The Pennsylvania State University

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Department of Architectural Engineering

A PROCESS MAPPING PROCEDURE FOR PLANNING BUILDING INFORMATION MODELING (BIM) EXECUTION ON A BUILDING CONSTRUCTION PROJECT

A Thesis in

Architectural Engineering

by

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ABSTRACT

The implementation of Building Information Modeling (BIM) in the Architecture, Engineering and Construction Industry is still in its formative stages. Project organizations frequently struggle with the development of a comprehensive BIM implementation strategy which considers process integration along with information interoperability throughout the lifecycle of a project. To successfully implement BIