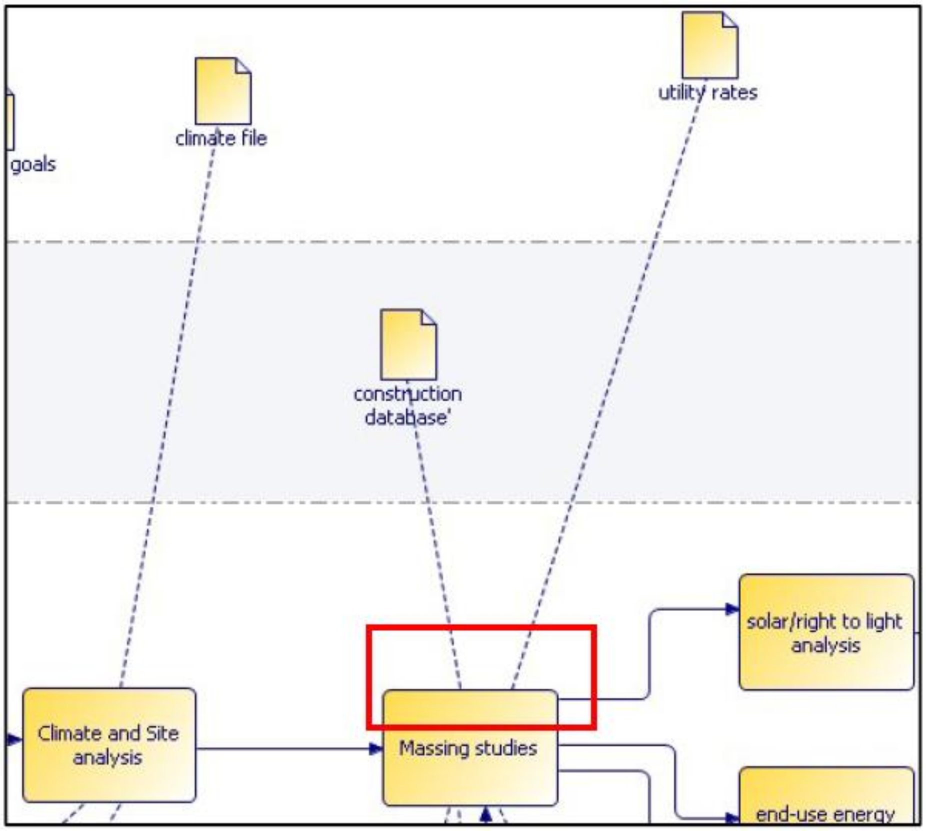


Figure 6.21: Information flow missing

A BIM deliverable cannot convert to another BIM deliverable in the 'Information Exchange' swimlane (refer to Figure 6.22). There needs to be an appropriate process to occur for such a transformation.

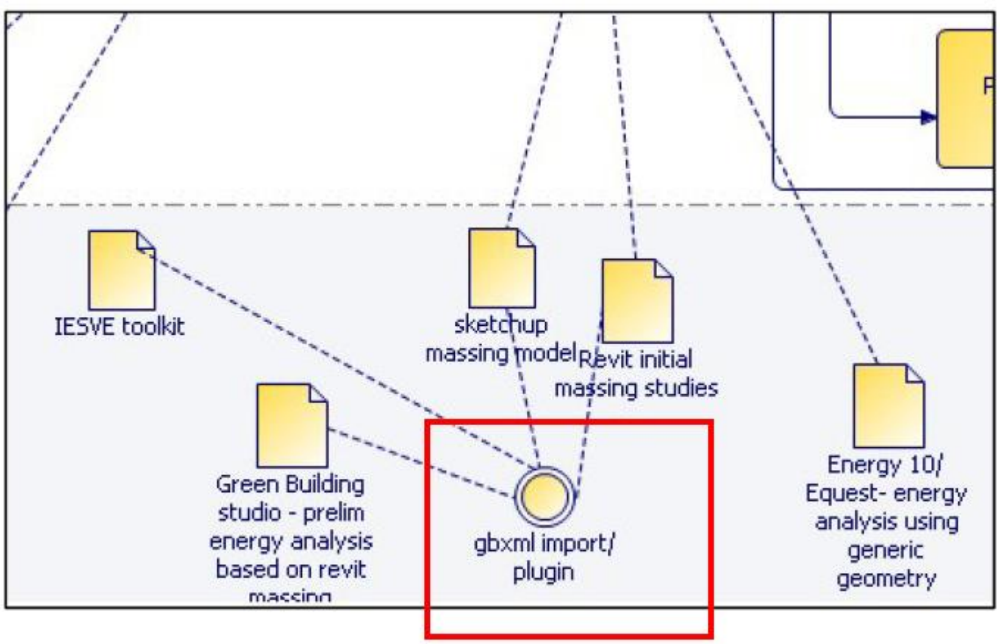


Figure 6.22: Incorrect use of intermediate event

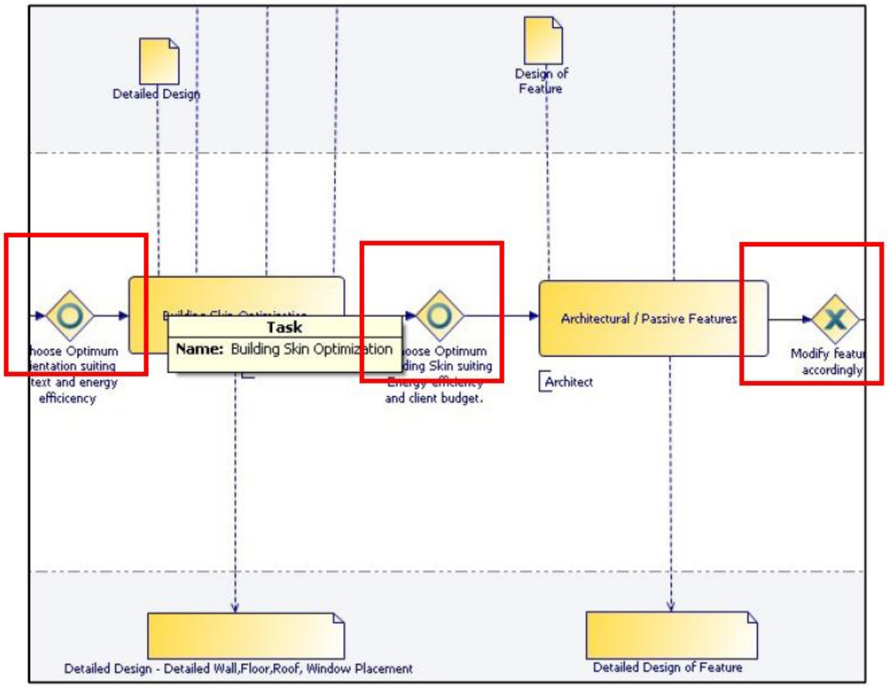


Figure 6.23: Incorrect use of symbols

In Figure 6.23, a decision making symbol should be followed by a minimum of two choices to demonstrate that there is an either/or situation.

In Figure 6.24, the symbol used displays a multi decision loop. However, there is only one arrow coming out of it which shows that there is no multi either/or situation.

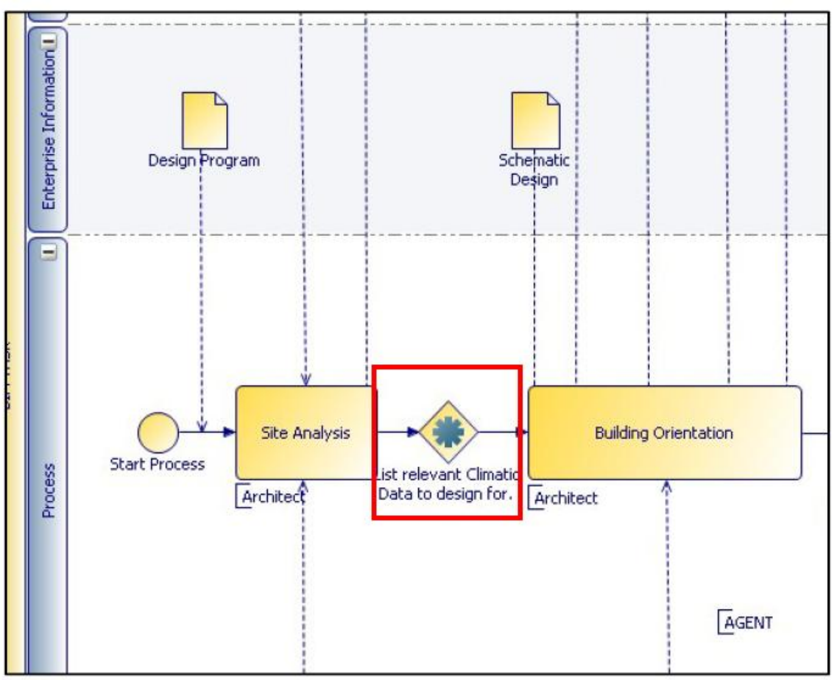


Figure 6.24: Incorrect use of symbols

6.5 SUMMARY AND LESSONS LEARNED

The quasi-experiment consisted of graduate students who were asked to create a PM using the Process Mapping Procedure for a BIM Use. A post-test questionnaire was administered to the students to collect data on the Procedure and the communication value of process mapping. Content analysis was performed to document the irregularities in the produced content. The results of the questionnaire and the content analysis have been documented in this chapter. The participants indicate that the Procedure and the template file were adequately detailed and find this as an interesting exercise to understand BIM workflows. Some of the lessons learned/major revisions are listed below:

1. **Shift from the 4 swimlanes to 3 swimlanes**
   The participants faced a challenge in differentiating the information into two areas of 'External' and 'Enterprise' swimlanes. This process was simplified by replacing the two swimlanes by a single 'Reference Information' swimlane.
2. **Correct usage of symbols**
   For encouraging correct usage of symbols and objects of BPMN while creating the PM, all the commonly used objects and their descriptions have been documented. These guidelines will aid in successful creation and understanding of the PM. The aim is that the PM should be self-explanatory to a person who needs to be aware of what exchange requirements are intended to achieve but who does not need to know the detail of how it is achieved. Typically, this person will be a 'user'; an example would be someone in a project management role.
3. **Template procedure in BPMN**
   For maintaining a similar formatting style throughout the creation of template maps and providing a starting place for the creation of project process maps, it is recommended to use the procedure template file created in TIBCO.

CHAPTER 7: PROCEDURE TO DEFINE THE INFORMATION EXCHANGE FOR BIM PROJECT EXECUTION

This section focuses on defining the Information Exchanges identified in the third swimlane of the PMs. The procedure to define the Information Exchange identifies a method to document the responsible parties for the deliverables, the information contained in the deliverable and a schedule for the identified information exchanges, which is produced in an 'Information Exchange (IE)' worksheet. The objective of defining each IE is to aid the project team by increasing the predictability of the model content. The deliverable can also be incorporated into contracts as appropriate to ensure desired results.

7.1 INFORMATION EXCHANGE COMPONENTS

For a model to be valuable, it does not necessarily need to include every element of the project; therefore, it is important to define the model components that are beneficial for each BIM Use.

The two major components identified for the IE worksheet are:

- **Model Element Breakdown:** Model element breakdown structure is a part of the Building Information Model representing a component, system or assembly within a building or building site. This structure defines the model components, which the project team intends on using to create the IE worksheet. The model element breakdown should include all the systems and the processes of installing them (temporary or permanent) to reflect the final as-built conditions. Some of the common model classification breakdown include the CSI UNIFORMAT II (adopted by AIA – E202 BIM Protocol Exhibit); CSI UNIFORMAT, variants of which are used informally in the United States; IFC model breakdown structure, the Canadian CIQS classification; the United Kingdom RICS classification, and the European CEEC classification for data exchange (Charette and Marshall 1999).

  For the purpose of the template IE, model element breakdown is represented by the Construction Specifications Institute (CSI) UNIFORMAT II classification system. Three additional components which are useful to the Building Information Model are also identified and added to the worksheet. However, the project team could also use team specific model element breakdown or refer to any other classification system as appropriate.
- **Information Exchange by work package**: Defining the Information Exchanges forms the major part of the IE worksheet. Given that the project team has already identified the BIM Uses to be implemented on the project in the Level 1 BIM Overview Map, these Uses need to be categorized according to the important project milestones/work packages. This essentially means to identify what the model will be used for across the different phases, e.g., schematic design, design development, construction document phase etc. This ensures that the involved parties know when the BIM deliverables should be complete to avoid delays. Next, each BIM Use is detailed with the following components:
  - **Information Content:** Information content describes the level of completion to which the model element is to be developed. This can be detailed using the categories listed in Table 7.1: Legend for Information Content.

Table 7.1: Legend for Information Content

Category	Meaning	Notes
A	Geometry, precise size and location	Model elements are modeled as specific assemblies that are accurate in terms of geometry and location, including material and object parameters.
B	Geometry, general size and location	Model elements are modeled as generalized systems or assemblies with approximate shape, size, location and orientation, including parametric data.
C	Schematic size and location	Model elements are modeled as generalized systems or assemblies with approximate shape, size, location

Not all necessary requirements for model content may be covered by the information and element breakdown, and more description can be added as a note. Notes can be specific to certain modeling content and/or depict a modeling technique.

- **Responsible Party**
  Responsible party refers to the party accountable for creating or authoring the content of the model element breakdown list. A generic categorization is shown in Table 7.2: Generic Categorization of Disciplines.

Table 7.2: Generic Categorization of Disciplines

Category	Discipline
Owner	Owner
Arch.	Architect
Engr.	Engineer
GC/CM	General Contractor/Construction Manager
TC	Trade Contractor
FM	Facilities Manager

For a detailed classification on organizational roles, Table 34 of the OmniClass™ classification systems can be referenced.

While working on the case study it was found useful to create a project specific legend for the responsible party which includes the company names on the project team, e.g., WT for Whiting-Turner Contracting Company. This would ensure that the parties understand who is responsible for what building elements and information.

- **Application, format and version**
  The role of the application, format and version rows in the IE worksheet are to inform the project team the particular version and application the responsible party is using. This aims to promote the discussion on interoperability issues that the team may face during model exchange.
- **Time of Exchange**
  The time of exchange (e.g., SD, DD, CD, etc.) ensures that the involved parties know when the BIM deliverables are expected to be completed along the project's schedule. This should be derived from the Level 1 Process Map.

The template IE worksheet has been added in Appendix F:.

7.2 Structure of the IE

In the IE template worksheet (refer to Figure 7.1), the model element breakdown is located on to the left side of the sheet. The IEs are listed across the worksheet in a chronological order, wherever possible. Each IE will be elaborated by the three categories of content: information content, responsible party, and additional notes. Further, to identify discussion areas on interoperability, supplemental information on the Application, Format of the content and Application Version can be identified by the responsible party(s).

Information Exchange Title			Architecture Model			Structural Model			Mechanical Model		
Time of Exchange (SD, DD, CD, Construction)			DD			DD			DD		
Reciever File Format			*.rvt			*.rvt			*.rvt		
Application & Version			Revit 2009			Revit 2009			Revit 2009		
Model Element Breakdown			Info	Resp Party	Notes	Info	Resp Party	Notes	Info	Resp Party	Notes
A	SUBSTRUCTURE										
	Foundations										
		Standard Foundations	C	Arch		A	CE		A	CE	
		Special Foundations	C	Arch		A	CE		A	CE	
		Slab on Grade	C	Arch		A	CE		A	CE	
	Basement Construction										
		Basement Excavation	A	Arch		A	Arch				
		Basement Walls	A	Arch		A	Arch				
B	SHELL										
	Superstructure										
		Floor Construction	B	Arch		A	CE		A	Arch	
		Roof Construction	B	Arch		A	CE		A	Arch	
	Exterior Enclosure										
		Exterior Walls	A	Arch		A	Arch		A	Arch	R Value
		Exterior Windows	A	Arch		A	Arch		A	Arch	R Value
		Exterior Doors	A	Arch		A	Arch		A	Arch	
	Roofing										
		Roof Coverings	A	Arch		A	Arch		A	Arch	
		Roof Openings	A	Arch		A	Arch		A	Arch	

Figure 7.1: Structure of the Information Exchange

7.3 Procedure to Complete the IE Worksheet

Defining Information Exchanges for a project includes the completion of the IE worksheet, which identifies the information content of the model, responsible parties for the elements listed in the model element breakdown and a schedule for BIM deliverables.

The procedure to complete the IE worksheet consists of the following steps:

1. **Import each potential BIM Use from the Level 1 BIM Overview Map;**

The key information exchanges identified in the Overview Map should be listed on the IE worksheet. The project phase in which this IE occurs should also be identified. When possible, the BIM Use exchanges should be listed in chronological order to give a visual representation of the progression of the model requirement. Note that each phase may have more than one IE.

2. **Identify the model element breakdown to be used for the project;**
   The model element breakdown structure used to develop the template IE worksheet is the UNIFORMAT II Classification System. However, it is vital that the project team uses the model element structure which fits the project requirements.
3. **Identify the Information for each Exchange.**
   Work through the model element breakdown for each IE identifying the information content for the model, responsible party and the application format and version. The legend defined for the information content should describe the geometric level of detail. Any specific parametric information must be included in the 'notes' column. Notes would also include any additional information, for e.g., a specific modeling technique, grouping requirements, etc.

7.4 CHAPTER SUMMARY

Having established the templates and structure for Process Mapping and IE, it is important to establish the synergies between them. The Overview Map identifies all the BIM Uses to be employed and the key IEs for a project. All the relevant details like the reference information; the process of implementation; and the internal and external IEs must be identified on the Detailed PM. The key IEs, identified in the Overview Map, must be detailed on the IE worksheet. Working through the model element breakdown structure for each IE, the information content for the model, responsible party and the application format and version must be identified. With the progress in design and construction, any information which was previously left out due to unavailability must be updated to monitor progress.

CHAPTER 8: PROCEDURE TO DEFINE THE SUPPORTING INFRASTRUCTURE FOR BIM IMPLEMENTATION

The final step in the four-part BIM Project Execution Planning Procedure is to identify and define the project infrastructure required to effectively implement BIM as planned. Fourteen specific categories support the BIM project execution process. These categories, as displayed in Figure 8.1, were developed after analyzing the documents listed below[6], reviewing current execution plans, discussing the issues with industry experts and revised through extensive review by various industry organizations.

BIM Project Execution Plan
Categories

- BIM Project Execution Plan Overview
- Project Information
- Key Project Contacts
- Project Goals / BIM Uses
- Organizational Roles / Staffing
- BIM Process Design
- BIM Information Exchanges
- BIM and Facility Data Requirements
- Collaboration Procedures
- Quality Control
- Technological Infrastructure Needs
- Model Structure
- Project Deliverables
- Delivery Strategy / Contract

Figure 8.1: BIM Project Execution Plan Categories

This chapter describes each category of the BIM Project Execution Plan. Information for each category can vary significantly by project, therefore the goal of the description is to initiate discussion and address content areas and decisions which need to be made by the project team. Additionally a template BIM Project Execution Plan has been developed and is available on the project website[7] and referenced in BIM Project Execution Plan Template. Please note that the information contained in the template will have to

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[6] The AIA BIM Protocol Exhibit, the ConsensusDOCS BIM Addendum, the United States Army Corps of Engineers (USACE) BIM Roadmap and the Autodesk Communication Specifications define processes, standards and/or contract language for BIM execution on projects. The contents of these documents were compiled and organized to determine key aspects of BIM implementation both on a project and within an organization. The content categories of these implementation documents are contained in Appendix G of this document, along with their relation to the BIM Project Execution Planning categories defined in this guide.

[7] www.engr.psu.edu/BIM

be customized based on the project. Additional information may be necessary, while other information could be removed. See Figure 8.2 for an example from the current BIM Project Execution Plan Template

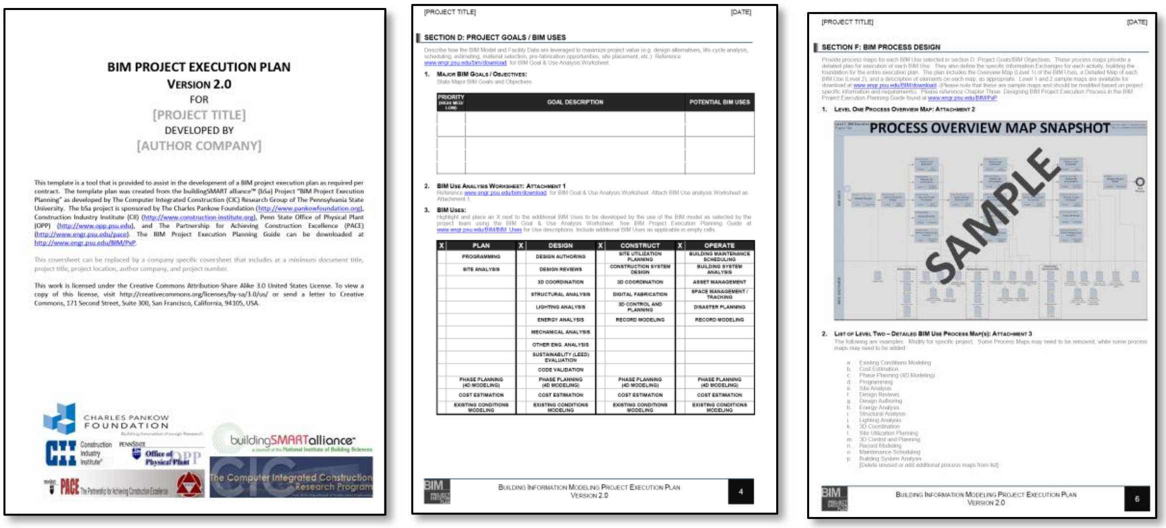


Figure 8.2: Portions of Current BIM Project Execution Plan Template

8.1 BIM Project Execution Plan Overview

It is important for the project team to understand the reason that a BIM Project Execution Plan was created. This section should include information such as a BIM mission statement and other executive summary level information. This section should be used to establish the importance of the plan.

8.2 Project Information

This section includes basic Project information that may be valuable for current and future. This section may include items such as project owner, project name, project location and address, contract type / delivery method, brief project description, project number(s) and the project schedule / phases / milestones. Any additional general project information can and should be included in this section such as unique project characteristics, project budget, project requirements, contract status, funding status, and unique project requirements, etc.

8.3 Key Project Contacts

At least one representative from each stakeholder involved should be identified including the owner, designers, consultants, prime contractors, subcontractors, manufacturers, and suppliers. These representatives could include personnel such as Project Managers, BIM Managers, Discipline Leads, Superintendents and other major project roles. All stakeholders' contact information should be collected, exchanged, and when convenient, posted on a shared collaborative project management web-portal.

8.4 Project BIM Goals / BIM Uses

The BIM Project Execution Plan should document the previous steps in the BIM project execution planning process. It is valuable for the team to document the underlying purpose for implementing BIM on the project as well as explain why key BIM Use decisions were made. The plan should include a clear list of the BIM goals, the BIM Use Analysis Worksheet, as well as specific information on the BIM Uses selected. The procedure to identify appropriate BIM Uses for a project is outlined in detail in Chapter 2: Identifying BIM Goals and BIM Uses.

8.5 Organizational Roles and Staffing

The roles in each organization and their specific responsibilities must be defined. For each BIM Use selected, the team must identify which organization(s) will staff and perform that use. This includes the number of personnel by job title necessary to complete the BIM Use, the estimated worker hours, the primary location that will complete the Use and the Lead organizational contact for that Use. Depending on which phase of a project's lifecycle this plan is completed several items in this section may be challenging to complete. Like the rest of the Plan, as much as possible should be completed and the remaining should be completed as the information becomes available.

8.6 BIM Process Design

The process maps created for each selected BIM Use in step two of the BIM Project Execution Planning Process should be documented in the Plan. The plan should include the overview map of the BIM Uses, a detailed map of each BIM Use, and a description of elements on each map. For further explanation of the steps to create process maps, please refer to Chapter 3: Designing the BIM Project Execution Process of the BIM Project Execution Planning Guide.

8.7 BIM Information Exchanges

The BIM Project Execution Plan should document the information exchanges created during the third step of the planning procedure The information exchanges illustrate the model elements by discipline, level of detail, and any specific attributes important to the project. For further explanation of the steps necessary to create information exchanges, please refer to Chapter 4: Developing Information Exchanges of the BIM Project Execution Planning Guide.

8.8 BIM and Facility Data Requirements

In this section, the owner specific BIM requirements are documented. In some cases owners have specific BIM Requirement such as require BIM the US Army Corps of Engineers' Attachment F, Indiana University, or the Penn State Office of Physical Plant.

8.9 Collaboration Procedures

The team must develop their electronic and activity collaboration procedures. This section should include collaboration strategies, collaboration activities procedures, Model delivery schedules, interactive workspaces, and electronic communication procedures. This includes model management (e.g., model check-out, revision procedures, etc.), and standard meeting actions and agendas.

8.10 Quality Control

Project teams should determine and document their overall strategy for quality control of the model. To ensure model quality in every project phase and before information exchanges, procedures must be defined and implemented. Each BIM created during lifecycle of the project must be pre-planned considering model content, level of detail, format and party responsible for updates; and distribution of the model and data to various parties. Each party contributing to the BIM model should have a responsible person to coordinate the model. This person, as part of the BIM team, should participate in all major BIM activities as required by the team. They should be responsible for addressing issues that might arise with keeping the model and data updated, accurate, and comprehensive.

8.11 Technology Infrastructure Needs

The team should determine the requirements for hardware, software platforms, software licenses, networks, and modeling content for the project.

8.12 Project Deliverables

The project team should consider what deliverables are required by the project owner. With the deliverable project phase, due date format and any other specific information about the deliverable should be considered.

8.13 Delivery Strategy / Contract

When implementing BIM on a project, attention should be paid to the delivery method and contraction methods before the project begins. Ideally a more integrated approach such as design-build or Integrated Project Delivery (IPD) would be used. While it usually yields the best results for the project, an integrated approach is not always possible on all projects. This could be because of a number of reasons. Additionally the contract type and delivery method may have already been selected before BIM planning takes place. If this is the case the team needs to consider future subcontractors and consultants and also consider what steps are necessary to ensure successful BIM implementation no matter what the delivery method. BIM can be implemented successfully within all delivery methods.

8.14 Summary

This chapter discussed the information that should be contained inside of a BIM project exaction plan. For more information about this subject, please see the Project Website (www.engr.psu.edu/BIM) or The BIM Project Execution Planning Guide.

CHAPTER 9: VALIDATION

The BIM Project Execution Planning Procedure was validated through three primary methods. The first was a quasi-experiment with students at Penn State. The second was to analyze the implementation of the procedure on 7 project case studies, 3 organizational case studies, and 2 academic case studies. The third method was to conduct surveys of practitioners who downloaded the guide to solicit their feedback. Each validation step is discussed in the following sections.

9.1 QUASI-EXPERIMENT

To ensure that the Procedure steps and the Business Process Modeling Notation (BPMN) representation of the Process Mapping Procedure were self-explanatory, quasi-experiments were conducted with eleven graduate students from the Department of Architecture and Architectural Engineering at The Penn State University. Before conducting the quasi-experiments, a pilot study was performed with two undergraduate students. Using the Process Mapping Procedure and the BPMN representation of the framework, these two students created template process maps for 3D MEP Coordination and 4D Modeling BIM use. During the quasi-experiments, all the participants were made familiar with the process modeling notation adopted to create process maps. A post experiment survey was conducted to obtain feedback on the Process Mapping Procedure. The quasi-experiment was performed to ensure that the Process Mapping Procedure could be followed and understood to create a process map. The deviations in the process maps produced were documented as part of the content analysis and relevant changes were made to the Procedure to address the challenges.

9.2 SURVEY BIM GUIDE READERS AND USERS

The research team developed a survey to validate the BIM Project Execution Planning Procedure and BIM Uses. The survey consisted of sixteen questions focused in four primary areas: demographic information, BIM Uses, Project Execution Planning Procedure, and Comments. On a 5-point Likert scale, most survey participants responded either positive or very positive about each step of the procedure. However, the more telling result may be that only 2.6% of respondents are not likely to implement the procedure, while 14.6% of respondents were already implementing it.

9.3 CASE STUDIES

After the Draft Guide was developed and released in October 2009, the team focused on the validation of the Planning Process through industry case studies. The value of the BIM Execution Planning Procedure is evaluated according to the following steps:

6. Perform Case Study observations of the development of a BIM Plan. A standard procedure for project implementation includes:

    - Meeting 1 – Identify BIM Uses to be implemented on a project (Step #1)
    - Meeting 2 – Review Project Specific Process Maps (Step #2)
    - Meeting 3 – Review Developed Information Exchanges (Step #3)
    - Meeting 4 – Review Draft BIM Plan with Team

- BIM Plan – Version 1.0 – revisit on a monthly basis

7. Survey Project Team Participants regarding value of the Procedure documented in the guide and the Final Product (BIM Project Execution Plan);
8. Document Case Study Content including project descriptions, process followed by the team, lessons learned, and human and project factors which influenced the success or failure of the implementation;
9. Analyze case study and survey results through detailed content analysis. The result of this process will identify necessary revisions to BIM Project Execution Planning process;
10. Revise BIM Project Execution Planning Guide based on results.

9.3.1 Case Study Projects

The following is a list of case study projects that have been completed or are ongoing by the BIM Project Execution Planning Team. Included are summaries for both project and organizational level case studies. Project level studies include a team member observing the creation of a BIM Plan using the four step procedure within a project team. Organizational level studies include a team member assisting an organization in the creation of a template for future BIM Project Execution Plans. These future plans can be used as project level case studies because the four step procedure is embedded into the organizational level approach.

9.3.2 Project Level Case Studies

9.3.2.1 Springfield Data Center –Draft BIM Plan Sent to Team

The Springfield Data Center is an 113,000 square foot and $92.4 million project with the purpose of providing an active back-up facility for the Commonwealth's Information Technology Division. In order to improve the use of BIM on the project, the Division of Capital Asset Management (DCAM) of the Commonwealth of Massachusetts decided to execute the process detailed in the BIM Project Execution Planning Guide. After stepping through several steps of the process, DCAM contacted the research team to collaborate on portions of the planning procedure and assist with the creation of its related documents. To better suit the needs of the team and project, DCAM customized the project execution plan template into an excel spread sheet. The document was developed over two 4-5 hour meetings, with additional time spent by the team both before and after for completion. The spreadsheet is constantly updated and revised, becoming a living document for the team. At each project milestone, the BIM Plan will undergo a major review. The team is currently scheduling a meeting to examine the BIM Plan after the fifty percent design milestone to ensure the plan's accuracy and make any necessary revisions.

9.3.2.2 Moore Building – BIM Plan V1.0 developed

The Office of Physical Plant (OPP) of The Pennsylvania State University requires all new building projects to deliver a BIM model at the end of construction. However, the OPP is only now in the process of developing these turnover requirements. In order to do this, the OPP called upon the research team to use the BIM Project Execution Planning Procedure on a major addition/renovation project on campus to assist with this initiative. The project will construct an approximate 58,000 SF addition to the existing Moore Building. Upon completion of the addition, the existing building will be renovated. The building will house the Psychology Department which is in the College of Liberal Arts. A project specific BIM Project Execution Plan was created by the research team and the project team members. The plan included the Penn State template as well as the verbiage from both the A/E and Contractors' company execution plans. There were many human and project factors that played both a positive and negative role in the creation of the BIM Execution Plan. This project demonstrated the experience of implementing the BIM Execution Plan during the middle of the project lifecycle.

9.3.2.3 Henderson Building – Meeting # 1 Complete

The Office of Physical Plant (OPP) of The Pennsylvania State University has recently begun its second BIM Project Execution Planning case study. The Henderson Building project is a renovation of an existing building on campus. Similar to the Moore Building case study, this project is in the construction documentation phase of design. The research team has met once with both the A/E and contractor to discuss the project BIM Goals and Uses. Due to the current status of design, the team is experiencing the same initial discussions and struggles as the Moore Building project. The research team reviewed the initial goals and uses and is currently developing their specific workflows. Over the next several months the team will complete the remaining steps in the procedure and develop a BIM Project Execution Plan, while continuing to track its development in order to validate the guide.

9.3.2.4 Richard H. Poff U.S. Courthouse – BIM Plan V1.0 Developed

The General Service Administration (GSA) contacted the research team to assist the project team with the creation a BIM Plan. The focal point for BIM implementation at the GSA is current tenant satisfaction during the design and construction of the facility. Additionally, models will be utilized to simulate the tenant sequencing, assist large design decisions, and coordinate the existing structure with new components to the best of the team's abilities. LEED goals also will be reviewed to ensure cohesiveness with BIM objectives and to implement sustainable technologies throughout the building.

9.3.2.5 UHS San Antonio – Drafting Final BIM Project Execution Plan

The University Heath System San Antonio Capital Improvement Program is embarking on one of the largest healthcare construction programs in the United States. The Capital Improvement Program consists of a combined $899M and is scheduled for completion in 2012. The objective was to validate the BIM Project Execution Planning Procedure and provide feedback to the research team. A secondary objective was to fully vet and produce a BIM Plan that considered all aspects of BIM for use prior to conceptual design phase. Both of these goals were accomplished through successful development of a BIM Project Execution Plan based on the developed planning procedure and its associated templates.

9.3.3 Organization Level Case Studies

9.3.3.1 The United States Army Corps of Engineers (US ACE) – BIM Plan Template Released

A US ACE specific BIM Project Execution Plan Template was created in collaboration with members from industry and the Penn State research team. This template will be referenced and required by Attachment F on all future USACE projects that include Attachment F by contract. This several month process resulted in the research of a US ACE specific template that was released in the beginning of February 2010. This version of the template created by the team includes the majority of the developed templates, while incorporating revisions from the US ACE template. Overall this project was successful demonstration of the adaptability of the BIM Project Execution Planning Guide and corresponding templates.

9.3.3.2 Los Angeles Community College District (LACCD) – Draft BIM Plan Template

The BIM Project Execution Planning Team is assisting LACCD in the development of a standardized template for BIM Project Execution Planning on future projects. The template is currently being modified to include information contained in the LACCD BIM Standard – Version 3.0. A large revision to the Standard includes the development of an OmniClass structure that will be submitted on future LACCD Projects.

9.3.4 Principal Lessons Learned From Case Studies

Throughout the validation of the BIM Project Execution Planning process, there have been many concepts identified that will need to be incorporated into the future releases of the guide. Several principal lessons learned include:

- A BIM champion(s) is critical;
- Owner involvement is necessary;
- Team buy-in and transparency is important;
- The BIM Planning Procedure should allow for adaptations by the project team;
- The BIM plan must be considered a living document; and
- Planning resources must be available.

If all of these aspects are considered during the BIM Planning Process, it should lead not only to a better BIM project execution plan, but also a better implementation of BIM throughout the life-cycle of the project.

9.3.5 A BIM Champion(s) is Critical

Every case study project that successfully developed a BIM Project Execution Plan had at least one person with a strong desire to develop the BIM Plan. This person was considered a BIM Champion. In all of the case study projects, this champion was either from the owner organization or a program/construction management role. The champions spent time to learn the

BIM Project Execution Planning Procedure and worked to help compile the information into the final BIM Plan. They also marketed the value of the concept to the other team members. It is important that the champion(s) on a project can encourage the team to take the time to plan the work, even if there is strong pressure to start developing model content.

9.3.6 Owner Involvement is Necessary

In each successful case study, the owner was involved in the planning process. In addition to providing guidelines for the desired model outcomes, the owner frequently played a role in emphasizing the importance of BIM implementation for meeting their desired end goals. This clear display of the value of BIM implementation by the owner frequently encouraged project team members to seek what was best for the project. Without the owner's involvement, teams were likely to push the planning process aside since there was no deliverable expectation. Owners should consider writing a BIM Project Execution Plan into their contract documents to ensure that the document and planning is completed to their expectations. Owner involvement and excitement are essential even if no owner requirements currently exist.

9.3.7 Team Buy-In and Transparency is Important

The BIM Project Execution Planning Procedure requires organizations to provide information regarding their standard practices including typical processes and information files. To be successful, the team members must buy-in to the process and be willing to share this intellectual content with other team members. This led to challenges for some projects since team members were not very open to this concept. Additionally, contract structures can often lead to collaboration challenges. In traditional contracting structures, there is a desire to keep processes internal and not share them with the group. Often times, there is a fear that if project participants come to an agreement within the BIM plan, they are then contractual obligated for the defined deliverables. In some cases, project team members may request a change order or additional services. However, the goal of this process is to educate all parties on what is possible to deliver. The team can agree on a process and deliverables that will be beneficial to all members involved. In order to reach this agreement, the project team needs to have open lines of communication. It is essential that the project team fosters an open environment of sharing and collaboration, even if it is deployed in less than ideal situations.

9.3.8 BIM Planning Procedure Should Allow for Adaptations by the Project Team

Even in its current state, the guide is very adaptable to multiple uses and situations beyond the original scope of the project. In almost all cases, the project team has not completed the entire process; rather they have taken what they need from the procedure. While not the intended use, these projects have created project execution plans that are more comprehensive than what was ever created prior by the organization. These teams now have the ability to eventually add other portions of the procedure, which will further develop their planning. Teams have also modified the template documents to fit their specific processes. However, in most cases these changes are only minor and do not modify any of the core steps of the planning procedure.

Additionally, the plan has been adapted to different contracting structures, which was not originally anticipated. The BIM process has the ability to be comprehensively adopted in more integrated delivery method. However, none of our case studies have used the Integrated Project Delivery (IPD) contracting and procurement method. Because of this, it is evident that the core steps of the procedure are helpful no matter the delivery method of the project. Depending on the delivery strategy, additional steps may be needed to ensure project planning success.

When this guide was developed, it was planned for just project level implementation. Interestingly, a number of organizations have internalized it and used the procedure to develop a BIM Project Execution Planning Process on the organizational level. While not the intended use, this has proven to be very valuable to those organizations. Often times the project team felt that performing some of the tasks in the procedure were too involved for the project team to conduct just for a single project. By performing organizational level planning, the team can reduce the amount of time spent on each step of the planning process and maintain a manageable planning scope because the team already has standard goals, uses, processes, and information exchanges defined. The ability for this process to be adapted to multiple situations speaks to the robustness and usefulness of the guide and procedure as a whole.

9.3.9 The BIM Plan Must Be Considered a Living Document

When beginning the project execution planning process, it is valuable to understand that the BIM Plan will be constantly changing and updated. It is unrealistic to assume that the project team will have all information necessary to completely develop a BIM Plan at the inception of the project. In most cases, many stakeholders may not be contracted or involved in the planning process in the early stages. It will take time to populate the information because additional and new information must be incorporated as project team members are added. (e.g., hiring of subcontractors and consultants that may not be involved at the onset of the project.) There is great value in early planning despite not having all stakeholders involved in the process. In this case, it is important that someone play the role of all project members, even if they have not yet been determined. Once an initial plan is developed, it needs to be reviewed regularly. A revision schedule needs to be set based on a frequency that the project team deems appropriate. Throughout the lifecycle of the project, it is important to keep the initial project goals in mind to ensure that the team is working towards their completion. If there is any deviation, there should be a reassessment of or a rededication of the original goals.

9.3.10 Planning Resources Must Be Available

Currently, there are not many organizations that plan their BIM implementation to the level of detail discussed in the BIM Project Execution Planning Guide. The project team must commit the level of manpower and other resources required to perform the planning process. On most projects, the planning process took more time than the teams anticipated. Project teams must consider the time allocated to planning when generating both the project schedule and project budget. Due to the learning curve associated with this process, teams should overestimate the time it will take to produce a BIM Plan. The time associated with the learning curve can be reduced by educating involved team member before delving into the process. Without proper planning before the project specific meetings begin, many unexpected issues may arise that could have been solved at an earlier time. However, even after organizations have performed their homework, BIM planning allows an opening for all BIM related discussions. Certain issues may have been assumed or not even considered before the initial meeting. These discussions, while maybe not pertaining directly to the BIM Plan, may be extremely important and necessary to allow for the entire project to run seamlessly. It is important that the team develop the process early in the project life. If planning does not happen early, extra time may be needed to resolve inconsistencies downstream. This often results in more time and resources used than the original planning would have needed. The BIM Project Execution Planning Process should become more efficient once the teams have gone through the process several times and have developed many of their own planning resources.

9.4 REVISE BIM PROJECT EXECUTION PLANNING GUIDE AND TEMPLATES

Once the feedback from the case studies, surveys, and industry review was collected and analyzed, the Guide was updated and released as Draft Version 2.0 for industry review in May of 2010. This version of the Guide incorporated a new chapter on BIM Project Execution Planning for Organizations. The purpose of this chapter is to define how organizations can use the BIM Project Execution Planning procedure to develop their typical methods for BIM project implementation. In addition, the lessons learned from the case studies were incorporated into a conclusion chapter for the Guide. Examples of the lessons learned from the case study implementation include the need for a BIM champion, for owner involvement, and for an open environment of sharing and collaboration. In addition to the chapter additions, the appendix was revised to include updated BIM Project Execution Planning Templates. A glossary of definitions used throughout the Guide was also added, as well as other improvements throughout the document to address comments received from Version 1.0 and areas for improvement identified throughout the case study projects.

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

This research report describes the development of the BIM Project Execution Planning Procedure. The goal of this project is to create a standardized procedure for project planning by creating typical company workflows and procedures to make it easier for teams to plan the BIM execution strategy on a project. This research outlines a four-step procedure to develop the BIM Execution Plan which was developed through a multi-step research process, including industry interviews, detailed analysis of existing planning documents, focus group meetings and case study research to validate the procedure. The four steps (refer to Figure 7-1) consist of identifying the appropriate BIM goals and uses on a project, designing the BIM execution process, developing the information exchanges , and defining supporting infrastructure for BIM implementation.

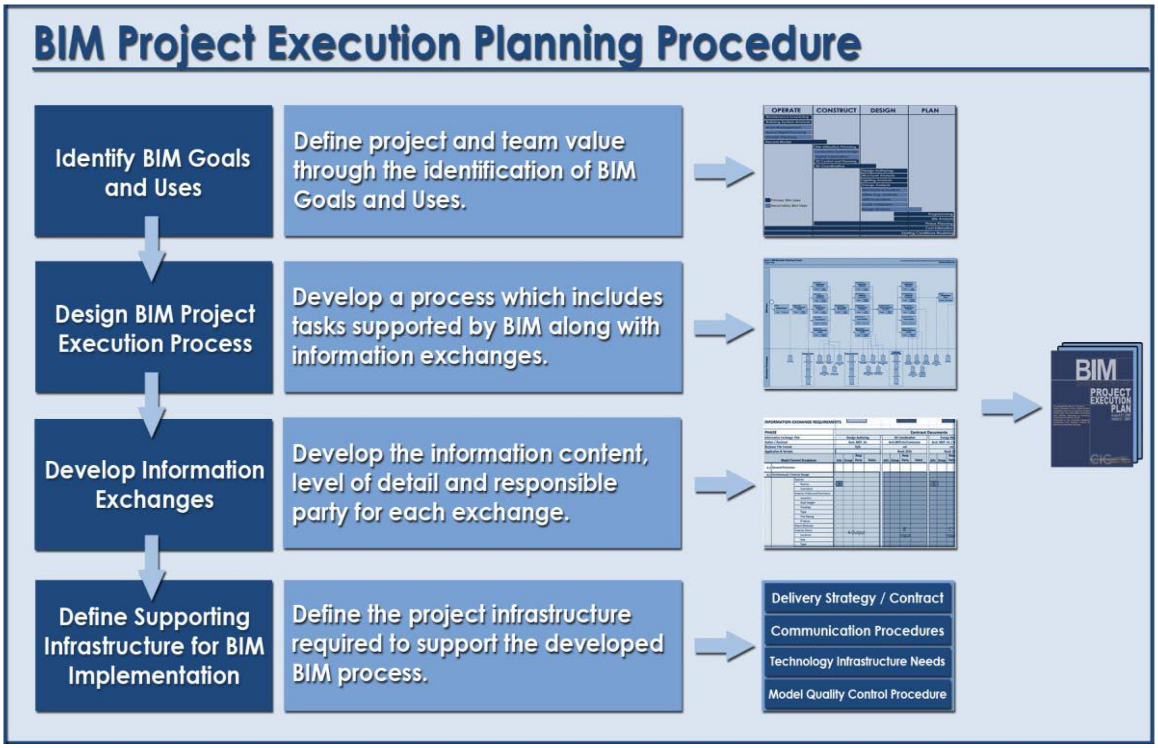


Figure 10.1: The BIM Execution Planning Procedure (The Computer Integrated Construction

10.1 RESEARCH CONTRIBUTION

The primary contributions of this research project are described in the following sections:

10.1.1 BIM PROJECT EXECUTION PLANNING PROCEDURE

The BIM Project Execution Planning Procedure provide project teams with a straightforward four step process for planning the application of BIM on a project. The procedure includes establishing goals and Uses, Mapping the BIM Process, Developing Information Exchanges, and Defining Supporting Infrastructure. By properly planning and performing these steps, a project team is more likely to successfully implement BIM and receive BIM's benefits on the project.

10.1.2 BIM PROJECT EXECUTION PLANNING GUIDE

The guide itself is a straightforward dissemination of the procedure. The guide has been downloaded over 3250 times and that the number is constantly increasing. Additionally, the guide continues to be updated and released to the industry free of charge for widespread adoption.

10.1.3 BIM USES

By creating a taxonomy of BIM Uses it give project team a basis for determining how they will apply to BIM during a facilities' life. It also allows for future researches to further define and categorize the BIM Uses.

10.1.4 VALUE OF PROCESS MAPPING AND INFORMATION EXCHANGE WORKSHEET

The results of the questionnaire survey and focus group discussion shows that PMs and IEs are valuable tools to communicate the BIM Process. By developing a BIM Process Mapping Procedure, the project team will be able to design an execution process which will be appropriate for each team members' business practices and typical workflows. By developing the information exchanges, the organizations involved will understand their roles and responsibilities in the implementation. Following a project implementation, the process can be used as a starting point for describing the plan to future team members. Additionally, the plan will provide goals for measuring progress throughout the project.

10.1.5 GUIDELINES FOR CREATING PROCESS MAP AND INFORMATION EXCHANGES

Procedural steps/guidelines have been developed for designing the BIM Process Mapping Procedure. This procedure will guide the project team to create PMs using the Business Process Modeling Notation. A detailed workflow of filling the IE worksheet is also provided.

10.1.6 TEMPLATE MAPS FOR BIM USES

To assist in the creation of the Detailed BIM PMs, Template PMs have been created for five BIM Uses. It is important to realize that each project and company is unique, so there may be many different potential methods that a team could use to achieve a particular task. Therefore, these Template PMs will need to be modified by project teams to achieve the project and company goals.

10.1.7 DEFINING SUPPORTING INFRASTRUCTURE AND ASSOCIATED BIM PROJECT EXECUTION PLAN TEMPLATE

By defining the fourteen categories that should be contained in a BIM Project Execution Plan, it give the architecture, engineering, construction and owner a common platform for the exchange of plans. In fact, a number of industry members currently standardizing upon across their organizations.

10.1.8 CASE STUDIES OF BIM PROJECT EXECUTION PLANNING

By conducting case studies, the research team has validated the BIM project execution planning procedure. If the procedure is not validated there is little reason for future project teams to implement it.

10.2 LIMITATIONS

10.2.1 BIM USES LIMITATIONS

The research is intended to provide the taxonomy of BIM uses for the BIM Execution Planning Guide by drawing on published articles, papers, guides, and experiences and best practices from the AEC industry. Although the findings of this study are believed to cover broad strategies, experiences, and implementation techniques; it is important to remember that the interviewed participants represent a sample of offices and companies experimenting and implementing BIM primarily in the Mid-Atlantic region of U.S.

This research presents the results from the interviews conducted in a period of August- December 2008. The responses received cannot be regarded as comprehensive of all BIM uses. Therefore, the conclusions cannot be considered to provide an comprehensive list, but more to be a common denominator for the responses received from the expert interviews.

Though it can be considered that the current status of BIM implementation, challenges, issues, risks and concerns were captured, some of the findings cannot be generalized. A large number of those interviewed have more advanced practices of BIM, while several of them have limited experience in BIM implementation. Regarding the BIM uses identified, though a very complete list was presented, there is still the possibility of adding other uses that were not recognized by interviewed industry participants or not yet developed at the time. The sample size of interviewees is representative, but by no means statistically significant to draw general conclusions for the whole population.

Another limitation that was noted is the non-existence of hard data to support BIM impact analysis. Measurements are rarely done, metrics are not established and only anecdotal data is presented. This form of study would greatly benefit from some quantitative data collected, analyzed and presented to support the statements and findings of the study.

10.2.2 TEMPLATE MAPS LIMITATIONS

Using the Procedure for creating a PM, five template maps were developed as part of this thesis research. One template map was created from plan, design, construct, operate and multiphase BIM Use. This was done specifically to ensure that the Procedure is valid under different types of tasks. As part of future work, template maps can be created for all the 25 BIM Uses identified in the BIM Project Execution Planning Procedure.

10.2.3 LIMITED VALIDATION OF THE BIM PROCESS MAPPING PROCEDURE

A historical mapping technique was utilized in the case study research. The case study project was observed, and the PMs and IEs were then developed by the researcher. However, the BIM Process Mapping Procedure is intended to be used by the project team members even with a limited knowledge of BIM. Future work will have to be undertaken in which the project team develops the Detailed PMs and IE for a project without the assistance of the researcher.

10.2.4 Limited Supporting Infrastructure

While the research into the Supporting Infrastructure has been reviewed extensively by industry and multiple firms, it only represents the information needed for a specific point in time. As the applications of BIM become more defined some sections may need to be added while other may become obsolete.

10.2.5 Limited Case Study Applications

The research only utilized the Case Studies mentioned about for creating the BIM Process Mapping Procedure. The focus group discussion with the project team members indicated that the BIM Process Mapping Procedure was an acceptable approach to creating a BIM Implementation Plan. Implementing the Procedure on more case studies will show the value of the BIM Project Execution Planning Procedure. Additional case studies will also help in analyzing possible gaps in the process mapping procedure.

10.3 **Future Work**

The results and conclusions of this research were used to develop the following suggestions for future research in creating a BIM Project Execution Plan.

10.3.1 BIM Uses

This report has identified an extensive list of BIM Uses. The results of the study show the taxonomy of potential BIM uses, and provide valuable insight into the strategic implementation topics that have been addressed by organizations on a corporate and project level. Various BIM impacts were identified in the study, but a detailed analysis of each of the factors or uses was not performed. The results and conclusions of this study are exploratory and are intended to be used to build upon, or as a starting point for further research in this area.

This study was primarily done with participants in the greater Washington D.C. metro area. Further research or comparison can be done in other areas of the United States to verify design BIM uses nationally. Also, the results of the national study could be used in comparison with BIM advances in Europe, Asia or Australia.

10.3.2 Additional Case Study Applications

Additional case study applications must be completed to validate the BIM Process Mapping Procedure. Focus group discussions and surveys should also be conducted to get feedback on the value provided by the Procedure. A comparison of current BIM implementation practices can also be made for these case studies to see the benefits of BIM Project Mapping Procedure. Data collection can also be done for different sizes of the projects and with different experience levels of the companies in BIM to see how that affects the BIM Implementation Plan.

10.3.3 Information Exchange Concept

One of the main concepts of the lean production system is to maximize flow and minimize waste. The concept of a “pull” driven system allows an efficient means of transfer, to deliver the right amount of material, exactly when it is needed. The same concept is true for BIM implementation. The downstream

BIM Use demands what the upstream BIM Use information content must be. Therefore, it is important to only define those model components that are necessary to implement each BIM Use.

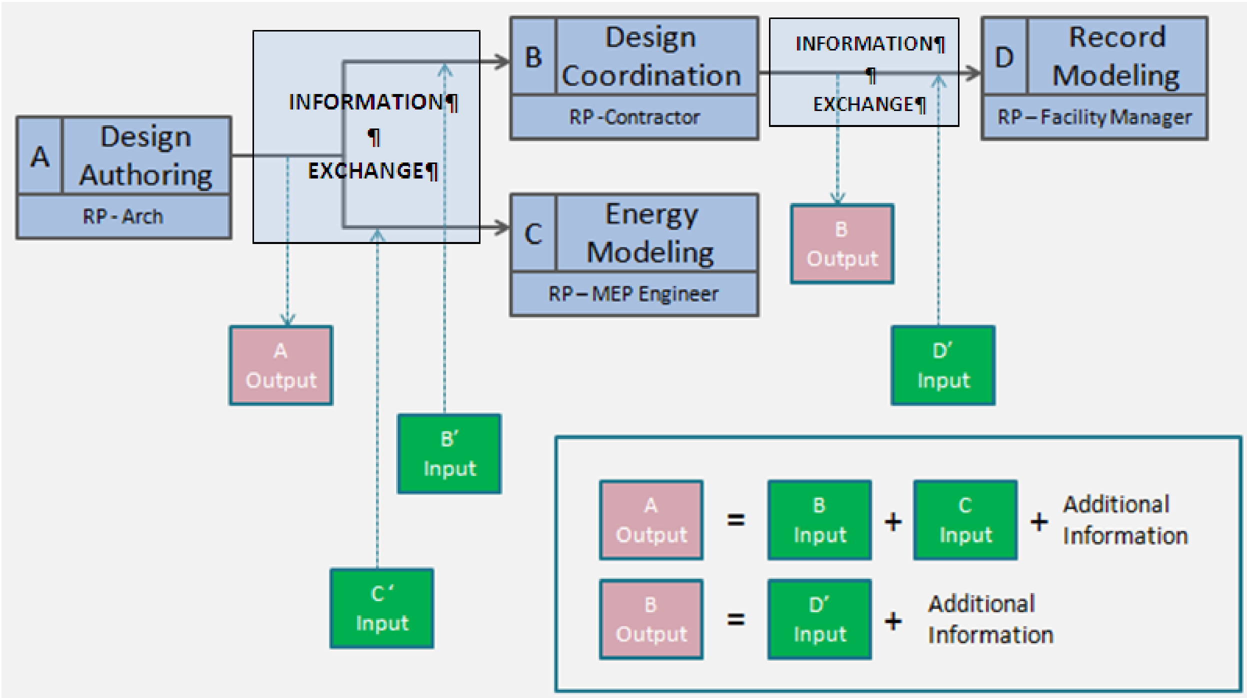


Figure 10.2: Information Exchange Concept

The concept not only defines the point in the process in which the exchange is occurring, but also defines what minimum information must be contained in the output of the model to so that the downstream BIM Uses can function efficiently (refer to Figure 10.2). In order for a model to be valuable, it does not necessarily need to include every element of information. Further efforts are required to improvise the IE template using this concept.

10.3.4 Defining Supporting Infrastructure

As Time Passes, more BIM Project Execution Plans will be created based on the templates created as part of this research project. These Plans should be collected and analyzed to ensure that the BIM Project Execution Planning templates contain all the necessary components. These Plans collected should also be released as examples for other organizations.

10.4 Concluding Remarks

BIM is a relatively new technology in the building industry and the execution of it encompasses many considerations. This study has provided a technique of implementing BIM on a project, yet there is still much to be learned in this area. By increasing the efficiency/quality of BIM implementation, a construction organization can utilize their capabilities and resources in an efficient manner by pursuing the BIM goals within the project as well as on an organizational level.

APPENDIX A: BIM GOAL WORKSHEET

Priority (1-3)	Goal Description	Potential BIM Uses
1- Most Important	Value Added Objectives	Achieve Goal

APPENDIX B: BIM USE DESCRIPTIONS

Please note that BIM Uses are organized in reference to Figure 2-2:

1. Building (Preventative) Maintenance Scheduling
2. Building System Analysis
3. Asset Management
4. Space Management and Tracking
5. Disaster Planning
6. Record Modeling
7. Site Utilization Planning
8. Construction System Design
9. Digital Fabrication
10. 3D Control and Planning
11. 3D Coordination
12. Design Authoring
13. Engineering Analysis
    a. Energy Analysis
    b. Structural Analysis
    c. Lighting Analysis
    d. Mechanical Analysis
    e. Other Engineering Analysis
14. Sustainability (LEED) Evaluation
15. Code Validation
16. Programming
17. Site Analysis
18. Design Reviews
19. Phase Planning (4D Modeling)
20. Cost Estimation
21. Existing Conditions Modeling

Building (Preventative) Maintenance Scheduling

Description:

A process in which the functionality of the building structure (walls, floors, roof, etc) and equipment serving the building (mechanical, electrical, plumbing, etc) are maintained over the operational life of a facility. A successful maintenance program will improve building performance, reduce repairs, and reduce overall maintenance costs.

Potential Value:

- Plan maintenance activities proactively and appropriately allocate maintenance staff
- Track maintenance history
- Reduce corrective maintenance and emergency maintenance repairs
- Increase productivity of maintenance staff because the physical location of equipment/system is clearly understood
- Evaluate different maintenance approaches based on cost
- Allow facility managers to justify the need and cost of establishing a reliability centered maintenance program

Resources Required:

- Design review software to view Record Model and components
- Building Automation System (BAS) linked to Record Model
- Computerized Maintenance Management System (CMMS) linked to Record Model
- User-Friendly Dashboard Interface linked to Record Model to provide building performance information and/or other information to educate building users

Team Competencies Required:

- Ability to understand and manipulate CMMS and building control systems with Record Model
- Ability to understand typical equipment operation and maintenance practices
- Ability to manipulate, navigate, and review a 3D Model

Selected Resources:

- Campbell, D.A. (2007). BIM – Web Applications for AEC, Web 3D Symposium.

- Fallon, K. (2008). “Interoperability: Critical to Achieving BIM Benefits”. AIA Edges Website: Singh, H.; W.H. Dunn (2008). Integrating Facilities Stovepipes for Total Asset Management (TAM). Journal of Building Information Modeling, Spring 2008. http://www.aia.ord/nwsltr_tap.cfm?pagename=tap_a_0704_interop

- ASHRAE (2003). HVAC design Manual for Hospitals and Clinics. Atlanta, GA. (2004). Federal energy Management Program. O&M Best Practices: A Guide to Achieving Operational Efficiency, Release 2.0. July 2004. www1.eere.energy.gov/femp/pds.OM_5.pdf

- Piotrowski, J. (2001). Pro-Active Maintenance for Pumps. Archives, February 2001, Pump-Zone.com

Building Systems Analysis

Description:

A process that measures how a building's performance compares to the specified design. This includes how the mechanical system operates and how much energy a building uses. Other aspects of this analysis include, but are not limited to, ventilated facade studies, lighting analysis, internal and external CFD airflow, , and solar analysis.

Potential Value:

- Ensure building is operating to specified design and sustainable standards
- Identify opportunities to modify system operations to improve performance
- Create a "what if" scenario and change different materials throughout the building to show better or worse performance conditions

Resources Required:

- 3D Model manipulation
- Building Systems Analysis Software (Energy, Lighting, Mechanical, Other)

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Ability to understand building systems and typical operations
- Ability to assess building systems using analysis software

Selected Resources:

- Ayat E. Osman, Robert Ries. " Optimization For Cogeneration Systems in Buildings Based on Life Cycle Assessment" May 2006, HTTP://ITOCN.ORG/2006/20/
- "Building Performance Analysis Using Revit" 2007 Autodesk Inc., HTTP://IMAGES.AUTODESK.COM/ADSK/FILES/BUILDING_PERFORMANCE_ANALYSIS_USING_REVIT.PDF

Asset Management

Description:

A process in which an organized management system will efficiently aid in the maintenance and operation of a facility and its assets. These assets, consisting of the physical building, systems, surrounding environment, and equipment, must be maintained, operated, and upgraded at an efficiency which will satisfy both the owner and users at the lowest appropriate cost. It assists in financial decision-making, as well as short-term and long-term planning. Asset Management utilizes the data contained in a record model to determine cost implications of changing or upgrading building assets, segregate costs of assets for financial tax purposes, and maintain a current comprehensive database that can produce the value of a company's assets.

Potential Value:

- Store operations, maintenance owner user manuals, and equipment specifications.
- Perform and analyze facility and equipment condition assessments
- Maintain up-to-date facility and equipment data including, but not limited to, maintenance schedules, warranties, cost data, upgrades, replacements, damages/deterioration, maintenance records, manufacturer's data, equipment functionality, and others required by owner.
- Provide one comprehensive source for tracking the use, performance, and maintenance of a building's assets for the owner, maintenance team, and financial department
- Produce accurate quantity takeoffs of current company assets which aids in financial reporting, bidding, and estimating the future cost implications of upgrades or replacements of a particular asset.
- Allow for future updates of record model to show current building asset information after upgrades, replacements, or maintenance by tracking changes
- Aid financial department in efficiently analyzing different types of assets through an increased level of visualization
- Increase the opportunity for measurement and verification of systems during building occupation

Resources Required:

- 3D Model manipulation
- Asset Management system

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D Model
- Ability to manipulate an asset management system
- Knowledge of tax requirements and related financial software
- Knowledge of construction and the operation of a building (replacements, upgrades, etc.)
- Knowledge of which assets require tracking, whether the building is dynamic vs. static, and the end needs of the building to satisfy the owner

Selected Resources:

- GSA Energy Performance and Operations: http://www.gsa.gov/Portal/gsa/ep/contentView.do?programId=12122&channelId=-8161&ooid=20917&contentId=21770&pageTypeId=8195&contentType=GSA_BASIC&programPage=%2Fep%2Fprogram%2FgsaBasic.jsp&P=PMBIM
- GSA Commissioning Overview: http://www.gsa.gov/Portal/gsa/ep/channelView.do?pageTypeId=8195&channelPage=%2Fep%2Fchannel%2FgsaOverview.jsp&channelId=-15163
- NIST **General Buildings Information Handover Guide: Principles, Methodology and Case Studies** http://www.fire.nist.gov/bfrlpubs/build07/PDF/b07015.pdf

Space Management and Tracking

Description:

A process in which BIM is utilized to effectively allocate, manage, and track assigned workspaces and related resources. A BIM model will allow the facility management team to analyze the existing use of the space and appropriately manage changes in clientele, use of space, and future changes throughout the facility's life. Space management and tracking is an application of the record model.

Potential Value:

- Identify and allocate space for appropriate building use
- Track current use of space
- Insure optimum use of the facility's space resources
- Assist in planning future space needs for the facility

Resources Required:

- 3D Model manipulation
- Content management application

Team Competencies Required:

- Ability to manipulate, navigate, and review record model
- Ability to assess current space and assets and manage appropriately for future needs

Selected Resources:

- Valcik, Nicolas A. and Patricia Huesca-Dorantes. “Building a GIS Database for Space and Facilities Management.” New Directions for Institutional Research, n120 p53-61 2003.

Disaster Planning

Description:

A process in which emergency responders would have access to critical building information in the form of a model and information system. The BIM would provide critical building information to the responders that would improve the efficiency of the response and minimize the safety risks. The dynamic building information would be provided by a building automation system (BAS), while the static building information, such as floor plans and equipment schematics, would reside in a BIM model. These two systems would be integrated via a wireless connection and emergency responders would be linked to an overall system. The BIM coupled with the BAS would be able to clearly display where the emergency was located within the building, possible routes to the area, and any other harmful locations within the building.

Potential Value:

- Provide police, fire, public safety officials, and first responders access to critical building information in real-time
- Improve the effectiveness of emergency response
- Minimize risks to responders

Resources Required:

- 3D Model manipulation
- Building Automation System (BAS) knowledge
- Emergency response knowledge

Team Competencies Required:

- Ability to manipulate, navigate, and review BIM model for facility updates
- Ability to understand dynamic building information through BAS
- Ability to make appropriate decisions during an emergency

Selected Resources:

- **Building Information for Emergency Responders**. Systemics, Cybernetics and Informatics, 11th World Multi-Conference (WMSCI 2007). Proceedings. Volume 3. Jointly with the Information Systems Analysis and Synthesis: ISAS 2007, 13th International Conference. July 8-11, 2007, Orlando, FL, Callaos, N.; Lesso, W.; Zinn, C. D.; Yang, H., Editor(s) (s), 1-6 pp, 2007. Treado, S. J.; Vinh, A.; Holmberg, D. G.; Galler, M.

Record Modeling

Description:

A process in which a 3D model contains an accurate depiction of the physical conditions and environment of a facility and its assets. This has potential to contain information relating to the main architectural and MEP elements, but equipment and asset information as well. Furthermore, with the continuous updating and improvement of the record model and the capability to store more information, the model contains a true depiction of space with a link to information such as serial codes, warranties and maintenance history of all the components in the building. The record model also contains information linking pre-build specification to as-built specifications. This allows the owner to monitor the project relative to the specifications provided.

Potential Value:

- Aid in future modeling and 3D design coordination for renovation
- Provide documentation of environment for future uses, e.g., renovation or historical documentation
- Aid in the permitting process (e.g. continuous change vs. specified code.)
- Dispute elimination (e.g. link to contract with historical data highlights expectations and comparisons drawn to final product.)
- Solid understanding of project sequencing by stakeholders leads to reduced project delivery times, risk, cost, and law suits

Resources Required:

- 3D Model manipulation

Team Competencies Required:

- Ability to manipulate, navigate, and review 3D model
- Ability to use BIM modeling application for facility updates
- Ability to thoroughly understand site processes to ensure correct input

Selected Resources:

- http://www.bimforum.org/index.php?option=com_content&task=view&id=19#Q6
- http://bentleybim.wordpress.com/2007/11/13/bentleys-bim-preferred-58-to-revit-38-executive-briefing/
- http://continuingeducation.construction.com/article.php?L=19&C=213&P=1
- http://www.aecbytes.com/buildingthefuture/2006/Expotitions_meeting.html

Site Utilization Planning

Description:

A process in which a 4D model is used to graphically represent both permanent and temporary facilities on site, with the construction activity schedule. Additional information incorporated into the model can include labor resources, materials and associated deliveries, and equipment location. Because the 3D model components are directly linked to the schedule, site management functions such as visualized planning, short-term re-planning, and resources can be analyzed over different spatial and temporal data.

Potential Value:

- Generate site usage layout for temporary facilities, assembly areas, and material deliveries for all phases of construction
- Identify potential and critical space and time conflicts
- Select a feasible construction scheme
- Update site organization and space usage as construction progresses

Resources Required:

- 3D Model manipulation
- Design authoring software
- Scheduling software

Team Competencies Required:

- Ability to manipulate, navigate, and review 3D model
- Ability to manipulate and asses construction schedule with 3D model
- Ability to understand typical construction methods

Selected Resources:

- Chau, K.W.; M. Anson, and J.P. Zhang. "Four-Dimensional Visualization of Construction Scheduling and Site Utilization." Journal of Construction Engineering and Management. (July/August 2004): 598-606. ASCE. 5 September 2008. http://cedb.asce.org/cgi/WWWdisplay.cgi?0410956.
- Dawood, Nashwam et al. "The Virtual Construction Site (VIRCON) Tools: An Industrial Evaluation." ITcon. Vol. 10 (2005): 43-54. 8 September 2008. http://www.itcon.org/cgi-bin/works/Show?2005_5.
- Heesom, David and Lamine Mahdjoubi. "Trends of 4D CAD Applications for Construction Planning." Construction Management and Economics. (February 2004). 22 171-182. 8 September 2008. http://www.tamu.edu/classes/choudhury/articles/1.pdf.

Construction System Design (Virtual Mockup)

Description:

A process in which 3D System Design Software is used to design and analyze the construction of a complex building system (e.g. form work, glazing, tie-backs, etc.) in order to increase planning.

Potential Value:

- Increase constructability of a complex building system
- Increase construction productivity
- Increase safety awareness of a complex building system
- Decrease language barriers

Resources Required:

- 3D System design software

Team Competencies Required:

- Ability to manipulate, navigate, and review 3D model
- Ability to make appropriate construction decisions using a 3D System Design Software
- Knowledge of typical and appropriate construction practices for each component

Selected Resources:

- Leventhal, Lauren." Delivering Instruction for Inherently-3D Construction Tasks: Lessons and Questions for Universal Accessibility". Workshop on Universal Accessibility of Ubiquitous Computing: Providing for the elderly.
- Khemlano (2007). AECbytes: Building the Future (October 18, 2007).

Digital Fabrication

Description:

A process that uses machine technology to fabricate objects directly from a 3D Model. The 3D Model is spooled into appropriate sections and inputted into fabrication equipment for production of system assemblies.

Potential Value:

- Automate building component fabrication
- Minimize tolerances through machine fabrication
- Maximize fabrication productivity

Resources Required:

- 3D Model manipulation
- Fabrication equipment
- Fabrication methods

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Ability to manufacture building components using digital information
- Ability to understand typical fabrication methods

Selected Resources:

- Rundell, Rick. "BIM and Digital Fabrication (1-2-3 Revit Tutorial)." http://www.cadalyst.com/aec/bim-and-digital-fabrication-1-2-3-revit-tutorial-3707. 8 February 2008.

3D Control and Planning (Digital Layout)

Description:

A process that utilizes a model to layout the building assemblies and produce lift drawings. Lift drawings are 2D/3D component drawings used by foremen during on site construction.

Potential Value:

- Decrease layout error by producing control directly from the 3D Construction Model
- Increase communication between office and field personal
- Decrease/Eliminate language barriers

Resources Required:

- 3D Model manipulation

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Ability to understand and interpret lift drawings

Selected Resources:

- http://www.construction-planning-and-control.com/

3D Coordination

Description:

A process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems. The goal of clash detection is to eliminate the major system conflicts prior to installation.

Potential Value:

- Coordinate building project through a model
- Reduce and eliminate field conflicts; which reduces RFI's significantly compared to other methods
- Visualize construction
- Increase productivity
- Reduced construction cost; potentially less cost growth (i.e. less change orders)
- Decrease construction time
- Increase productivity on site
- More accurate as built drawings

Resources Required:

- 3D Model manipulation
- Model Review application

Team Competencies Required:

- Ability to deal with people and project challenges
- Ability to manipulate, navigate, and review a 3D model
- Knowledge of BIM model applications for facility updates
- Knowledge of building systems.

Selected References:

- Staub-French S and Khanzode A (2007) **3D AND 4D MODELING FOR DESIGN AND CONSTRUCTION COORDINATION: ISSUES AND LESSONS LEARNED** ITcon Vol. 12, pg. 381-407, **HTTP://WWW.ITCON.ORG/2007/26**
- Khanzode A, Fischer M, Reed D (2008) **BENEFITS AND LESSONS LEARNED OF IMPLEMENTING BUILDING VIRTUAL DESIGN AND CONSTRUCTION (VDC) TECHNOLOGIES FOR COORDINATION OF MECHANICAL, ELECTRICAL, AND PLUMBING (MEP) SYSTEMS ON A LARGE HEALTHCARE PROJECT**, ITcon Vol. 13, Special Issue **CASE STUDIES OF BIM USE** , pg. 324-342, **HTTP://WWW.ITCON.ORG/2008/22**
- **AECbytes.com - venderhub**

Design Authoring

Description:

A process in which 3D software is used to develop a Building Information Model based on criteria that is important to the translation of the building's design. Two groups of applications are at the core of BIM-based design process are *design authoring tools* and *audit and analysis tools.*

Authoring tools create models while audit and analysis tools study or add to the richness of information in a model. Most of audit and analysis tools can be used for Design Review and Engineering Analysis BIM Uses. Design authoring tools are a first step towards BIM and the key is connecting the 3D model with a powerful database of properties, quantities, means and methods, costs and schedules.

Potential Value:

- Transparency of design for all stakeholders
- Better control and quality control of design, cost and schedule
- Powerful design visualization
- True collaboration between project stakeholders and BIM users
- Improved quality control and assurance

Resources Required:

- 3D Model manipulation

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Knowledge of construction means and methods
- Design and construction experience

Selected References:

- Tardif, M. (2008). BIM: Reaching Forward, Reaching Back. AIArchitect This Week. Face of the AIA. **AIARCHITECT**

Engineering Analysis (Structural, Lighting, Energy, Mechanical, Other)

Description:

A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications. Development of this information is the basis for what will be passed on to the owner and/or operator for use in the building's systems (i.e. energy analysis, structural analysis, emergency evacuation planning, etc.). These analysis tools and performance simulations can significantly improve the design of the facility and its energy consumption during its lifecycle in the future.

Potential Value:

- Automating analysis and saving time and cost
- Analysis tools are less costly than BIM authoring tools, easier to learn and implement and less disruptive to established workflow
- Improve specialized expertise and services offered by the design firm
- Achieve optimum, energy-efficient design solution by applying various rigorous analyses
- Faster return on investment with applying audit and analysis tools for engineering analyses
- Improve the quality and reduce the cycle time of the design analyses

Resources Required:

- 3D Model manipulation
- Engineering analysis tools and software

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D Model
- Ability to assess a model through engineering analysis tools
- Knowledge of construction means and methods
- Design and construction experience

Selected References:

- Malin, N. (2008). BIM Companies Acquiring Energy Modeling Capabilities. HTTP://GREENSOURCE.CONSTRUCTION.COM/NEWS/080403BIMMODELING.ASP
- Marsh, A. (2006). Ecotect as a Teaching Tool. HTTP://NATURALFREQUENCY.COM/ARTICLES/ECOTECTASTEACHER
- Marsh, A. (2006). Building Analysis: Work Smart, Not Hard. HTTP://NATURALFREQUENCY.COM/ARTICLES/SMARTMODELLING
- Novitzki, B. (2008). Energy Modeling for Sustainability. HTTP://CONTINUINGEDUCATION.CONSTRUCTION.COM/ARTICLE.PHP?L=5&C=399
- Stumpf, A., Brucker, B. (2008). BIM Enables Early Design Energy Analysis. HTTP://WWW.CECER.ARMY.MIL/TD/TIPS/DOCS/BIM-ENERGYANALYSIS.PDF
- PIER Building Program (2008). Estimating Energy Use Early and Often. www.esource.com/esource/getpub/public/pdf/cec/CEC-TB-13_EstEnergyUse.pdf
- Ecotect - Building Analysis for Designers. HTTP://WWW.CABS-CAD.COM/ECOTECT.HTM
- Khemlani (2007). AECbytes: Building the Future (October 18, 2007).

Sustainability (LEED) Evaluation

Description:

A process in which a project is evaluated based on LEED or other sustainable criteria. This can refer to materials, performance, or a process. Sustainability Evaluations can be applied across all four phases of a construction project, Planning, Design, Construction, and Operation. Sustainability evaluation is most effective when it is done in planning and design stages and then applied in the construction and operations phase. Model all sustainable aspects of a project throughout its life-cycle in order to obtain the desired LEED certification in the most efficient manner by condensing design analyses into a single database.

Potential Value:

- Accelerate design review and LEED certification process with efficient use of a single database with all the sustainable features present and archived
- Improved communication between project participants in order to achieve LEED credits and decreased redesign efforts as a result
- Align scheduling and material quantities tracking for more efficient material use and better cash flow analysis
- Optimize building performance by tracking energy use, indoor air quality and space planning for the adherence to LEED standards leading to integrated facility management using a BIM model

Resources Required:

- 3D Model manipulation
- LEED credit knowledge

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Knowledge of current LEED credit information

Selected Resources:

- Building Information Modeling for Sustainable Design: http://goliath.ecnext.com/coms2/gi_0199-7985352/Building-information-modeling-for-sustainable.html
- Sustainable Perspectives: Building Information Modeling for Sustainable Design: http://www.edcmag.com/Articles/Featured_Special_Sections/BNP_GUID_9-5-2006_A_10000000000000214529
- Building Information for Sustainable Design (Revit White Paper)
- Building Information Modeling and the Adoption of Green Technologies: http://www.triplepundit.com/2008/05/building-information-modeling-and-the-adoption-of-green-technologies/
- Krygiel, E., and Brad N. (2008). Green BIM: Successful Sustainable Design with Building Information Modeling. San Francisco: Sybex, 2008.

Code Validation

Description:

A process in which code validation software is utilized to check the model parameters against project specific codes. Code validation is currently in its infant stage of development within the U.S. and is not in widespread use. However, as model checking tools continue to develop, code compliance software with more codes, code validation should become more prevalent within the design industry.

Potential Value:

- Validate that building design is in compliance with specific codes, e.g. IBC International Building Code, ADA Americans with Disabilities Act guidelines and other project related codes using the 3D BIM model.
- Code validation done early in design reduces the chance of code design errors, omissions or oversights that would be time consuming and more expensive to correct later in design or construction.
- Code validation done automatically while design progresses gives continuous feedback on code compliance.
- Reduced turnaround time for 3D BIM model review by local code officials or reduced time that needs to be spent meeting with code commissioners, visiting the site, etc. or fixing code violations during punch list or closeout phase.
- Saves time on multiple checking for code compliance and allows for a more efficient design process since mistakes cost time and money.

Resources Required:

- Local codes
- Model checking software
- 3D Model manipulation

Team Competencies Required:

- Ability to use BIM authoring tool for design and model checking tool for design review
- Ability to use code validation software and previous knowledge and experience with checking codes is needed.

Selected Resources:

- Automated Circulation Validation using BIM. GSA. 1-22.
- Eastman, C., Liston, K., Sacks, R. and Teicholz, P. BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. New York, NY: Wiley, 2008.

Design Reviews

Description:

A process in which a 3D model is used to showcase the design to the stakeholders and evaluate meeting the program and set criteria such as layout, sightlines, lighting, security, ergonomics, acoustics, textures and colors, etc. Virtual mock-up can be done in high detail even on a part of the building like façade to quickly analyze design alternatives and solve design and constructability issues. If properly executed, these reviews can resolve design issues by offering different options, and cutting down the cost and time invested considering basic construction, making modifications after reviews and final demolition and removal expense.

Evaluation of the designed space can be facilitated by high degree of interactivity in order to get positive feedback from end users and owner. Some of the top criteria in evaluation of the courtrooms are: sightlines, lighting, ADA compliance, safety, security, acoustics, HVAC, ergonomics, aesthetics and millwork tolerances. Real-time modifications of design are enabled based on the end users feedback. Therefore, decision making time is cut in half since the attention focus is on one issue at a time until the consensus is reached.

Potential Value:

- Eliminate costly and timely traditional construction mock-ups
- Different design options and alternatives are easy to model and change real-time during design review by end users or owner
- Create shorter and more efficient design reviews
- Resolve the conflicts that would arise in a mock-up and model the potential fixes in real-time along with tolerances revised and RFI's answered
- Preview space aesthetics and layout during design review in a virtual environment
- Evaluate effectiveness of design in meeting building program criteria and owner's needs
- Creates efficiencies in design process
- Easily communicate the design to the owner, construction team and end users. Get instant feedback on meeting program requirements, owner's needs and building or space aesthetics

Resources Required:

- 3D Model manipulation
- Design Review Software
- Interactive review space

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Ability to model photo realistically including textures, colors and finishes and easily navigable by using different software or plug-ins.

Selected Resources:

- Dunston, Phillip S., Arns, Laura L., and McGlothin, James D. (2007). "An Immersive Virtual Reality Mock-up for Design Review of Hospital Patient Rooms," 7th International Conference on Construction Applications of Virtual Reality, University Park, Pennsylvania, October 22-23, 9 pages
- Majumdar, Tulika, Fischer, Martin A., and Schwegler, Benedict R. (2006). "Conceptual Design Review with a Virtual Reality Mock-Up Model," Building on IT: Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Hugues Rivard, Edmond Miresco, and Hani Melham, editors, Montreal, Canada, June 14-16, 2902-2911.
- Maldovan, Kurt D., Messner, John I., and Faddoul, Mera (2006). "Framework for Reviewing Mockups in an Immersive Environment," CONVR 2006: 6th International Conference on Construction Applications of Virtual Reality, R. Raymond Issa, editor, Orlando, Florida, August 3-4, on CD, 6 pages

Programming

Description:

A process in which a spatial program is used to efficiently and accurately assess design performance in regard to spatial requirements. The developed BIM model allows the project team to analyze space and understand the complexity of space standards and regulations. Critical decisions are made in this phase of design and bring the most value to the project when needs and options are discussed with the client and the best approach is analyzed.

Potential Value:

- Efficient and accurate assessment of design performance in regard to spatial requirements by the owner.

Resources Required:

- Design Authoring Software

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model

Selected Resources:

- GSA BIM Guide

Site Analysis

Description:

A process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project. The site data collected is used to first select the site and then position the building based on other criteria.

Potential Value:

- Use calculated decision making to determine if potential sites meet the required criteria according to project requirements, technical factors, and financial factors
- Decrease costs of utility demand and demolition
- Increase energy efficiency
- Minimize risk of hazardous material
- Maximize return on investment

Resources Required:

- GIS software
- 3D Model manipulation

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Knowledge and understanding of local authority's system (GIS, database information)

Selected Resources:

- **The Site Selection Guide**. US General Services Administration (GSA) Public Building Service.
- Optimal Site Selection for Military Land Management, R.M. Wallace, ASCE Conf. Proc. 138, 159 (2004). DOI: 10. 1061/40737(2004)159.
- Farnsworth, Stephen J. "Site Selection Perspective." Prospecting Sites. June 1995, 29-31.
- WPBG Sustainable Committee. **Optimizing Site Potential.**
- Suermann P.C. Leveraging GIS Tools in Defense and Response at the U.S. Air Force Academy. ASCE Conf. Proc. 179, 82 (2005) DOI: 10. 1061/40794(179)82.
- GIS – Based Engineering Management Service Functions: Taking GIS Beyond Mapping for Municipal Governments.

Phase Planning (4D Modeling)

Description:

A process in which a 4D model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site. 4D modeling is a powerful visualization and communication tool that can give a project team the including owner a better understanding of project milestones and construction plans.

Potential Value:

- Better understanding of the phasing schedule by the owner and project participants and showing the critical path of the project
- Dynamic phasing plans of occupancy offering multiple options and solutions to space conflicts
- Integrate planning of human, equipment and material resources with the BIM model to better schedule and cost estimate the project
- Space and workspace conflicts identified and resolved ahead of the construction process
- Marketing purposes and publicity
- Identification of schedule, sequencing or phasing issues
- More readily constructible, operable and maintainable project
- Monitor procurement status of project materials
- Increased productivity and decreased waste on job sites
- Conveying the spatial complexities of the project, planning information, and support conducting additional analyses

Resources Required:

- 3D Model manipulation
- Scheduling software
- 4D Modeling Software

Team Competencies Required:

- Knowledge of construction scheduling and general construction process. A 4D model is connected to a schedule, and is therefore only as good as the schedule to which it is linked.
- Ability to manipulate, navigate, and review a 3D model.
- Knowledge of 4D software: import geometry, manage links to schedules, produce and control animations, etc.

Selected Resources:

- Dawood, N., and Mallasi, Z. (2006). Construction Workplace Planning: Assignment and Analysis Utilizing 4D Visualization Technologies. ***Computer-aided Civil and Infrastructure Engineering***, Pgs. 498-513.
- Jongeling, R., Kim, J., Fischer, M., Morgeous, C., and Olofsson, T. (2008). Quantitative analysis of workflow, temporary structure usage, and productivity using 4D models. ***Automation in Construction***, Pgs. 780-791.
- Kang, J. H., Anderson, S. D., and Clayton, M. J. (2007). Empirical Study on the Merit of Web-based 4D Visualization in Collaborative Construction Planning and Scheduling. ***Journal of Construction Engineering and Management***, Pgs. 447-461.

Cost Estimation

Description:

A process in which a BIM model can be used to generate an accurate quantity take-off and cost estimate early in the design process and provide cost effects of additions and modifications with potential to save time and money and avoid budget overruns. This process also allows designers to see the cost effects of their changes in a timely manner which can help curb excessive budget overruns due to project modifications.

Potential Value:

- Precisely estimate material quantities and generate quick revisions if needed
- Stay within budget constraints with frequent preliminary cost estimate while the design progresses
- Better visual representation of project and construction elements that need to be estimated: taken off and priced
- Provide cost information to the owner during the early decision making phase of design
- Focus on more value adding activities in estimating like identifying construction assemblies, generating pricing and factoring risks then quantity take-off, which are essential for high quality estimates.
- Exploring different design options and concepts within the owner's budget
- Saving estimator's time and allowing them to focus on more important issues in an estimate since take-offs can be automatically provided.
- Quickly determine costs of specific objects

Resources Required:

- Model-based estimating software
- Design authoring software
- Cost data

Team Competencies Required:

- Ability to define specific design modeling procedures which yield accurate quantity take-off information
- Ability to identify quantities for the appropriate estimating level (e.g. ROM, SF, etc.) upfront

Selected Resources:

- Lee, H., Lee, Kim, J. (2008). **A COST-BASED INTERIOR DESIGN DECISION SUPPORT SYSTEM FOR LARGE-SCALE HOUSING PROJECTS**, ITcon Vol. 13, Pg. 20-38, **HTTP://WWW.ITCON.ORG/2008/2**
- Autodesk Revit. "BIM and Cost Estimating." Press release. Jan. 2007. Autodesk. 11 Sept. 2008. **HTTP://IMAGES.AUTODESK.COM/ADSK/FILES/BIM_COST_ESTIMATING_JAN07_1_.PDF**
- Dean, R. P., and McClendon, S. (2007). "Specifying and Cost Estimating with BIM." ARCHI TECH. Apr. 2007. ARCHI TECH. 13 Sept. 2008. http://www.architechmag.com/articles/detail.aspx?contentid=3624.
- Khemlani, L. (2006). "Visual Estimating: Extending BIM to Construction." AEC Bytes. 21 Mar. 2006. 13 Sept. 2008. http://www.aecbytes.com/buildingthefuture/2006/visualestimating.html
- Buckley, B. (2008). "BIM Cost Management." California Construction. June 2008. 13 Sept. 2008.
- Manning, R.; Messner, J. (2008). **CASE STUDIES IN BIM IMPLEMENTATION FOR PROGRAMMING OF HEALTHCARE FACILITIES**, ITcon Vol. 13, Special Issue **CASE STUDIES OF BIM USE**, Pg. 246-257, http://www.itcon.org/2008/18

Existing Conditions Modeling

Description:

A process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility. This model can be developed in multiple ways depending on what is desired and what is most efficient. Once the model is constructed, it can be queried for information, whether it is for new construction or a modernization project.

Potential Value:

- Document existing building for historical use
- Provide documentation of environment for future uses
- Enhance efficiency and accuracy of existing conditions documentation
- Provide location information
- Aids in future modeling and 3D design coordination
- Use for visualization purposes

Resources Required:

- 3D Model manipulation
- 3D Laser scanning
- 3D Laser scanning point cloud translation into objects

Team Competencies Required:

- Ability to manipulate, navigate, and review a 3D model
- Knowledge of BIM authoring tools
- Knowledge of 3D laser scanning tools

Selected Resources:

- GSA BIM Guide Series 3. **3D Laser Scanning**.

APPENDIX C: BIM USE ANALYSIS WORKSHEET

BIM Use*	Value to Project	Responsible Party	Value to Resp Party	Capability Rating			Additional Resources / Competencies Required to Implement	Notes	Proceed with Use
	High / Med / Low		High / Med / Low	Scale 1-3 (1 = Low)					YES / NO / MAYBE
				Resources	Competency	Experience			
Maintenance Scheduling									
Building Systems Analysis									
Record Modeling									
Cost Estimation									
4D Modeling									
Site Utilization Planning									
Layout Control & Planning									
3D Coordination (Construction)									
Engineering Analysis									
Site Analysis									
Design Reviews									
3D Coordination (Design)									
Existing Conditions Modeling									
Design Authoring									
Programming									

* Additional BIM Uses as well as information on each Use can be found at http://www.engr.psu.edu/ae/cic/bimex/

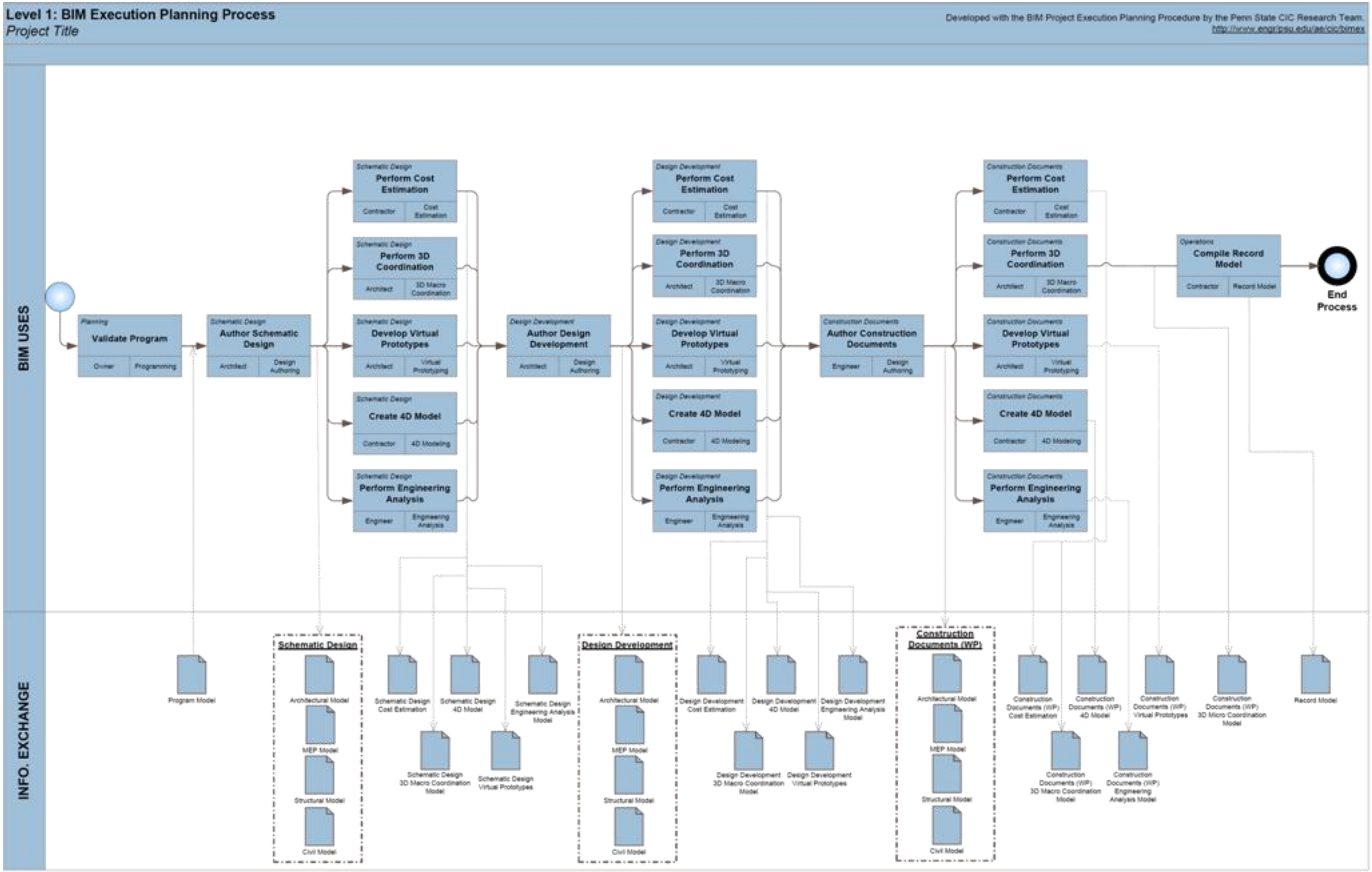
APPENDIX D: TEMPLATE PROCESS MAPS

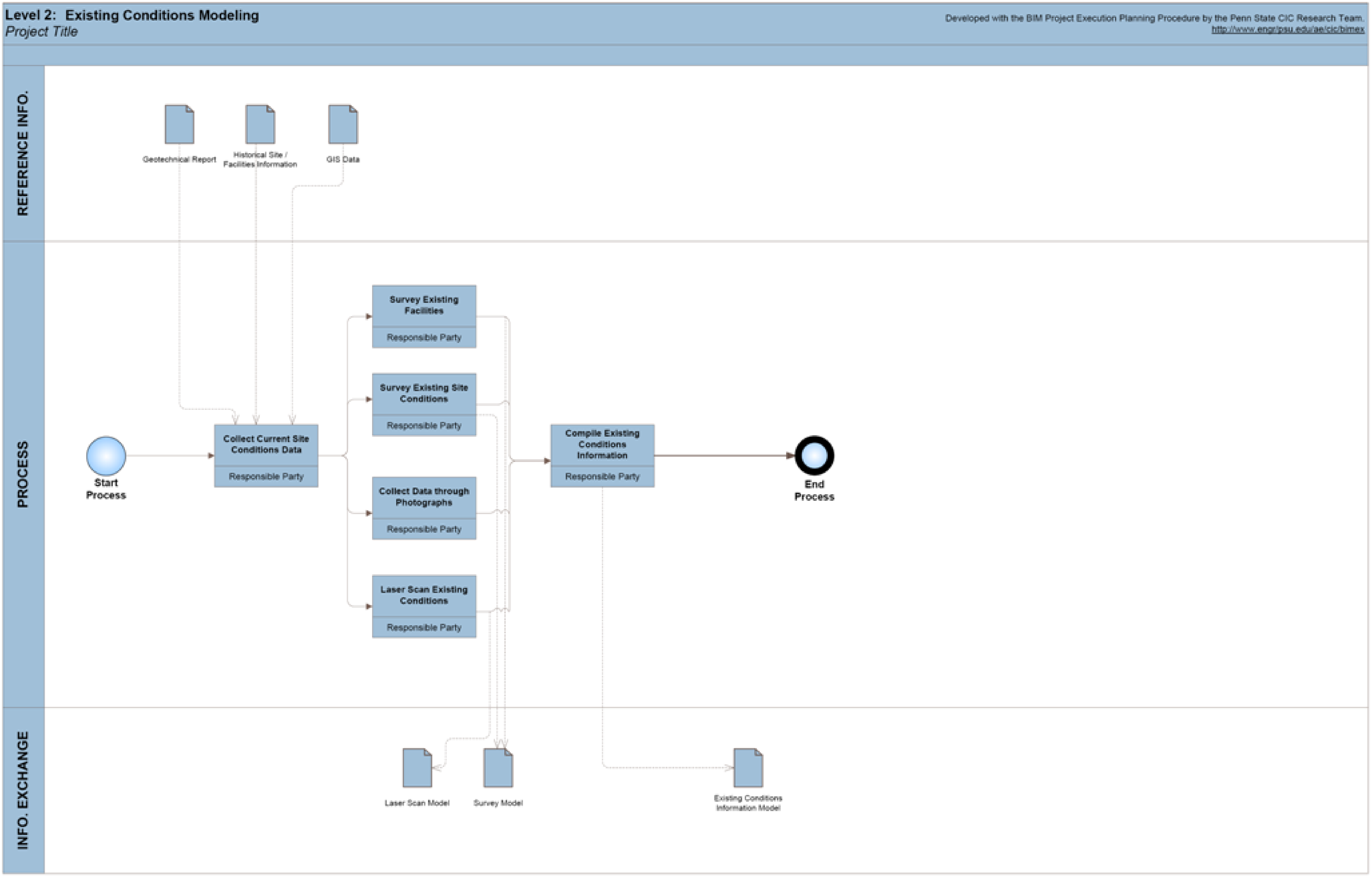
This appendix contains the following BIM Process Map Templates:

Level 1: BIM Overview Map

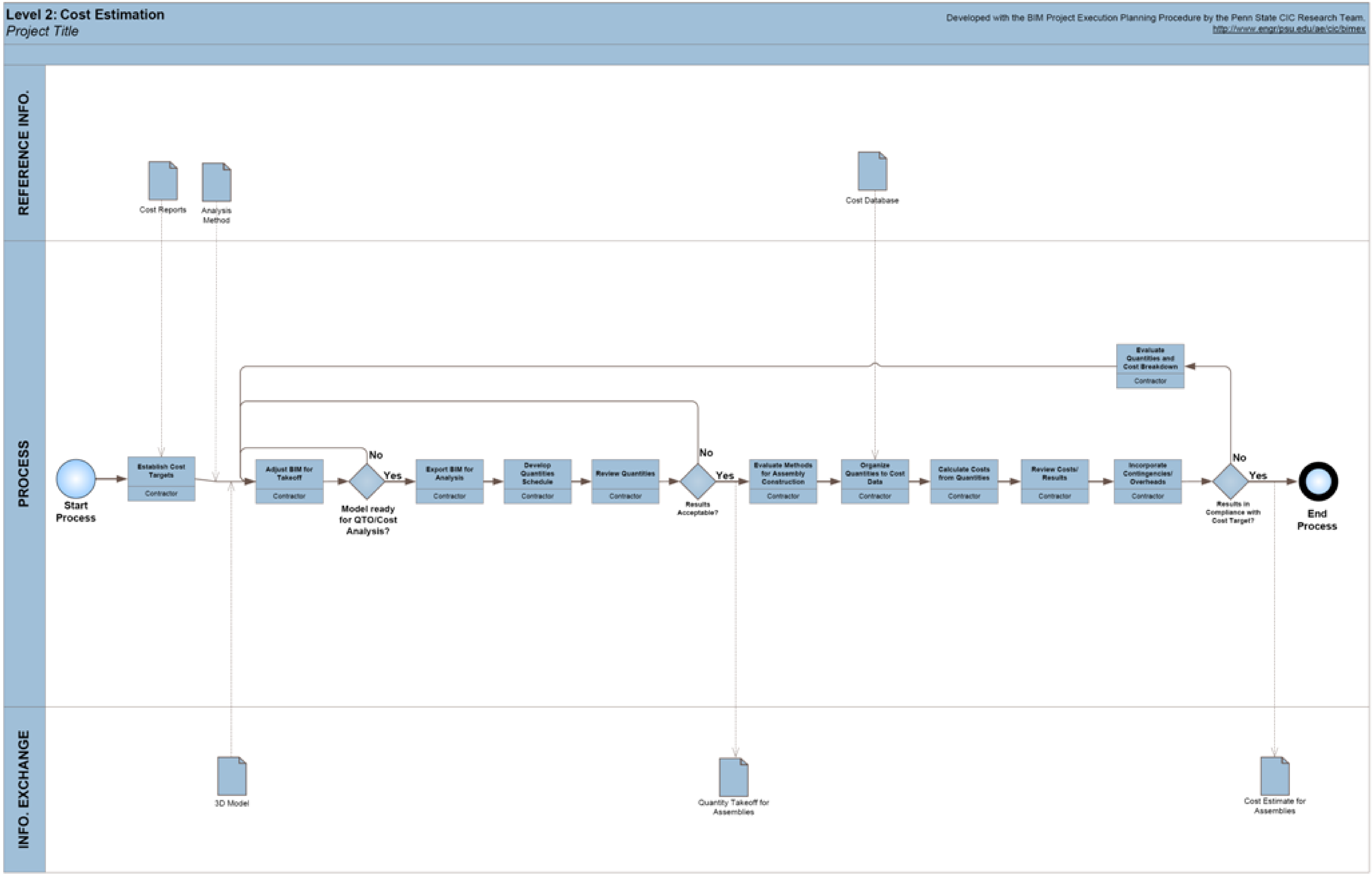
Level 2: Detailed BIM Use Process Maps:

1. Existing Conditions Modeling
2. Cost Estimation
3. 4D Modeling
4. Programming
5. Site Analysis
6. Design Reviews
7. Design Authoring
8. Energy Analysis
9. Structural Analysis
10. Lighting Analysis
11. 3D Design Coordination
12. Site Utilization Planning
13. 3D Control and Planning
14. Record Modeling
15. Maintenance Scheduling
16. Building System Analysis

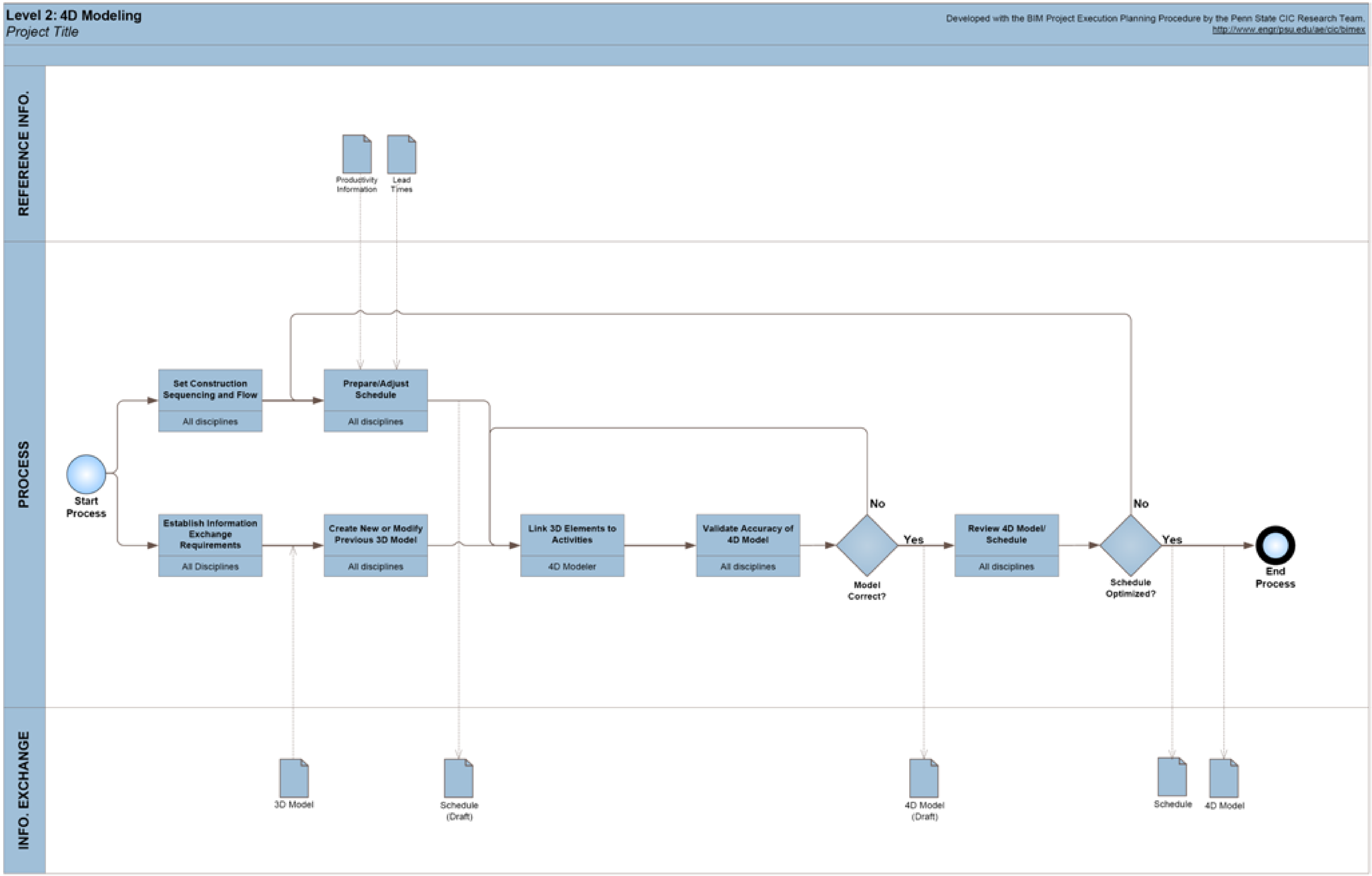

Level 1: BIM Execution Planning Process
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
BIM USES
INFO. EXCHANGE
Validate Program
Author Schematic Design
Perform Cost Estimation
Perform 3D Coordination
Develop Virtual Prototypes
Create 4D Model
Perform Engineering Analysis
Author Design Development
Author Construction Documents
Compile Record Model
End Process
Schematic Design
Design Development
Construction Documents (WP)
Program Model
Architectural Model
MEP Model
Structural Model
Civil Model
Record Model

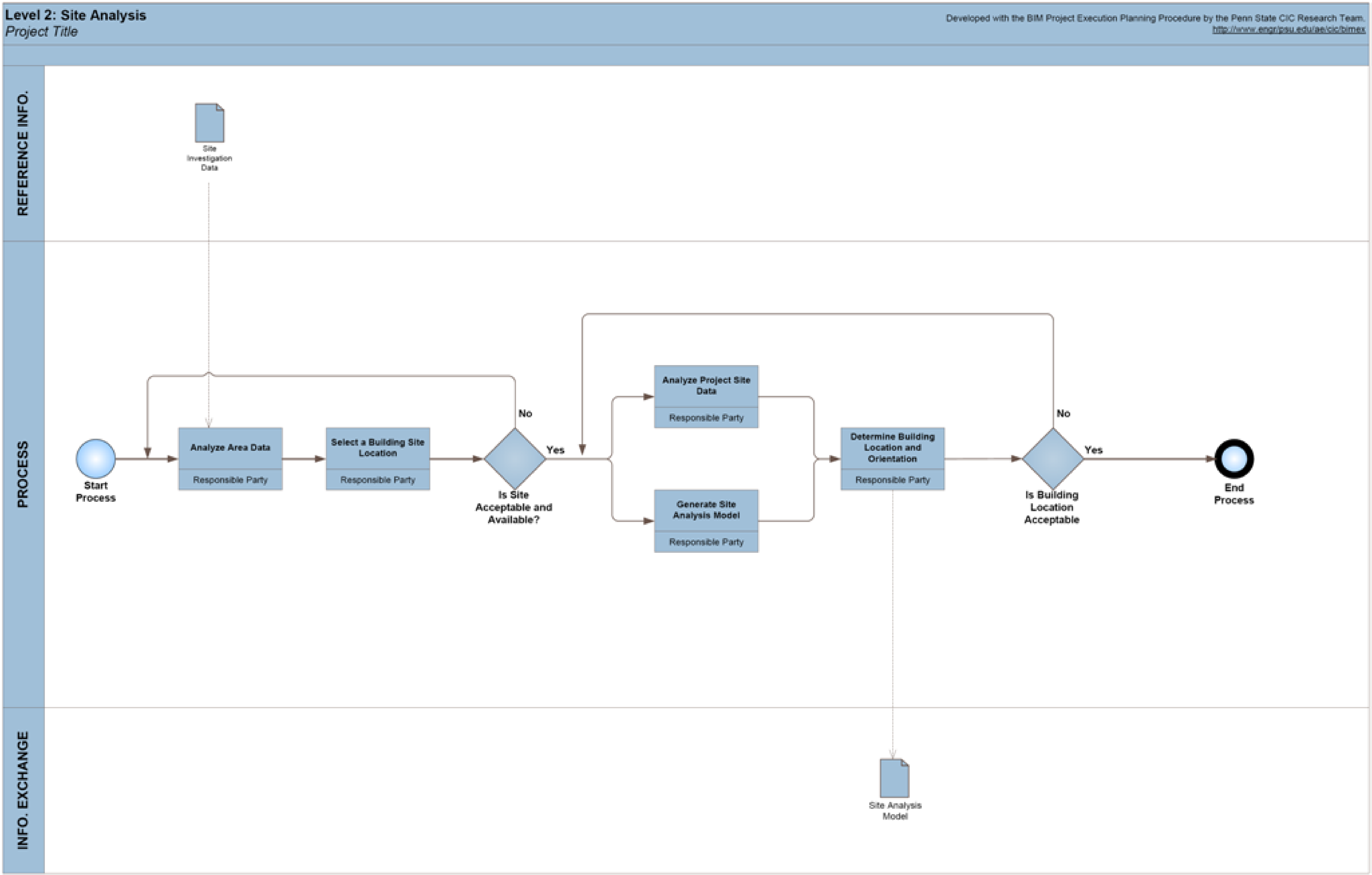


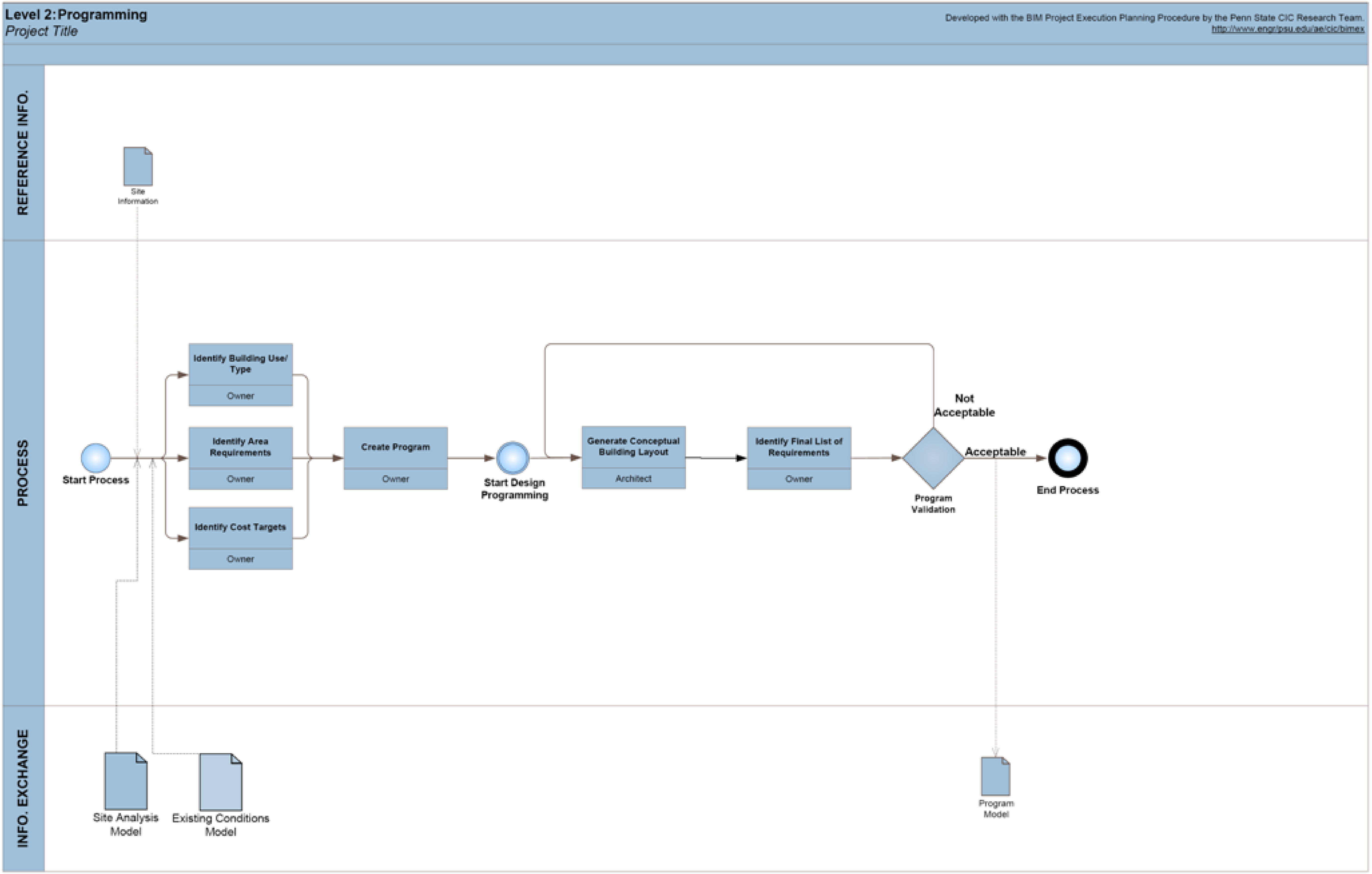
Level 2: Existing Conditions Modeling
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
Geotechnical Report
Historical Site / Facilities Information
GIS Data
PROCESS
Start Process
Collect Current Site Conditions Data
Responsible Party
Survey Existing Facilities
Responsible Party
Survey Existing Site Conditions
Responsible Party
Collect Data through Photographs
Responsible Party
Laser Scan Existing Conditions
Responsible Party
Compile Existing Conditions Information
Responsible Party
End Process
INFO. EXCHANGE
Laser Scan Model
Survey Model
Existing Conditions Information Model

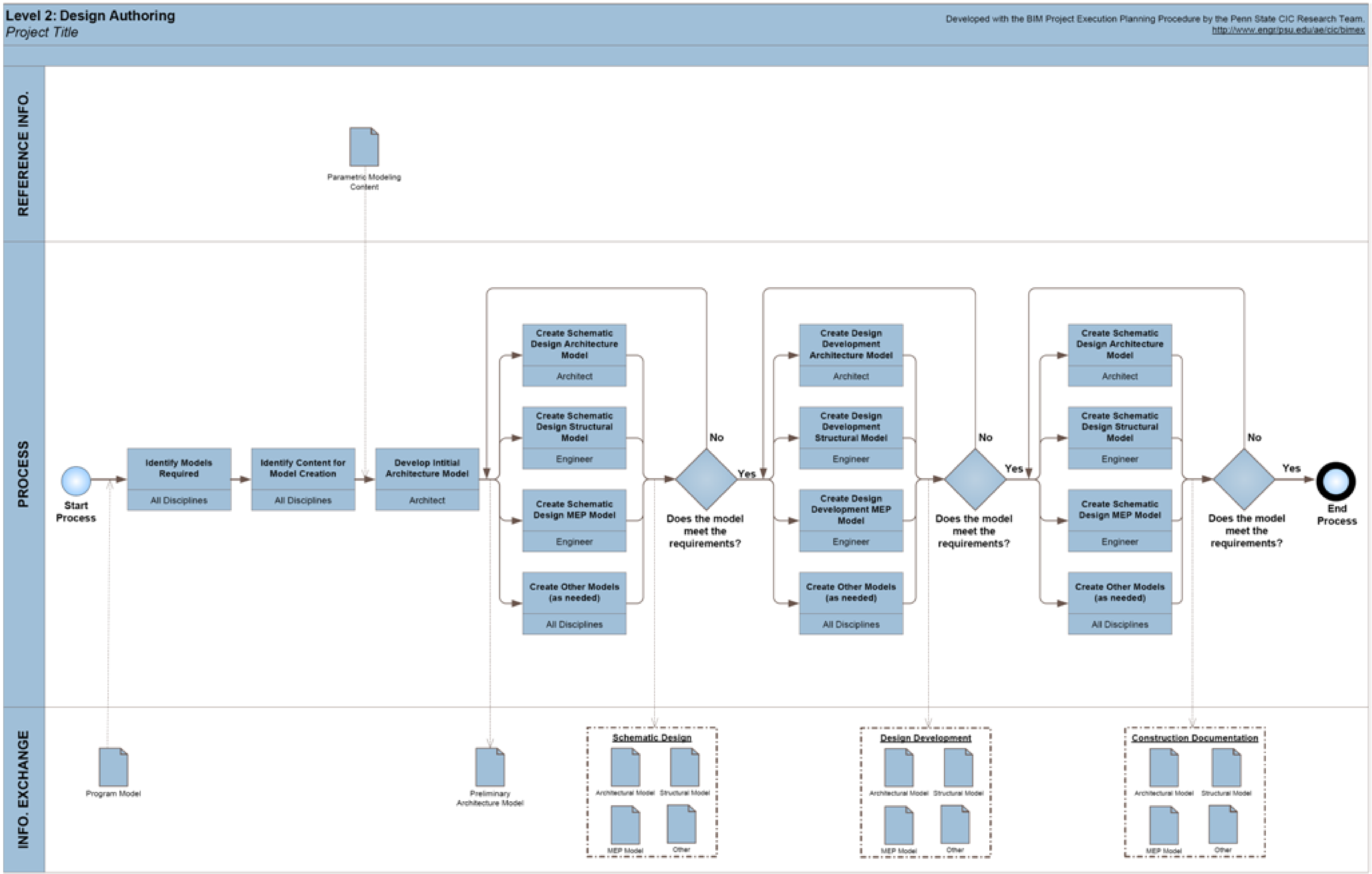


Level 2: Cost Estimation
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
Cost Reports
Analysis Method
Cost Database
PROCESS
Start Process
Establish Cost Targets
Contractor
Adjust BIM for Takeoff
Contractor
Model ready for QTO/Cost Analysis?
No
Yes
Export BIM for Analysis
Contractor
Develop Quantities Schedule
Contractor
Review Quantities
Contractor
Results Acceptable?
No
Yes
Evaluate Methods for Assembly Construction
Contractor
Organize Quantities to Cost Data
Contractor
Calculate Costs from Quantities
Contractor
Review Costs/ Results
Contractor
Incorporate Contingencies/ Overheads
Contractor
Results in Compliance with Cost Target?
No
Yes
Evaluate Quantities and Cost Breakdown
Contractor
End Process
INFO. EXCHANGE
3D Model
Quantity Takeoff for Assemblies
Cost Estimate for Assemblies

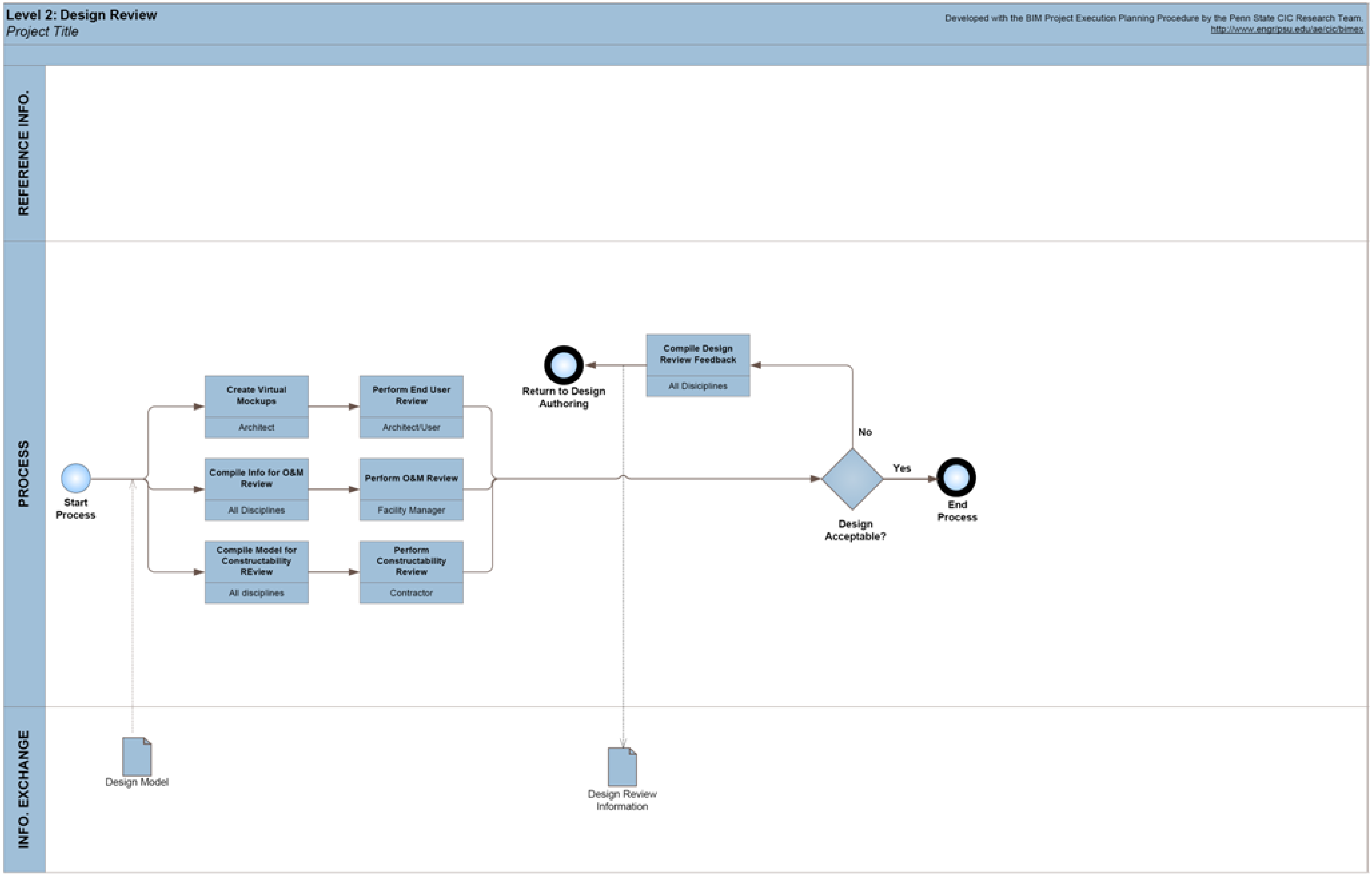

Level 2: 4D Modeling
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Productivity Information
Lead Times
Start Process
Set Construction Sequencing and Flow
All disciplines
Prepare/Adjust Schedule
All disciplines
Establish Information Exchange Requirements
All Disciplines
Create New or Modify Previous 3D Model
All disciplines
Link 3D Elements to Activities
4D Modeler
Validate Accuracy of 4D Model
All disciplines
No
Yes
Model Correct?
Review 4D Model/ Schedule
All disciplines
No
Yes
Schedule Optimized?
End Process
3D Model
Schedule (Draft)
4D Model (Draft)
Schedule
4D Model

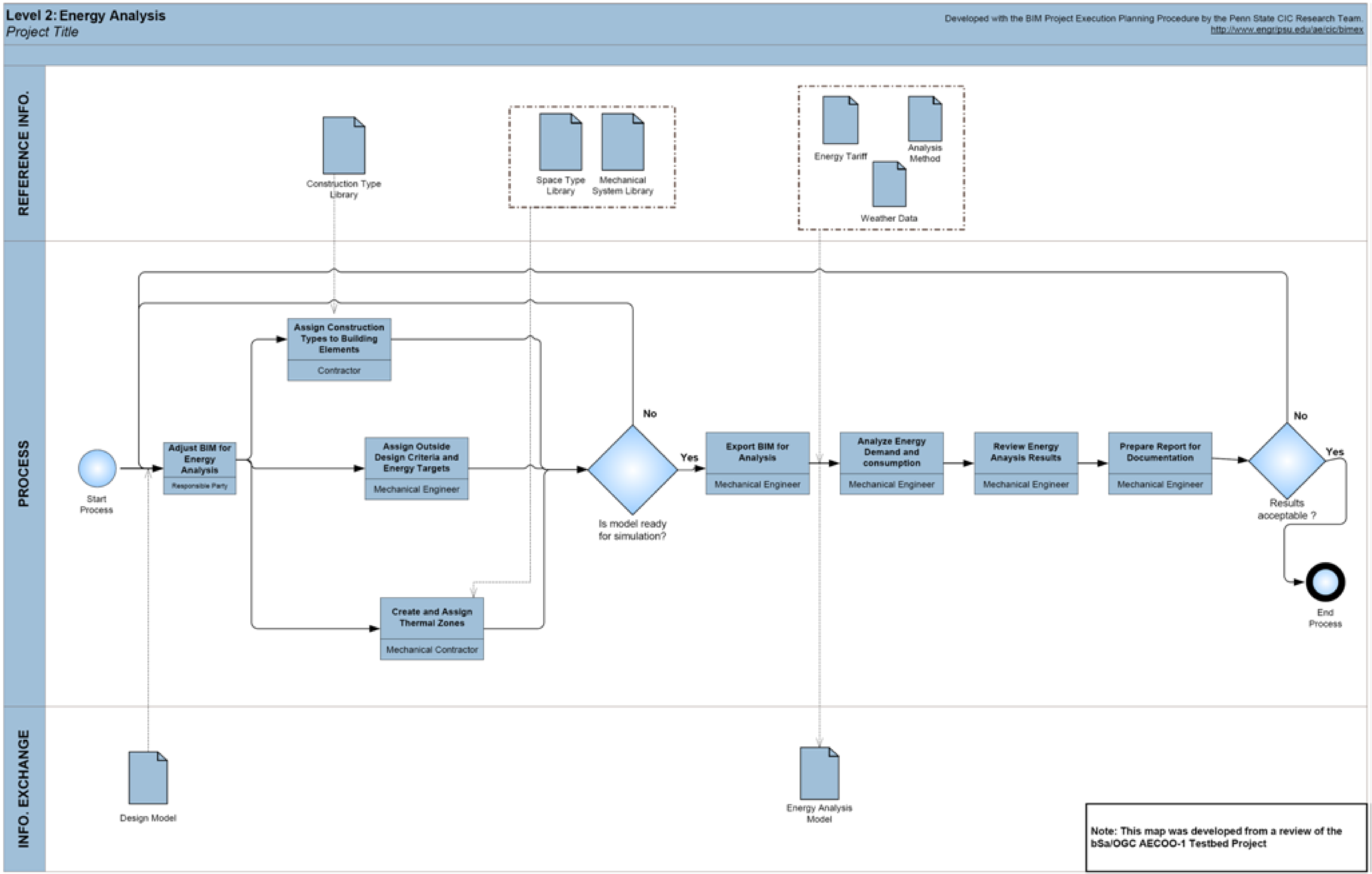

Level 2: Site Analysis
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Site Investigation Data
Start Process
Analyze Area Data
Responsible Party
Select a Building Site Location
Responsible Party
No
Yes
Is Site Acceptable and Available?
Analyze Project Site Data
Responsible Party
Generate Site Analysis Model
Responsible Party
Determine Building Location and Orientation
Responsible Party
No
Yes
Is Building Location Acceptable
End Process
Site Analysis Model

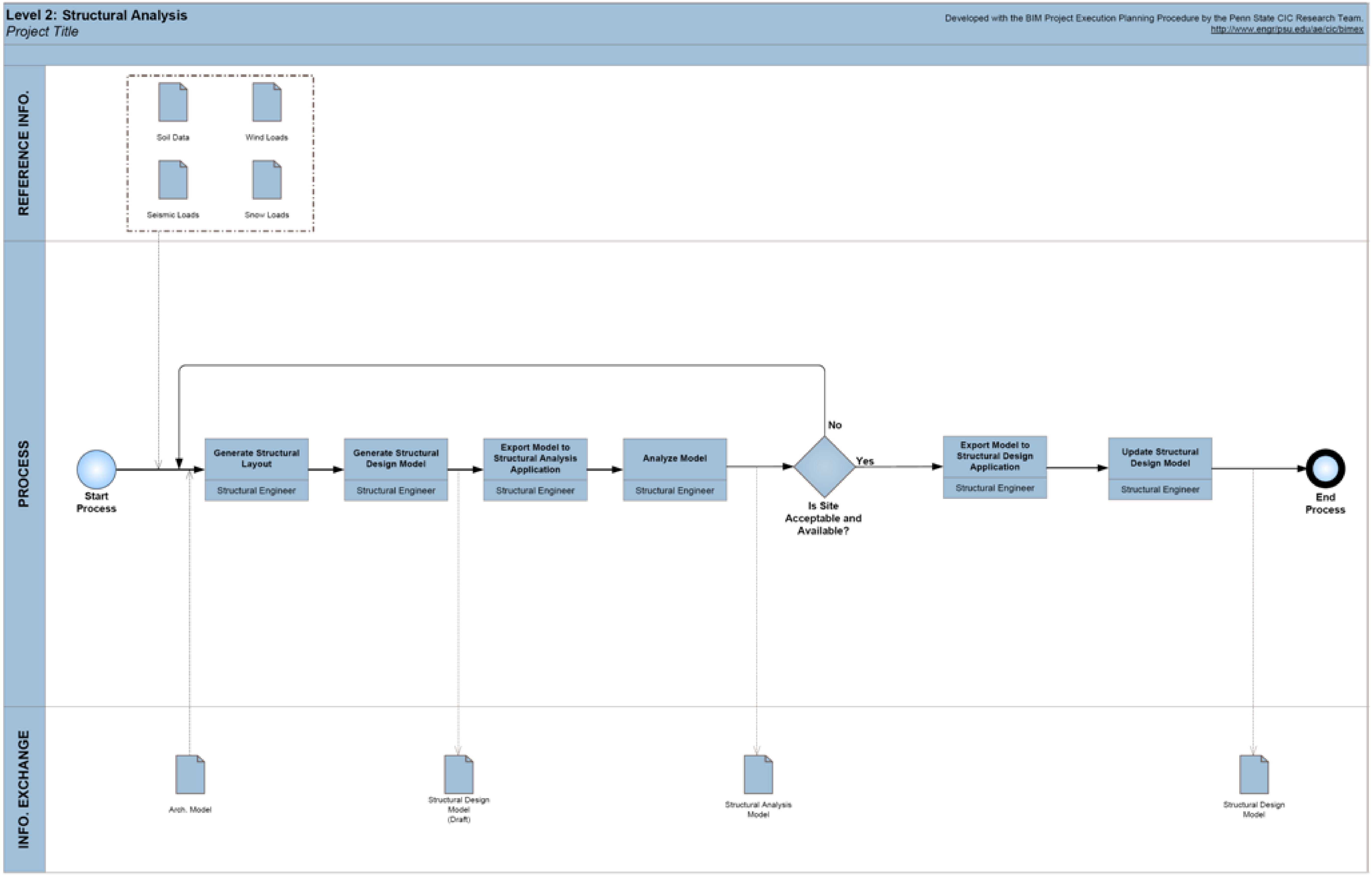

Level 2: Programming
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Site Information
Start Process
Identify Building Use/ Type
Owner
Identify Area Requirements
Owner
Identify Cost Targets
Owner
Create Program
Owner
Start Design Programming
Generate Conceptual Building Layout
Architect
Identify Final List of Requirements
Owner
Not Acceptable
Acceptable
Program Validation
End Process
Site Analysis Model
Existing Conditions Model
Program Model

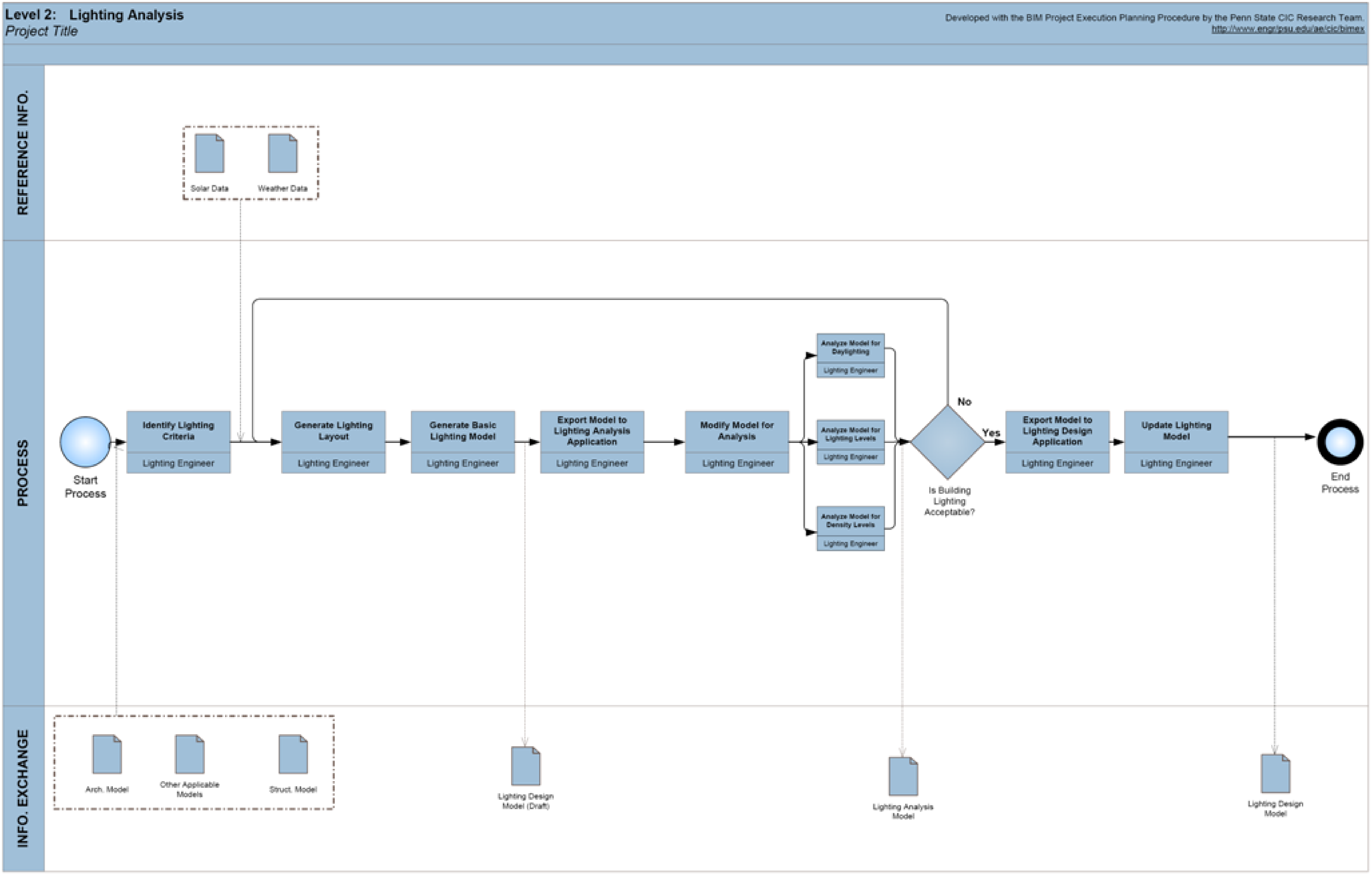


Level 2: Design Authoring
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Parametric Modeling Content
Start Process
Identify Models Required
All Disciplines
Identify Content for Model Creation
All Disciplines
Develop Initial Architecture Model
Architect
Create Schematic Design Architecture Model
Architect
Create Schematic Design Structural Model
Engineer
Create Schematic Design MEP Model
Engineer
Create Other Models (as needed)
All Disciplines
Does the model meet the requirements?
No
Yes
Create Design Development Architecture Model
Architect
Create Design Development Structural Model
Engineer
Create Design Development MEP Model
Engineer
Create Other Models (as needed)
All Disciplines
Does the model meet the requirements?
No
Yes
Create Schematic Design Architecture Model
Architect
Create Schematic Design Structural Model
Engineer
Create Schematic Design MEP Model
Engineer
Create Other Models (as needed)
All Disciplines
Does the model meet the requirements?
No
Yes
End Process
Program Model
Preliminary Architecture Model
Schematic Design
Architectural Model
Structural Model
MEP Model
Other
Design Development
Architectural Model
Structural Model
MEP Model
Other
Construction Documentation
Architectural Model
Structural Model
MEP Model
Other

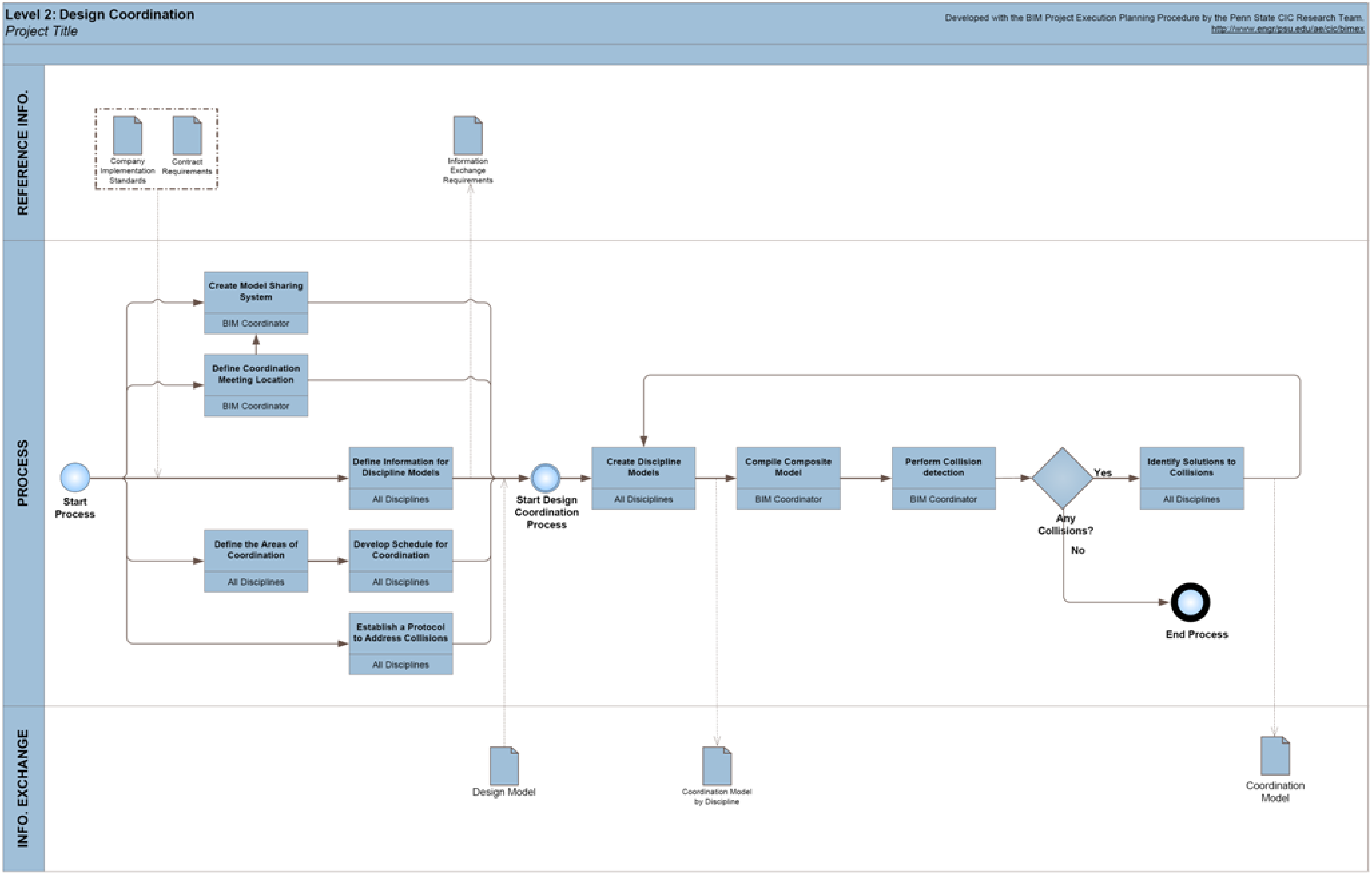

Level 2: Design Review
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Start Process
Create Virtual Mockups
Architect
Perform End User Review
Architect/User
Compile Info for O&M Review
All Disciplines
Perform O&M Review
Facility Manager
Compile Model for Constructability REview
All disciplines
Perform Constructability Review
Contractor
Return to Design Authoring
Compile Design Review Feedback
All Disiciplines
No
Yes
Design Acceptable?
End Process
Design Model
Design Review Information


Level 2: Energy Analysis
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Construction Type Library
Space Type Library
Mechanical System Library
Energy Tariff
Analysis Method
Weather Data
Start Process
Adjust BIM for Energy Analysis
Responsible Party
Assign Construction Types to Building Elements
Contractor
Assign Outside Design Criteria and Energy Targets
Mechanical Engineer
Create and Assign Thermal Zones
Mechanical Contractor
No
Yes
Is model ready for simulation?
Export BIM for Analysis
Mechanical Engineer
Analyze Energy Demand and consumption
Mechanical Engineer
Review Energy Anaysis Results
Mechanical Engineer
Prepare Report for Documentation
Mechanical Engineer
No
Yes
Results acceptable ?
End Process
Design Model
Energy Analysis Model
Note: This map was developed from a review of the bSa/OGC AECOO-1 Testbed Project

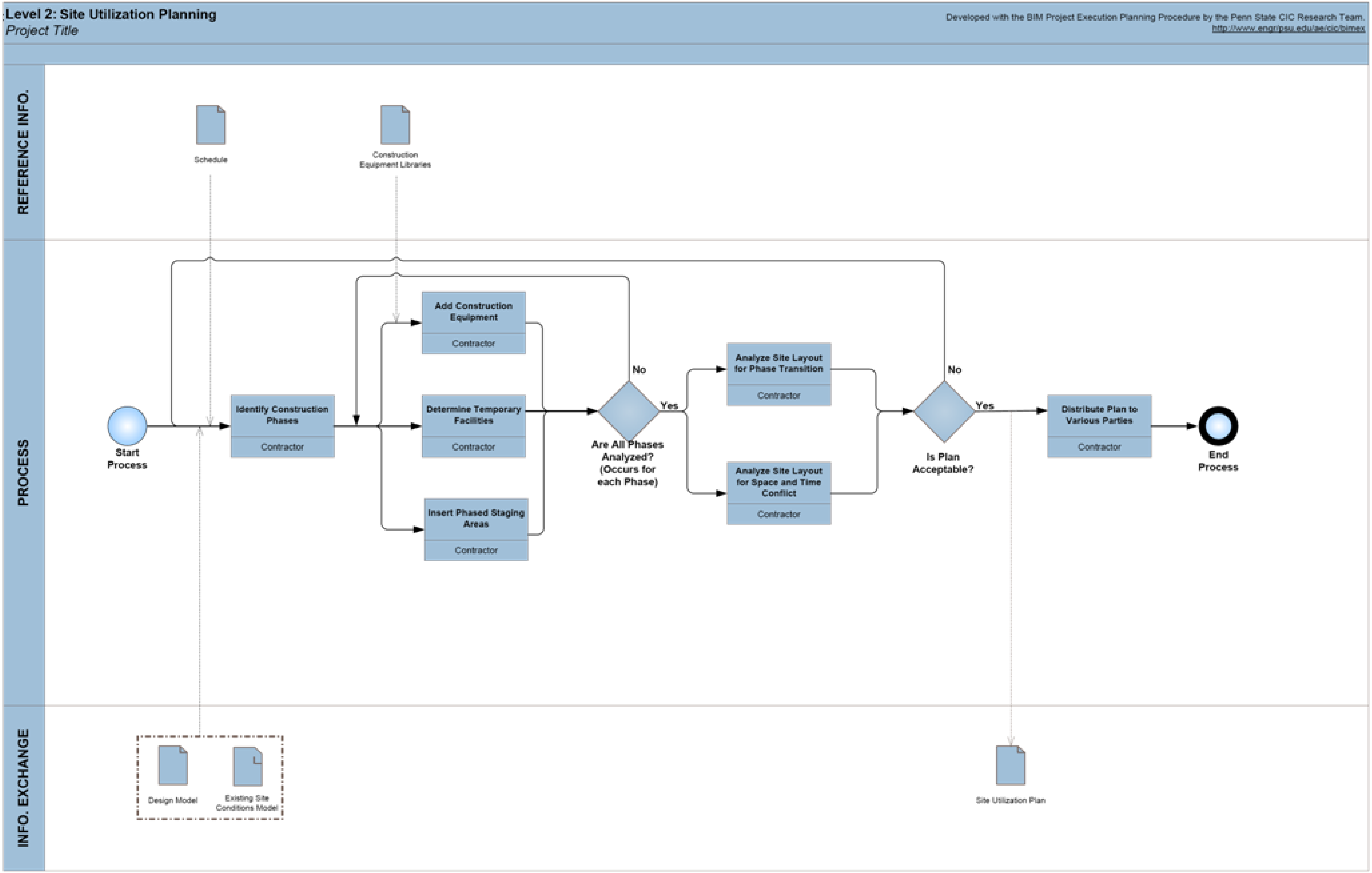

Level 2: Structural Analysis
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
Soil Data
Wind Loads
Seismic Loads
Snow Loads
PROCESS
Start Process
Generate Structural Layout
Structural Engineer
Generate Structural Design Model
Structural Engineer
Export Model to Structural Analysis Application
Structural Engineer
Analyze Model
Structural Engineer
No
Yes
Is Site Acceptable and Available?
Export Model to Structural Design Application
Structural Engineer
Update Structural Design Model
Structural Engineer
End Process
INFO. EXCHANGE
Arch. Model
Structural Design Model (Draft)
Structural Analysis Model
Structural Design Model



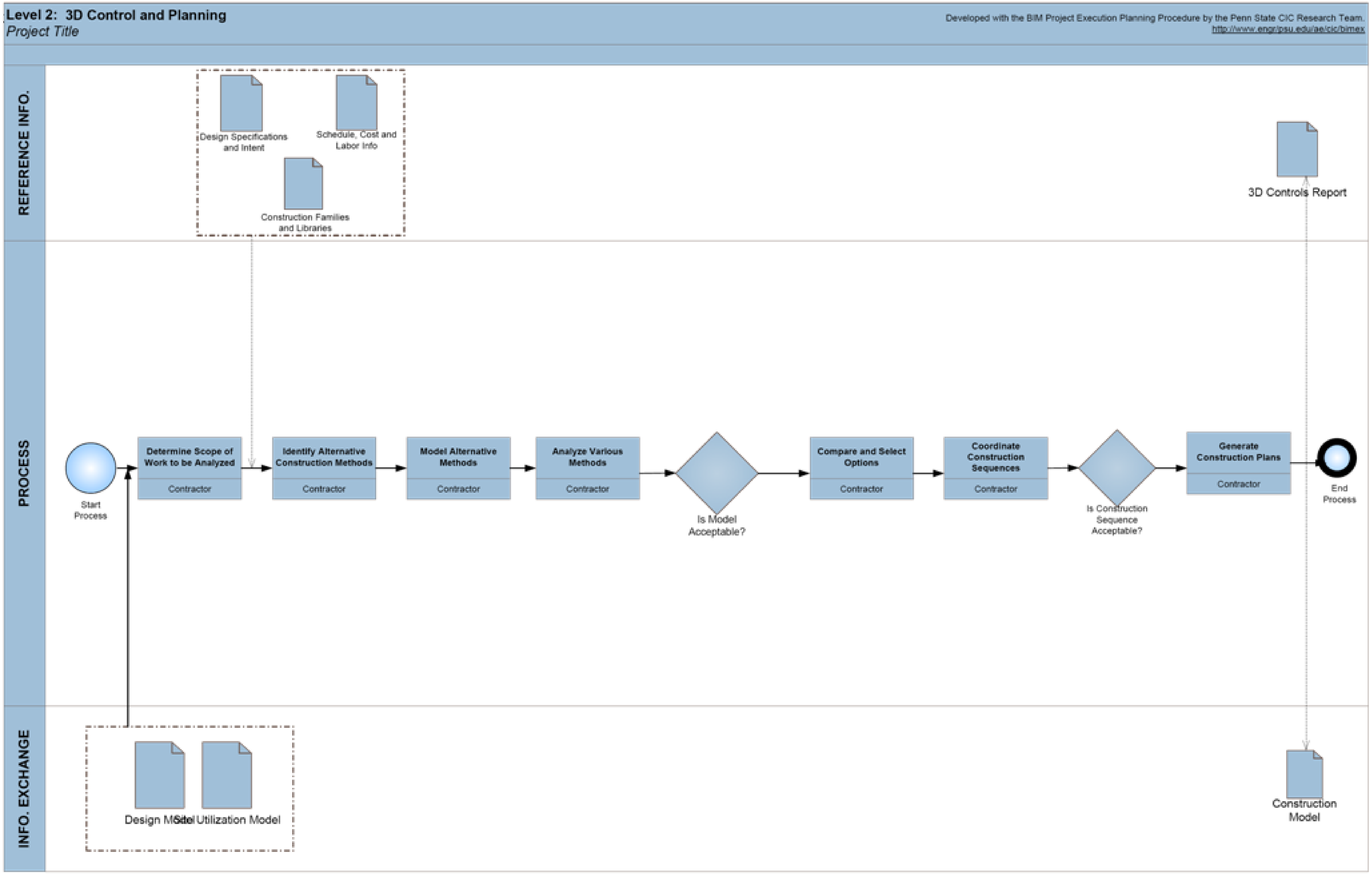
Level 2: Lighting Analysis
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Solar Data
Weather Data
Start Process
Identify Lighting Criteria
Lighting Engineer
Generate Lighting Layout
Lighting Engineer
Generate Basic Lighting Model
Lighting Engineer
Export Model to Lighting Analysis Application
Lighting Engineer
Modify Model for Analysis
Lighting Engineer
Analyze Model for Daylighting
Lighting Engineer
Analyze Model for Lighting Levels
Lighting Engineer
Analyze Model for Density Levels
Lighting Engineer
No
Yes
Is Building Lighting Acceptable?
Export Model to Lighting Design Application
Lighting Engineer
Update Lighting Model
Lighting Engineer
End Process
Arch. Model
Other Applicable Models
Struct. Model
Lighting Design Model (Draft)
Lighting Analysis Model
Lighting Design Model



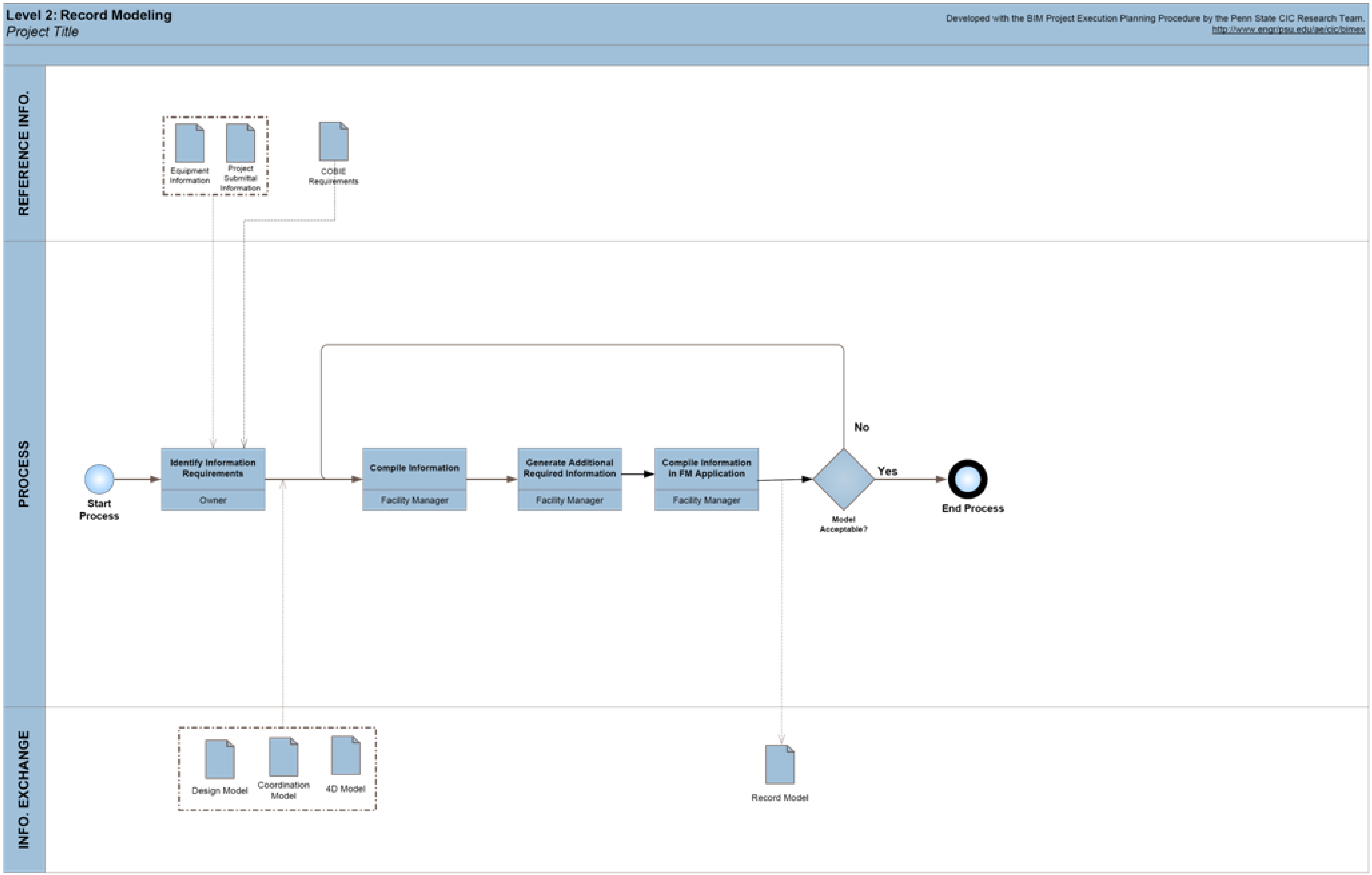
Level 2: Design Coordination
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr/psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Company Implementation Standards
Contract Requirements
Information Exchange Requirements
Start Process
Create Model Sharing System
BIM Coordinator
Define Coordination Meeting Location
BIM Coordinator
Define Information for Discipline Models
All Disciplines
Define the Areas of Coordination
All Disciplines
Develop Schedule for Coordination
All Disciplines
Establish a Protocol to Address Collisions
All Disciplines
Start Design Coordination Process
Create Discipline Models
All Disiciplines
Compile Composite Model
BIM Coordinator
Perform Collision detection
BIM Coordinator
Any Collisions?
Yes
No
Identify Solutions to Collisions
All Disciplines
End Process
Design Model
Coordination Model by Discipline
Coordination Model

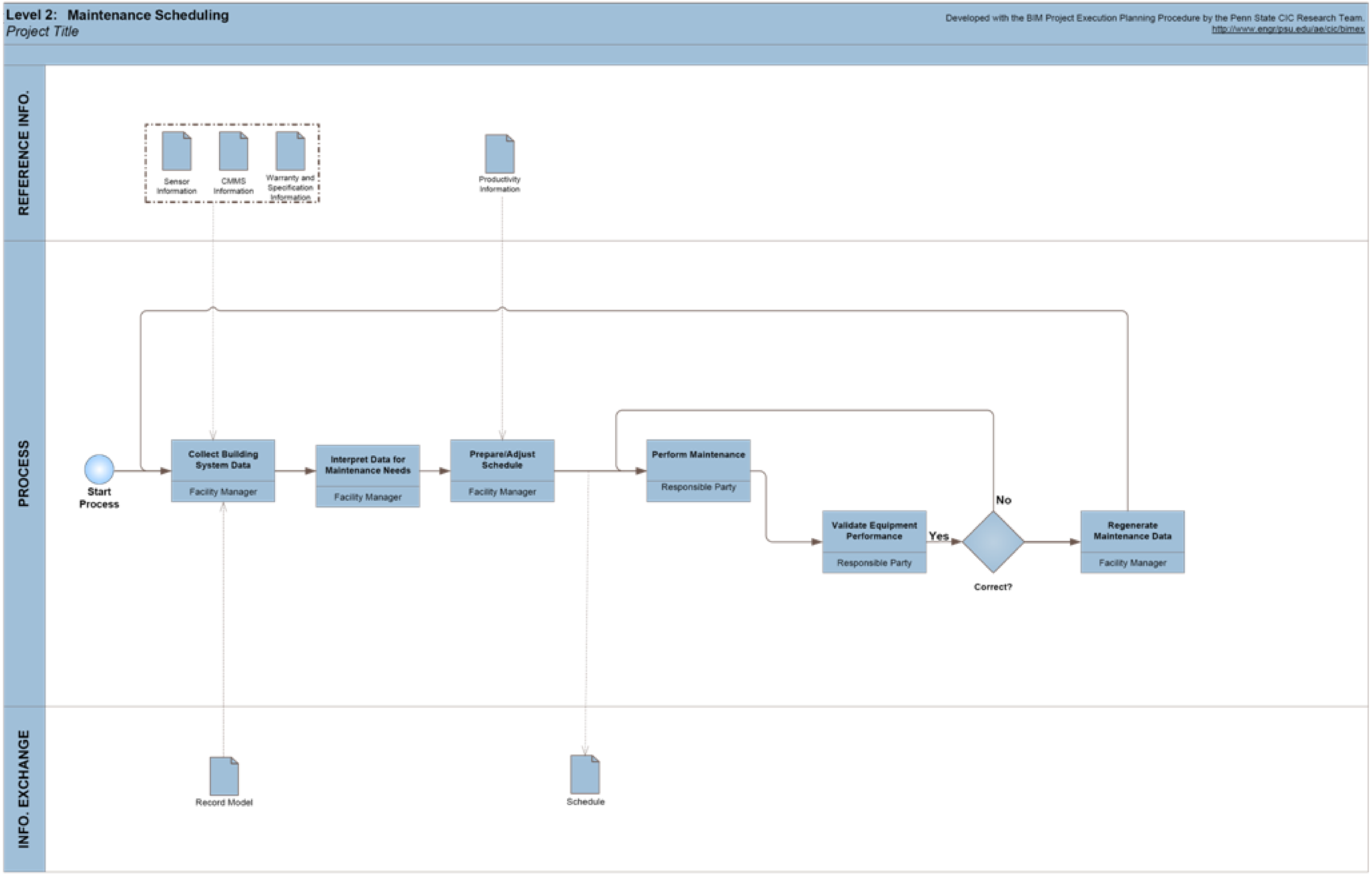


Level 2: Site Utilization Planning
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Schedule
Construction Equipment Libraries
Start Process
Identify Construction Phases
Contractor
Add Construction Equipment
Contractor
Determine Temporary Facilities
Contractor
Insert Phased Staging Areas
Contractor
No
Yes
Are All Phases Analyzed? (Occurs for each Phase)
Analyze Site Layout for Phase Transition
Contractor
Analyze Site Layout for Space and Time Conflict
Contractor
No
Yes
Is Plan Acceptable?
Distribute Plan to Various Parties
Contractor
End Process
Design Model
Existing Site Conditions Model
Site Utilization Plan

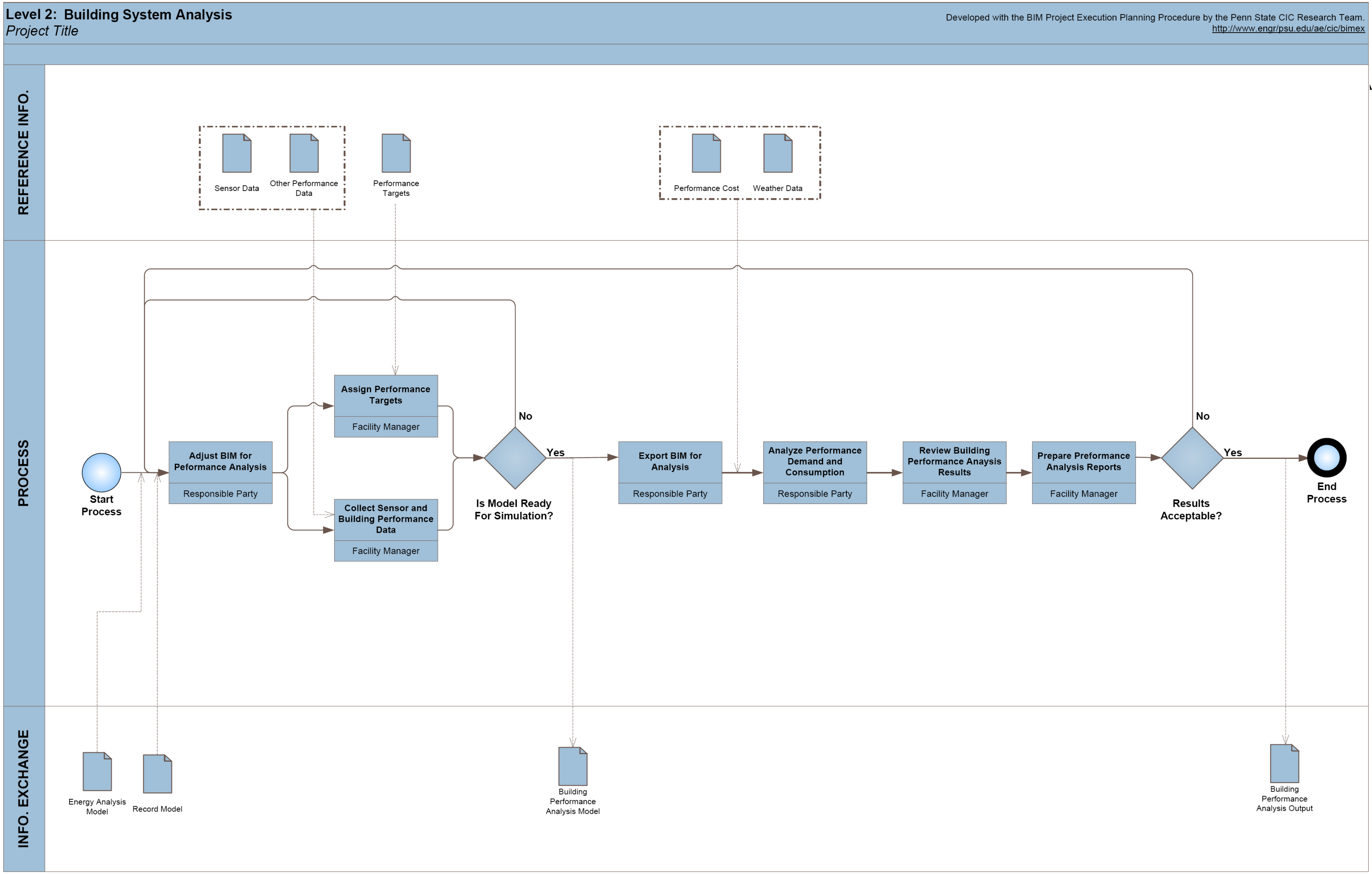


Level 2: 3D Control and Planning
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
Design Specifications and Intent
Schedule, Cost and Labor Info
Construction Families and Libraries
3D Controls Report
PROCESS
Start Process
Determine Scope of Work to be Analyzed
Contractor
Identify Alternative Construction Methods
Contractor
Model Alternative Methods
Contractor
Analyze Various Methods
Contractor
Is Model Acceptable?
Compare and Select Options
Contractor
Coordinate Construction Sequences
Contractor
Is Construction Sequence Acceptable?
Generate Construction Plans
Contractor
End Process
INFO. EXCHANGE
Design Model
Site Utilization Model
Construction Model


Level 2: Record Modeling
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
Equipment Information
Project Submittal Information
COBIE Requirements
PROCESS
Start Process
Identify Information Requirements
Owner
Compile Information
Facility Manager
Generate Additional Required Information
Facility Manager
Compile Information in FM Application
Facility Manager
No
Yes
Model Acceptable?
End Process
INFO. EXCHANGE
Design Model
Coordination Model
4D Model
Record Model



Level 2: Maintenance Scheduling
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr.psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Sensor Information
CMMS Information
Warranty and Specification Information
Productivity Information
Start Process
Collect Building System Data
Facility Manager
Interpret Data for Maintenance Needs
Facility Manager
Prepare/Adjust Schedule
Facility Manager
Perform Maintenance
Responsible Party
Validate Equipment Performance
Responsible Party
Yes
No
Correct?
Regenerate Maintenance Data
Facility Manager
Record Model
Schedule


Level 2: Building System Analysis
Project Title
Developed with the BIM Project Execution Planning Procedure by the Penn State CIC Research Team.
http://www.engr/psu.edu/ae/cic/bimex
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Sensor Data
Other Performance Data
Performance Targets
Performance Cost
Weather Data
Start Process
Adjust BIM for Peformance Analysis
Responsible Party
Assign Performance Targets
Facility Manager
Collect Sensor and Building Performance Data
Facility Manager
No
Yes
Is Model Ready For Simulation?
Export BIM for Analysis
Responsible Party
Analyze Performance Demand and Consumption
Responsible Party
Review Building Performance Anaysis Results
Facility Manager
Prepare Preformance Analysis Reports
Facility Manager
No
Yes
Results Acceptable?
End Process
Energy Analysis Model
Record Model
Building Performance Analysis Model
Building Performance Analysis Output
analysis

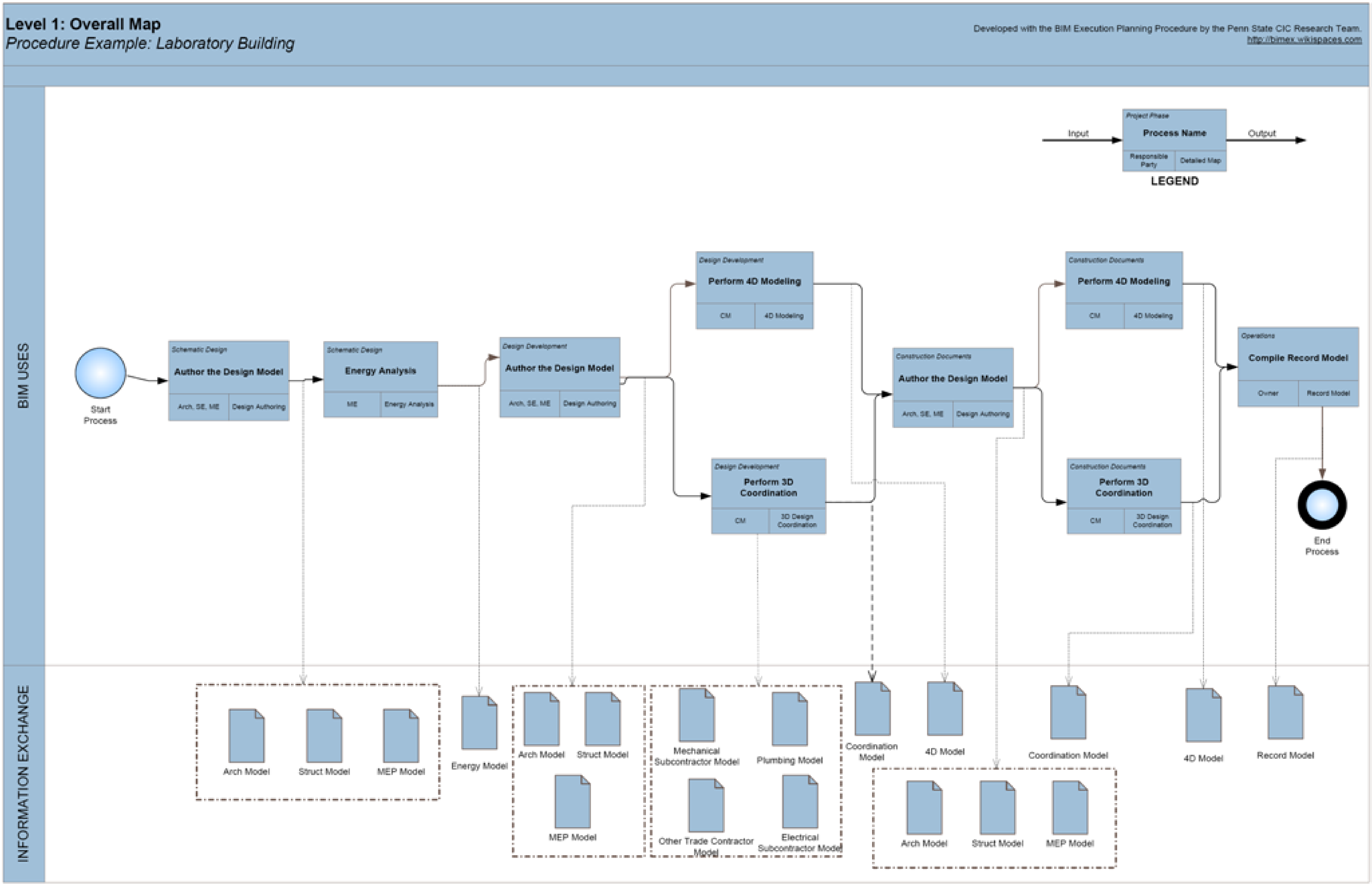
APPENDIX E: LAB EXAMPLE PROCESS MAPS

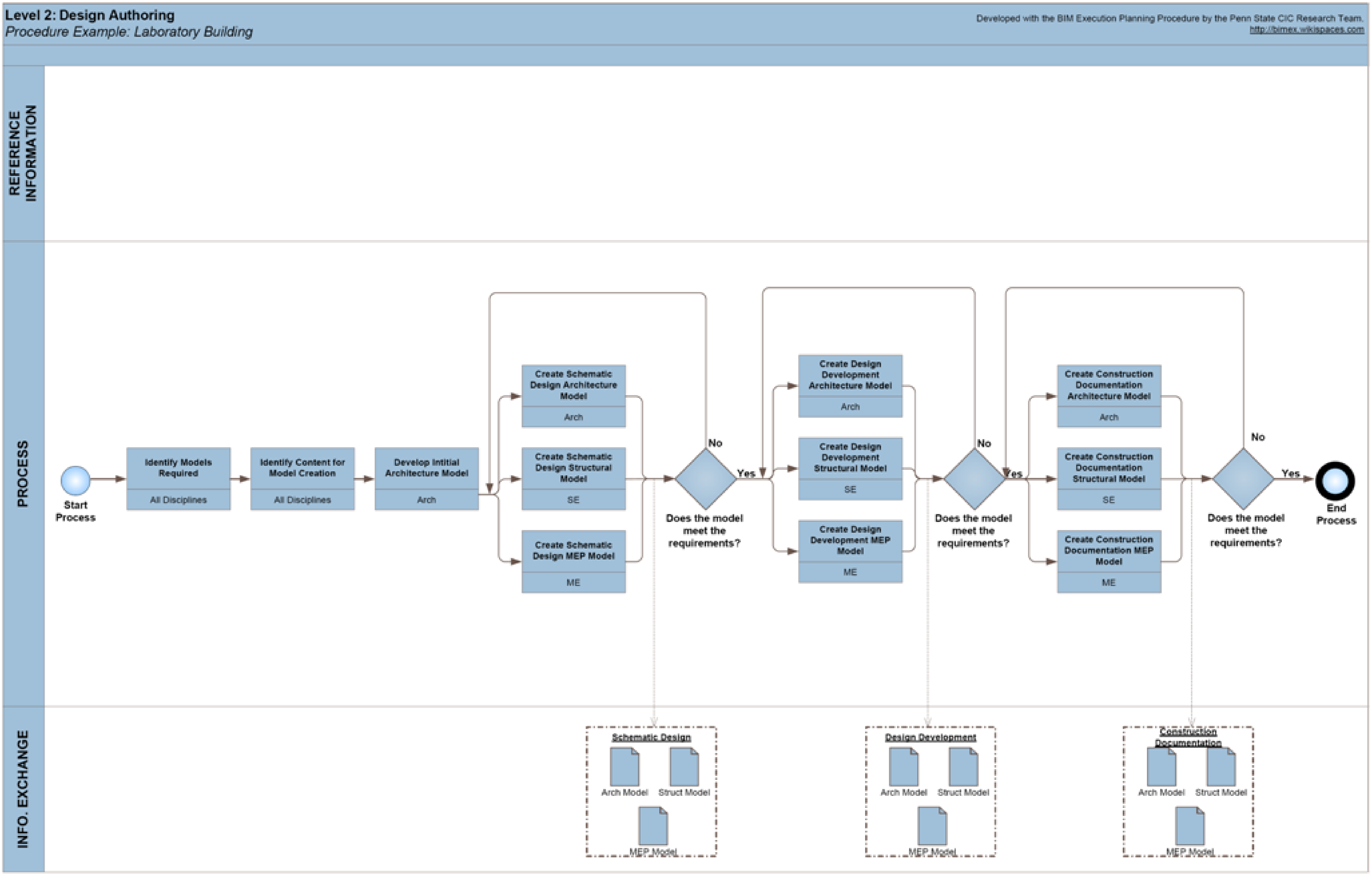
This appendix contains the following Laboratory Example BIM Process Maps:

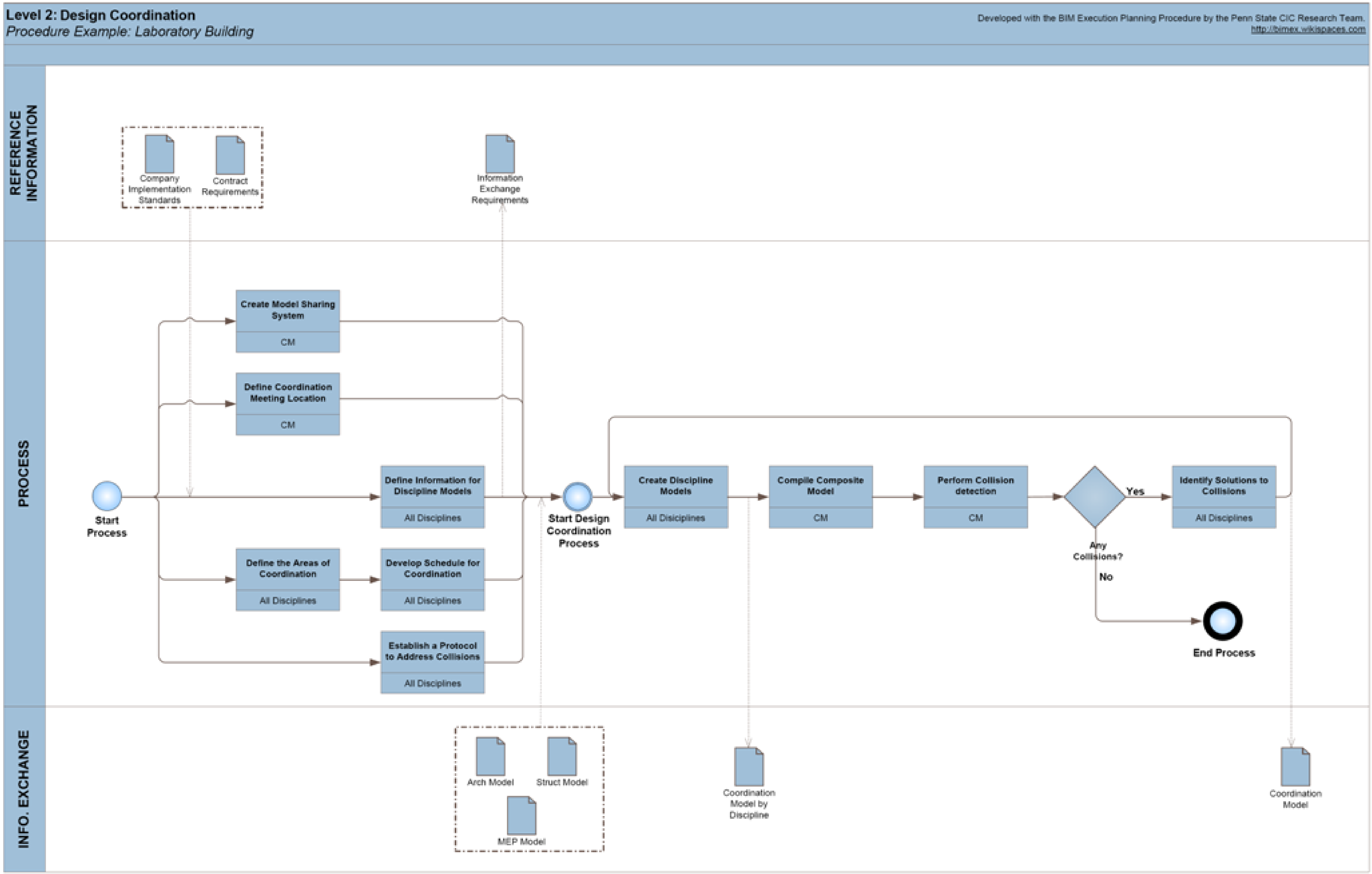
Level 1: BIM Overview Map

Level 2: Detailed BIM Use Process Maps:

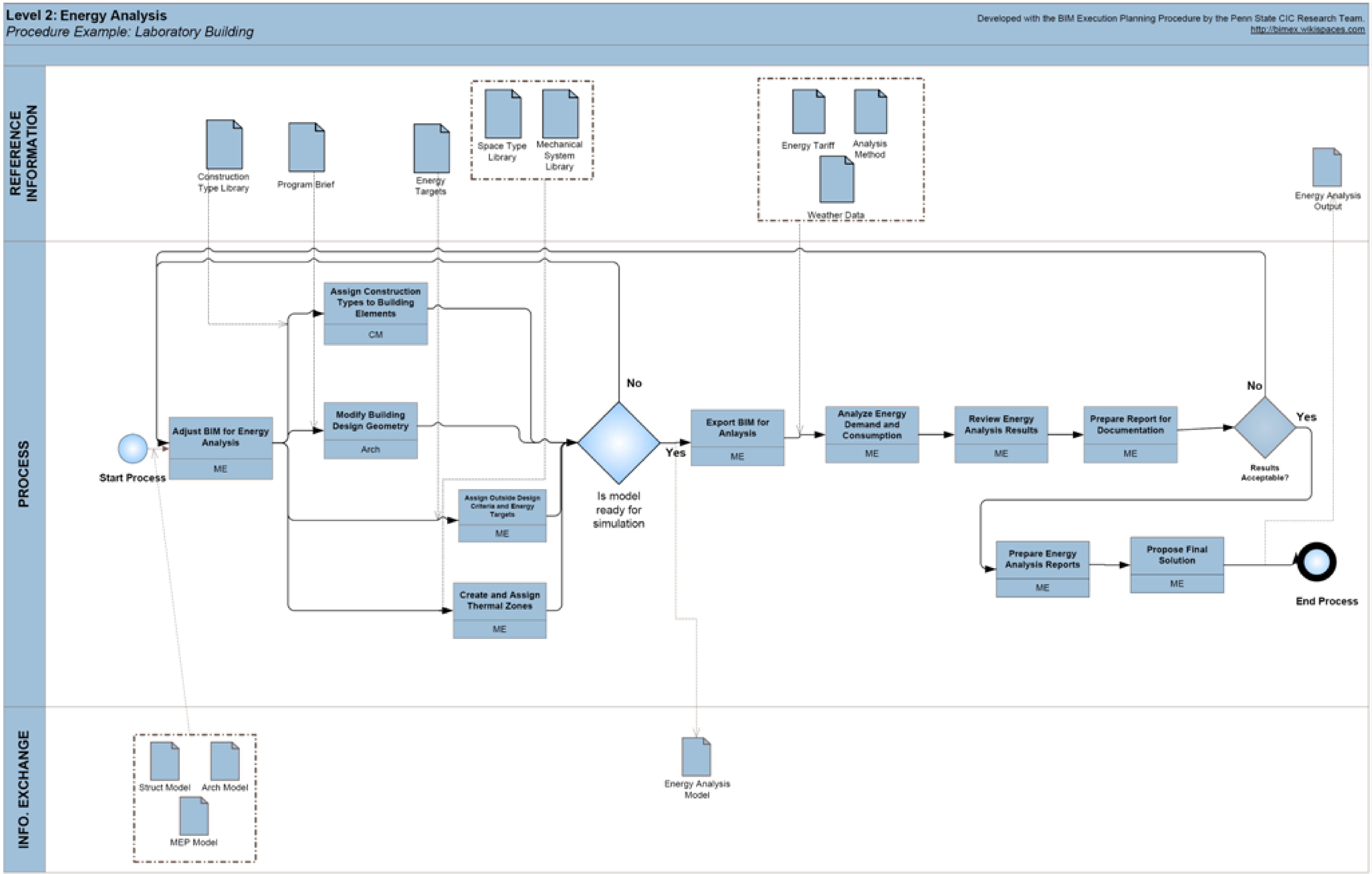
1. Design Authoring
2. 3D Design Coordination
3. Energy Analysis
4. 4D Modeling
5. Record Modeling


Level 1: Overall Map
Procedure Example: Laboratory Building
Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com
BIM USES
INFORMATION EXCHANGE
Input
Project Phase
Process Name
Responsible Party
Detailed Map
Output
LEGEND
Start Process
Schematic Design
Author the Design Model
Arch, SE, ME
Design Authoring
Schematic Design
Energy Analysis
ME
Energy Analysis
Design Development
Author the Design Model
Arch, SE, ME
Design Authoring
Design Development
Perform 4D Modeling
CM
4D Modeling
Design Development
Perform 3D Coordination
CM
3D Design Coordination
Construction Documents
Author the Design Model
Arch, SE, ME
Design Authoring
Construction Documents
Perform 4D Modeling
CM
4D Modeling
Construction Documents
Perform 3D Coordination
CM
3D Design Coordination
Operations
Compile Record Model
Owner
Record Model
End Process
Arch Model
Struct Model
MEP Model
Energy Model
Arch Model
Struct Model
MEP Model
Mechanical Subcontractor Model
Plumbing Model
Other Trade Contractor Model
Electrical Subcontractor Model
Coordination Model
4D Model
Arch Model
Struct Model
MEP Model
Coordination Model
4D Model
Record Model

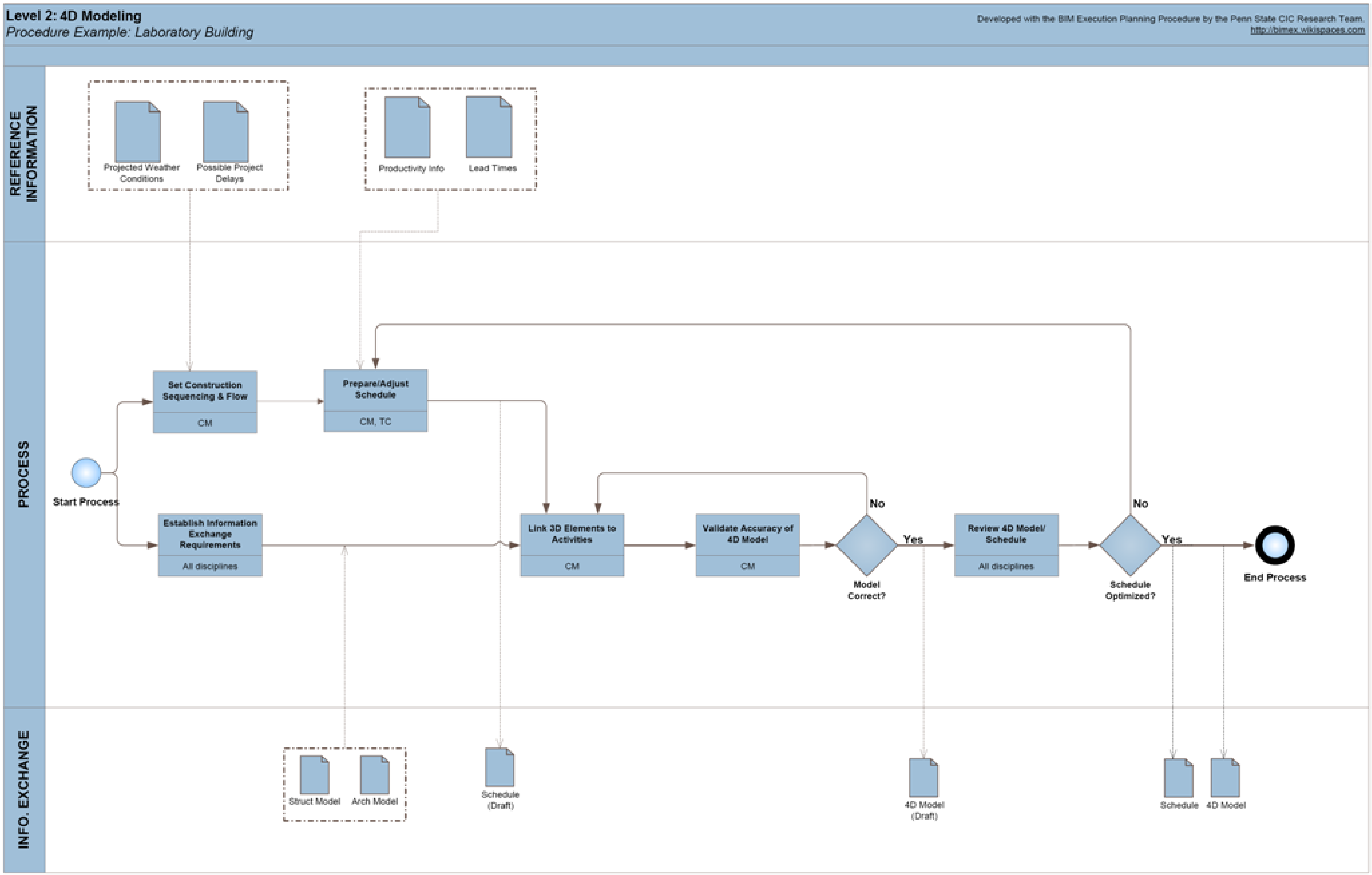

Level 2: Design Authoring
Procedure Example: Laboratory Building
Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com
REFERENCE INFORMATION
PROCESS
INFO. EXCHANGE
Start Process
Identify Models Required
All Disciplines
Identify Content for Model Creation
All Disciplines
Develop Intitial Architecture Model
Arch
Create Schematic Design Architecture Model
Arch
Create Schematic Design Structural Model
SE
Create Schematic Design MEP Model
ME
Does the model meet the requirements?
No
Yes
Create Design Development Architecture Model
Arch
Create Design Development Structural Model
SE
Create Design Development MEP Model
ME
Does the model meet the requirements?
No
Yes
Create Construction Documentation Architecture Model
Arch
Create Construction Documentation Structural Model
SE
Create Construction Documentation MEP Model
ME
Does the model meet the requirements?
No
Yes
End Process
Schematic Design
Arch Model
Struct Model
MEP Model
Design Development
Arch Model
Struct Model
MEP Model
Construction Documentation
Arch Model
Struct Model
MEP Model

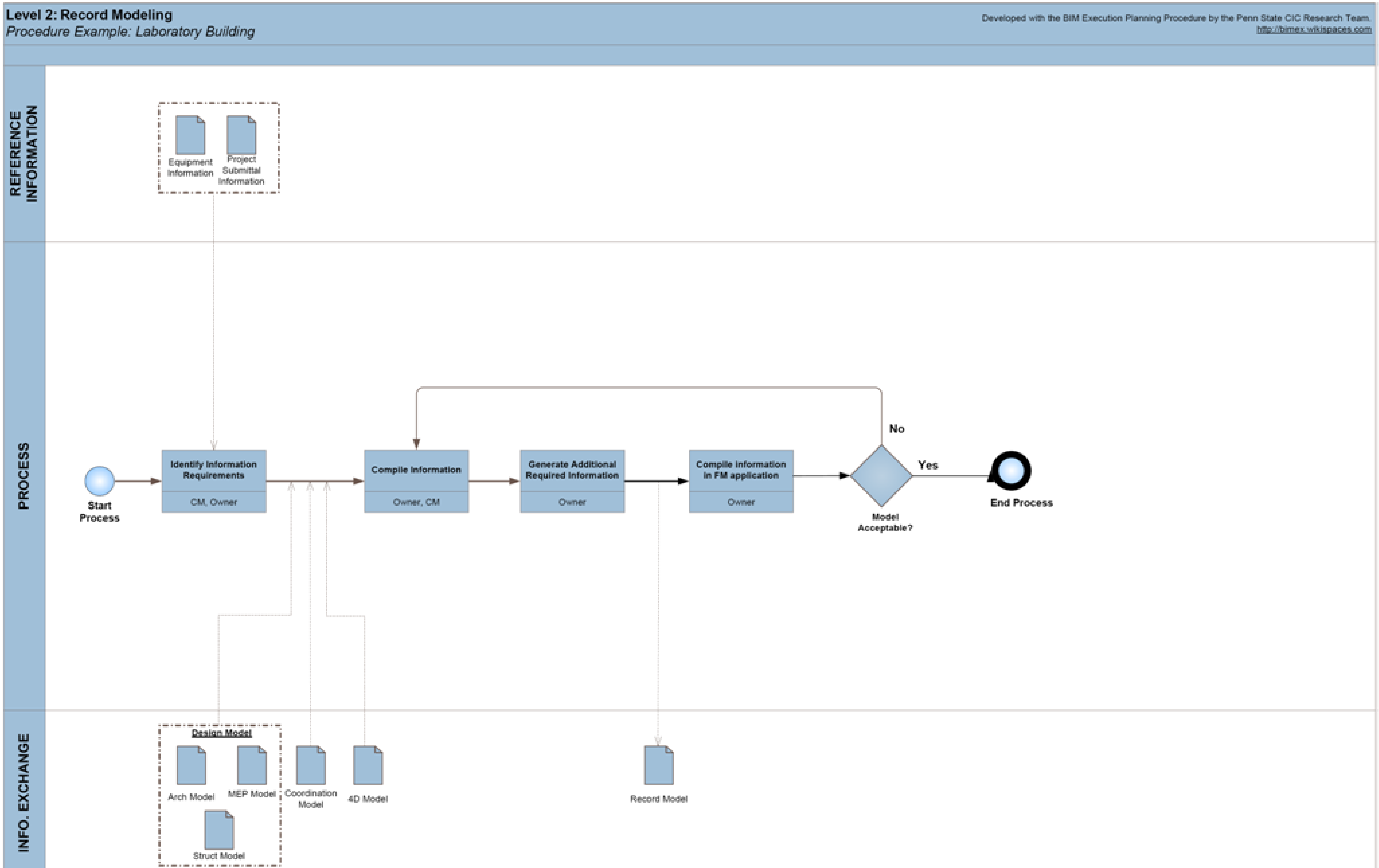


Level 2: Design Coordination
Procedure Example: Laboratory Building
Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com
REFERENCE INFORMATION
PROCESS
INFO. EXCHANGE
Company Implementation Standards
Contract Requirements
Information Exchange Requirements
Start Process
Create Model Sharing System
CM
Define Coordination Meeting Location
CM
Define Information for Discipline Models
All Disciplines
Define the Areas of Coordination
All Disciplines
Develop Schedule for Coordination
All Disciplines
Establish a Protocol to Address Collisions
All Disciplines
Start Design Coordination Process
Create Discipline Models
All Disciplines
Compile Composite Model
CM
Perform Collision detection
CM
Any Collisions?
Yes
No
Identify Solutions to Collisions
All Disciplines
End Process
Arch Model
Struct Model
MEP Model
Coordination Model by Discipline
Coordination Model



Level 2: Energy Analysis
Procedure Example: Laboratory Building
Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com
REFERENCE INFORMATION
PROCESS
INFO. EXCHANGE
Construction Type Library
Program Brief
Energy Targets
Space Type Library
Mechanical System Library
Energy Tariff
Analysis Method
Weather Data
Energy Analysis Output
Start Process
Adjust BIM for Energy Analysis
ME
Assign Construction Types to Building Elements
CM
Modify Building Design Geometry
Arch
Assign Outside Design Criteria and Energy Targets
ME
Create and Assign Thermal Zones
ME
No
Yes
Is model ready for simulation
Export BIM for Anlaysis
ME
Analyze Energy Demand and Consumption
ME
Review Energy Analysis Results
ME
Prepare Report for Documentation
ME
No
Yes
Results Acceptable?
Prepare Energy Analysis Reports
ME
Propose Final Solution
ME
End Process
Struct Model
Arch Model
MEP Model
Energy Analysis Model


Level 2: 4D Modeling
Procedure Example: Laboratory Building
Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com
REFERENCE INFORMATION
PROCESS
INFO. EXCHANGE
Projected Weather Conditions
Possible Project Delays
Productivity Info
Lead Times
Start Process
Set Construction Sequencing & Flow
CM
Prepare/Adjust Schedule
CM, TC
Establish Information Exchange Requirements
All disciplines
Link 3D Elements to Activities
CM
Validate Accuracy of 4D Model
CM
Model Correct?
No
Yes
Review 4D Model/ Schedule
All disciplines
Schedule Optimized?
No
Yes
End Process
Struct Model
Arch Model
Schedule (Draft)
4D Model (Draft)
Schedule
4D Model



Level 2: Record Modeling
Procedure Example: Laboratory Building
Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com
REFERENCE INFORMATION
PROCESS
INFO. EXCHANGE
Equipment Information
Project Submittal Information
Start Process
Identify Information Requirements
CM, Owner
Compile Information
Owner, CM
Generate Additional Required Information
Owner
Compile information in FM application
Owner
No
Yes
Model Acceptable?
End Process
Design Model
Arch Model
MEP Model
Struct Model
Coordination Model
4D Model
Record Model

APPENDIX F: INFORMATION EXCHANGE WORKSHEET

Information	
A	Accurate Size & Location, include materials and object parameters
B	General Size & Location, include parameter data
C	Schematic Size & Location

Responsible Party	
A	Architect
C	Contractor
CV	Civil Engineer
FM	Facility Manager
MEP	MEP Engineer
SE	Structural Engineer
TC	Trade Contractors

Information Exchange Title											
Time of Exchange (SD, DD, CD, Construction)											
Model Reciever											
Reciever File Format											
Application & Version											
Model Element Breakdown			**Info**	**Resp Party**	**Notes**	**Info**	**Resp Party**	**Notes**	**Info**	**Resp Party**	**Notes**
A	**SUBSTRUCTURE**										
	Foundations										
		Standard Foundations									
		Special Foundations									
		Slab on Grade									
	Basement Construction										
		Basement Excavation									
		Basement Walls									
B	**SHELL**										
	Superstructure										
		Floor Construction									
		Roof Construction									
	Exterior Enclosure										
		Exterior Walls									
		Exterior Windows									
		Exterior Doors									
	Roofing										
		Roof Coverings									
		Roof Openings									
C	**INTERIORS**										
	Interior Construction										
		Partitions									
		Interior Doors									
		Fittings									
	Stairs										
		Stair Construction									
		Stair Finishes									
	Interior Finishes										
		Wall Finishes									
		Floor Finishes									
		Ceiling Finishes									
D	**SERVICES**										
	Conveying Systems										
		Elevators & Lifts									
		Escalators & Moving Walks									
		Other Conveying Systems									
	Plumbing										
		Plumbing Fixtures									
		Domestic Water Distribution									
		Sanitary Waste									
		Rain Water Drainage									
		Other Plumbing Systems									
	HVAC										
		Energy Supply									
		Heat Generating Systems									
		Cooling Generating Systems									
		Distribution Systems									
		Terminal & Package Units									
		Systems Testing & Balancing									
		Other HVAC Systems & Equipment									

	Fire Protection										
		Sprinklers									
		Standpipes									
		Fire Protection Specialties									
		Other Fire Protection Systems									
	Electrical										
		Electrical Service & Distribution									
		Lighting and Branch Wiring									
		Communications & Security									
		Other Electrical Systems									
E	**EQUPMENT & FURNISHINGS**										
	Equipment										
		Commercial Equipment									
		Institutional Equipment									
		Vehicular Equipment									
		Other Equipment									
	Furnishings										
		Fixed Furnishings									
F	**SPECIAL CONSTRUCATION & DEMOLITION**										
	Special Construction										
		Special Structures									
		Integrated Construction									
		Special Construction Systems									
		Special Facilities									
		Special Controls & Instrumentation									
	Selective Bldg Demo										
		Building Elements Demolition									
		Hazardous Components Abatement									
G	**BUILDING SITEWORK**										
	Site Preparation										
		Site Clearing									
		Site Demolition & Relocations									
		Site Earthwork									
		Hazardous Waste Remediation									
	Site Improvements										
		Roadways									
		Parking Lots									
		Pedestrian Paving									
		Site Development									
		Landscaping									
	Site Civil/Mech Utilities										
		Water Supply & Distribution Systems									
		Sanitary Sewer Systems									
		Storm Sewer Systems									
		Heating Distribution									
		Cooling Distribution									
		Fuel Distribution									
		Other Civil/Mechanical Utilities									
	Site Electrical Utilities										
		Electrical Distribution									
		Site Lighting									
		Site Communications & Security									
		Other Electrical Utilities									
	Other Site Construction										
		Service Tunnels									
		Other Site Systems & Equipment									
1	**Construction Systems**										
		Construction Equipment									
		Temporary Safety									
		Temporary Security									
		Temporary Facilities									
		Weather Protection									
2	**Space**										
		Construction Activity Space									
		Analysis Space									
3	**Information**										
		Construction Information									
		Engineering Information									
		Record Information									

[PROJECT TITLE] [DATE]

APPENDIX G: BIM PROJECT EXECUTION PLAN TEMPLATE

BIM PROJECT EXECUTION PLAN

VERSION 2.0

FOR

[PROJECT TITLE]

DEVELOPED BY

[AUTHOR COMPANY]

This template is a tool that is provided to assist in the development of a BIM project execution plan as required per contract. The template plan was created from the buildingSMART alliance™ (bSa) Project "BIM Project Execution Planning" as developed by The Computer Integrated Construction (CIC) Research Group of The Pennsylvania State University. The bSa project is sponsored by The Charles Pankow Foundation (http://www.pankowfoundation.org), Construction Industry Institute (CII) (http://www.construction-institute.org), Penn State Office of Physical Plant (OPP) (http://www.opp.psu.edu), and The Partnership for Achieving Construction Excellence (PACE) (http://www.engr.psu.edu/pace). The BIM Project Execution Planning Guide can be downloaded at http://www.engr.psu.edu/BIM/PxP.

This coversheet can be replaced by a company specific coversheet that includes at a minimum document title, project title, project location, author company, and project number.

BIM PROJECT EXECUTION PLAN

VERSION 2.0

FOR

[PROJECT TITLE]

DEVELOPED BY

[AUTHOR COMPANY]

TABLE OF CONTENTS

SECTION A: BIM PROJECT EXECUTION PLAN OVERVIEW

To successfully implement Building Information Modeling (BIM) on a project, the project team has developed this detailed BIM Project Execution Plan. The BIM Project Execution Plan defines uses for BIM on the project (e.g. design authoring, cost estimating, and design coordination), along with a detailed design of the process for executing BIM throughout the project lifecycle.

[INSERT ADDITIONAL INFORMATION HERE IF APPLICABLE. FOR EXAMPLE: BIM MISSION STATEMENT This is the location to provide additional BIM overview information. Additional detailed information can be included as an attachment to this document.

Please note: Instructions and examples to assist with the completion of this guide are currently in grey. The text can and should be modified to suit the needs of the organization filling out the template. If modified, the format of the text should be changed to match the rest of the document. This can be completed, in most cases, by selecting the normal style in the template styles.

SECTION B: PROJECT INFORMATION

This section defines basic project reference information and determined project milestones.

PROJECT OWNER:

PROJECT NAME:

PROJECT LOCATION AND ADDRESS:

CONTRACT TYPE / DELIVERY METHOD:

BRIEF PROJECT DESCRIPTION: [NUMBER OF FACILITIES, GENERAL SIZE, ETC]

Additional Project Information: [UNIQUE BIM PROJECT CHARACTERISTICS AND REQUIREMENTS]

PROJECT NUMBERS:

PROJECT INFORMATION	NUMBER
CONTRACT NUMBER:	
TASK ORDER:	
PROJECT NUMBER:	

PROJECT SCHEDULE / PHASES / MILESTONES:

Include BIM milestones, pre-design activities, major design reviews, stakeholder reviews, and any other major events which occur during the project lifecycle.

PROJECT PHASE / MILESTONE	ESTIMATED START DATE	ESTIMATED COMPLETION DATE	PROJECT STAKEHOLDERS INVOLVED
PRELIMINARY PLANNING			
DESIGN DOCUMENTS			
CONSTRUCTION DOCUMENTS			
CONSTRUCTION			

SECTION C: KEY PROJECT CONTACTS

List of lead BIM contacts for each organization on the project. Additional contacts can be included later in the document.

ROLE	ORGANIZATION	CONTACT NAME	LOCATION	E-MAIL	PHONE
Project Manager(s)					
BIM Manager(s)					
Discipline Leads					
Other Project Roles					

SECTION D: PROJECT GOALS / BIM USES

Describe how the BIM Model and Facility Data are leveraged to maximize project value (e.g. design alternatives, life-cycle analysis, scheduling, estimating, material selection, pre-fabrication opportunities, site placement, etc.) Reference www.engr.psu.edu/bim/download for BIM Goal & Use Analysis Worksheet.

1. MAJOR BIM GOALS / OBJECTIVES:

State Major BIM Goals and Objectives

PRIORITY (HIGH/ MED/ LOW)	GOAL DESCRIPTION	POTENTIAL BIM USES

2. BIM USE ANALYSIS WORKSHEET: ATTACHMENT 1

Reference www.engr.psu.edu/bim/download for BIM Goal & Use Analysis Worksheet. Attach BIM Use analysis Worksheet as Attachment 1.

3. BIM USES:

Highlight and place an X next to the additional BIM Uses as selected by the project team using the BIM Goal & Use Analysis Worksheet. See BIM Project Execution Planning Guide at www.engr.psu.edu/BIM/BIM_Uses for Use descriptions. Include additional BIM Uses as applicable in empty cells.

X	PLAN	X	DESIGN	X	CONSTRUCT	X	OPERATE
	PROGRAMMING		DESIGN AUTHORING		SITE UTILIZATION PLANNING		BUILDING MAINTENANCE SCHEDULING
	SITE ANALYSIS		DESIGN REVIEWS		CONSTRUCTION SYSTEM DESIGN		BUILDING SYSTEM ANALYSIS
			3D COORDINATION		3D COORDINATION		ASSET MANAGEMENT
			STRUCTURAL ANALYSIS		DIGITAL FABRICATION		SPACE MANAGEMENT / TRACKING
			LIGHTING ANALYSIS		3D CONTROL AND PLANNING		DISASTER PLANNING
			ENERGY ANALYSIS		RECORD MODELING		RECORD MODELING
			MECHANICAL ANALYSIS				
			OTHER ENG. ANALYSIS				
			SUSTAINABLITY (LEED) EVALUATION				
			CODE VALIDATION				
	PHASE PLANNING (4D MODELING)		PHASE PLANNING (4D MODELING)		PHASE PLANNING (4D MODELING)		PHASE PLANNING (4D MODELING)
	COST ESTIMATION		COST ESTIMATION		COST ESTIMATION		COST ESTIMATION
	EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING		EXISTING CONDITIONS MODELING

SECTION E: ORGANIZATIONAL ROLES / STAFFING

Determine the project's BIM Roles and Responsibilities and BIM Use Staffing.

1. BIM Roles and Responsibilities:

Describe BIM roles and responsibilities such as BIM Managers, Project Manager, Draftspersons, etc.

2. BIM Use Staffing:

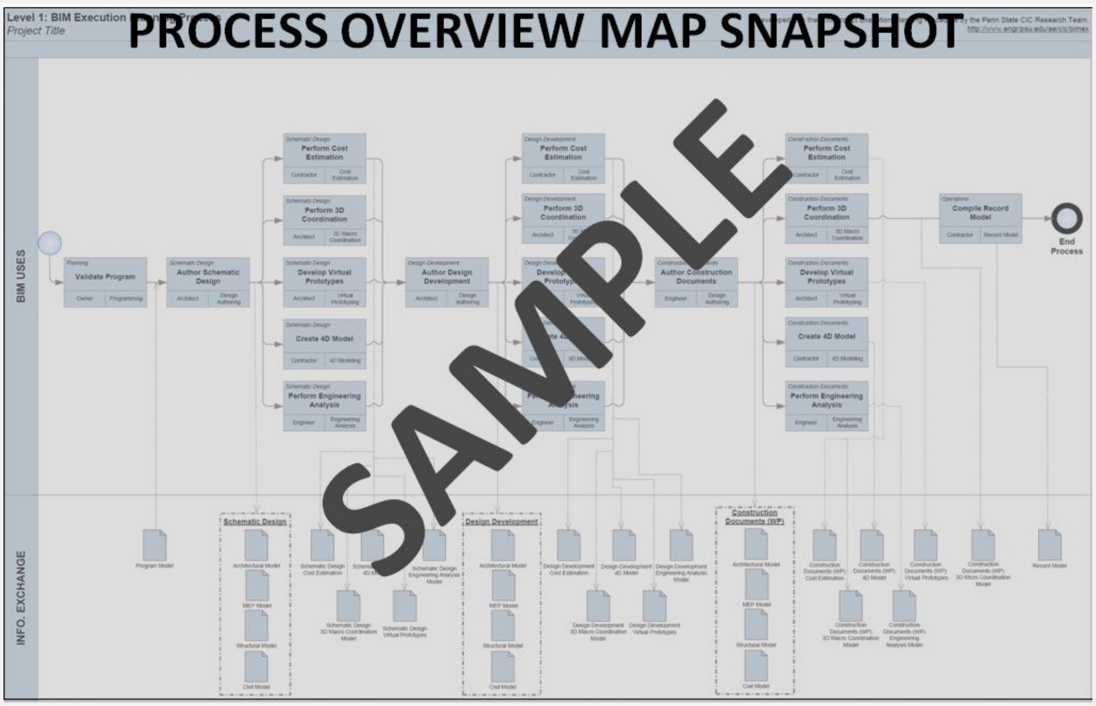
For each BIM Use selected, identify the team within the organization (or organizations) who will staff and perform that Use and estimate the personal time required.

BIM Use	Organization	Number of Total Staff for BIM Use	Estimated Worker Hours	Location(s)	Lead Contact
3D coordination	Contractor A				
	B				
	C				

SECTION F: BIM PROCESS DESIGN

Provide process maps for each BIM Use selected in section D: Project Goals/BIM Objectives. These process maps provide a detailed plan for execution of each BIM Use. They also define the specific Information Exchanges for each activity, building the foundation for the entire execution plan. The plan includes the Overview Map (Level 1) of the BIM Uses, a Detailed Map of each BIM Use (Level 2), and a description of elements on each map, as appropriate. Level 1 and 2 sample maps are available for download at www.engr.psu.edu/BIM/download. (Please note that these are sample maps and should be modified based on project specific information and requirements). Please reference Chapter Three: Designing BIM Project Execution Process in the BIM Project Execution Planning Guide found at www.engr.psu.edu/BIM/PxP

1. LEVEL ONE PROCESS OVERVIEW MAP: ATTACHMENT 2



2. LIST OF LEVEL TWO – DETAILED BIM USE PROCESS MAP(S): ATTACHMENT 3

The following are examples. Modify for specific project. Some Process Maps may need to be removed, while some process maps may need to be added.

a. Existing Conditions Modeling
b. Cost Estimation
c. 4D Modeling
d. Programming
e. Site Analysis
f. Design Reviews
g. Design Authoring
h. Energy Analysis
i. Structural Analysis
j. Lighting Analysis
k. 3D Coordination
l. Site Utilization Planning
m. 3D Control and Planning
n. Record Modeling
o. Maintenance Scheduling
p. Building System Analysis

[Delete unused or add additional process maps from list]

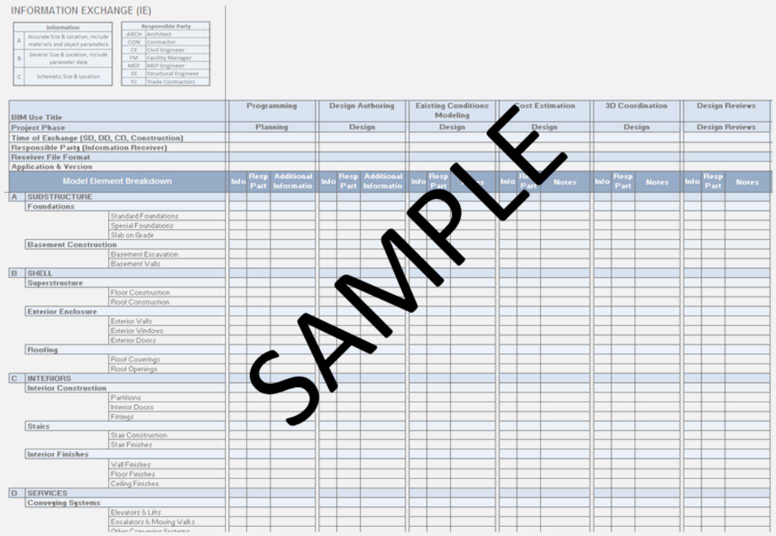
SECTION G: BIM INFORMATION EXCHANGES

Model elements by discipline, level of detail, and any specific attributes important to the project are documented using information exchange worksheet. See Chapter Four: Defining the Requirements for Information Exchanges in the BIM Project Execution Planning Guide for details on completing this template.

1. LIST OF INFORMATION EXCHANGE WORKSHEET(S): ATTACHMENT 4

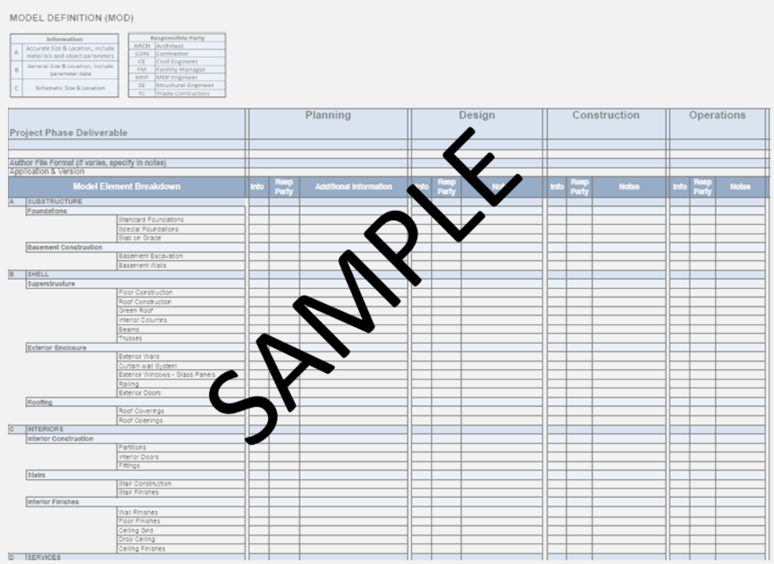
The following are examples. Modify for specific project. Some Information Exchanges may need to be removed, while some Information Exchanges may need to be added.

a. Existing Conditions Modeling
b. Cost Estimation
c. 4D Modeling
d. Programming
e. Site Analysis
f. Design Reviews
g. Design Authoring
h. Energy Analysis
i. Structural Analysis
j. Lighting Analysis
k. 3D Coordination
l. Site Utilization Planning
m. 3D Control and Planning
n. Record Modeling
o. Maintenance Scheduling
p. Building System Analysis
q. [Delete unused information exchanges from list]



2. MODEL DEFINITION WORKSHEET: ATTACHMENT 5

(Attach Model Definition Worksheet)



SECTION H: BIM AND FACILITY DATA REQUIREMENTS

The section should include the owners BIM requirements. It is important that the owner's requirements for BIM be considered so that they can be incorporated into the project's BIM process.

SECTION I: COLLABORATION PROCEDURES

1. COLLABORATION STRATEGY:

Describe how the project team will collaborate. Include items such as communication methods, document management and transfer, and record storage, etc.

2. MEETING PROCEDURES:

The following are examples of meetings that should be considered.

MEETING TYPE	PROJECT STAGE	FREQUENCY	PARTICIPANTS	LOCATION
BIM REQUIREMENTS KICK-OFF				
BIM EXECUTION PLAN DEMONSTRATION				
DESIGN COORDINATION				
CONSTRUCTION OVER-THE-SHOULDER PROGRESS REVIEWS				
ANY OTHER BIM MEETINGS THAT OCCURS WITH MULTIPLE PARTIES				

3. MODEL DELIVERY SCHEDULE OF INFORMATION EXCHANGE FOR SUBMISSION AND APPROVAL:

Document the information exchanges and file transfers that will occur on the project.

INFORMATION EXCHANGE	FILE SENDER	FILE RECEIVER	ONE-TIME or FREQUENCY	DUE DATE or START DATE	MODEL FILE	MODEL SOFTWARE	NATIVE FILE TYPE	FILE EXCHANGE TYPE
DESIGN AUTHORING TO 3D COORDINATION	STRUCTURAL ENGINEER	(FTP POST) (COORDINATION LEAD)	WEEKLY	[DATE]	STRUCT	DESIGN APP	.XYZ	.XYZ .ABC
	MECHANICAL ENGINEER	(FTP POST) (COORDINATION LEAD)	WEEKLY	[DATE]	MECH	DESIGN APP	.XYZ	.XYZ .ABC

4. INTERACTIVE WORKSPACE

The project team should consider the physical environment it will need throughout the lifecycle of the project to accommodate the necessary collaboration, communication, and reviews that will improve the BIM Plan decision making process. Describe how the project team will be located. Consider questions like "will the team be collocated?" If so, where is the location and what will be in that space? Will there be a BIM Trailer? If yes, where will it be located and what will be in the space such as computers, projectors, tables, table configuration? Include any additional information necessary information about workspaces on the project.

5. ELECTRONIC COMMUNICATION PROCEDURES:

(Note: File Naming and Folder Structure will be discussed in Section L: Model Structure).
The following document management issues should be resolved and a procedure should be defined for each: Permissions / access, File Locations, FTP Site Location(s), File Transfer Protocol, File / Folder Maintenance, etc.

FILE LOCATION	FILE STRUCTURE / NAME	FILE TYPE	PASSWORD PROTECT	FILE MAINTAINER	UPDATED
FTP SITE: ftp://ftp.****.com/***/****	ROOT PROJECT FOLDER	FOLDER	YES ***********	JIM McBIM	ONCE
	ARCH ROOT FOLDER	FOLDER			ONCE
	ARCH-11111-BL001.xyz	.xyz			DAILY
NETWORK drive @ PSU F:\PROJECT\BIM	ROOT PROJECT FOLDER	FOLDER	NO	JIM McBIM	ONCE
Project Management Software www.*****.com					

SECTION J: QUALITY CONTROL

1. OVERALL STRATEGY FOR QUALITY CONTROL:

Describe the strategy to control the quality of the model.

2. QUALITY CONTROL CHECKS:

The following checks should be performed to assure quality.

CHECKS	DEFINITION	RESPONSIBLE PARTY	SOFTWARE PROGRAM(S)	FREQUENCY
VISUAL CHECK	Ensure there are no unintended model components and the design intent has been followed			
INTERFERENCE CHECK	Detect problems in the model where two building components are clashing including soft and hard			
STANDARDS CHECK	Ensure that the BIM and AEC CADD Standard have been followed (fonts, dimensions, line styles, levels/layers, etc)			
MODEL INTEGRITY CHECKS	Describe the QC validation process used to ensure that the Project Facility Data set has no undefined, incorrectly defined or duplicated elements and the reporting process on non-compliant elements and corrective action plans			

3. MODEL ACCURACY AND TOLERANCES:

Models should include all appropriate dimensioning as needed for design intent, analysis, and construction. Level of detail and included model elements are provided in the Information Exchange Worksheet.

PHASE	DISCIPLINE	TOLERANCE
DESIGN DOCUMENTS	ARCH	ACCURATE TO +/- [#] OF ACTUAL SIZE AND LOCATION
SHOP DRAWINGS	MECH CONTRACTOR	ACCURATE TO +/- [#] OF ACTUAL SIZE AND LOCATION

SECTION K: TECHNOLOGICAL INFRASTRUCTURE NEEDS

1. SOFTWARE:

List software used to deliver BIM. Remove software that is not applicable.

BIM USE	DISCIPLINE (if applicable)	SOFTWARE	VERSION
DESIGN AUTHORING	ARCH	XYZ DESIGN APPLICATION	VER. X.X (YEAR)

2. COMPUTERS / HARDWARE:

Understand hardware specification becomes valuable once information begins to be shared between several disciplines or organizations. It also becomes valuable to ensure that the downstream hardware is not less powerful than the hardware used to create the information. In order to ensure that this does not happen, choose the hardware that is in the highest demand and most appropriate for the majority of BIM Uses.

BIM USE	HARDWARE	OWNER OF HARDWARE	SPECIFICATIONS
DESIGN AUTHORING	XXX COMPUTER SYSTEM	ARCHITECT X	**PROCESSOR, OPERATING SYSTEM, MEMORY STORAGE, GRAPHICS, NETWORK CARD, ETC.**

3. MODELING CONTENT AND REFERENCE INFORMATION

Identify items such as families, workspaces, and databases.

BIM USE	DISCIPLINE (if applicable)	MODELING CONTENT / REFERENCE INFORMATION	VERSION
DESIGN AUTHORING	ARCH	XYZ APP FAMILIES	VER. X.X. (YEAR)
ESTIMATING	CONTRACTOR	PROPRIETARY DATABASE	VER. X.X (YEAR)

SECTION L: MODEL STRUCTURE

1. File Naming Structure:

Determine and list the structure for model file names.

FILE NAMES FOR MODELS SHOULD BE FORMATTED AS:	
DISCIPLINE - PROJECT NUMBER – BUILDING NUMBER.XYZ (example: ARCH-11111-BL001.xyz)	
ARCHITECTURAL MODEL	ARCH-
CIVIL MODEL	CIVIL-
MECHANICAL MODEL	MECH-
PLUMBING MODEL	PLUMB-
ELECTRICAL MODEL	ELEC-
STRUCTURAL MODEL	STRUCT-
ENERGY MODEL	ENERGY-
CONSTRUCTION MODEL	CONST-
COORDINATION MODEL	COORD-

2. Model Structure:

Describe and diagram how the Model is separated, e.g., by building, by floors, by zones, by areas, and/or by disciplines.

3. Measurement and Coordinate Systems:

Describe the measurement system (Imperial or Metric) and coordinate system (geo-referenced) used.

4. BIM and CAD Standards:

Identify items such as the BIM and CAD standards, content reference information, and the version of IFC, etc.

STANDARD	VERSION	BIM USES APLICABLE	ORGANIZATIONS APLICABLE
CAD STANDARD		DESIGN AUTHORING	ARCHITECT
IFC	VERSION/MVD(s)	RECORD MODELING	CONSTRUTION MANAGER

SECTION M: PROJECT DELIVERABLES

In this section, list the BIM deliverables for the project and the format in which the information will be delivered.

BIM SUBMITTAL ITEM	STAGE	APPROXIMATE DUE DATE	FORMAT	NOTES
	Design Development			
	Construction Documents			
	Construction			
Record Model	Close out		(.xyz)	See Record Model Information Exchange to ensure that the proper information is contained in this model

SECTION N: DELIVERY STRATEGY / CONTRACT

1. DELIVERY AND CONTRACTING STRATEGY FOR THE PROJECT:

What additional measures need to be taken to successfully use BIM with the selected delivery method and contract type?

2. TEAM SELECTION PROCEDURE:

How will you select future team members in regards to the above delivery strategy and contract type?

3. BIM CONTRACTING PROCEDURE:

How should BIM be written into the future contracts? (If documents / contracts are developed, please attach as attachment 6)

SECTION O: ATTACHMENTS

1. **BIM USE SELECTION WORKSHEET** [FROM SECTION D]
2. **LEVEL 1 PROCESS OVERVIEW MAP** [FROM SECTION F]
3. **LEVEL 2 DETAILED BIM USE PROCESS MAP(S)** [FROM SECTION F]
4. **INFORMATION EXCHANGE REQUIREMENT WORKSHEET(S)** [FROM SECTION G]
5. **MODEL DEFINITION WORKSHEET** [FROM SECTION G]
6. **DEVELOPED DOCUMENTS / CONTRACTS** [FROM SECTION H]

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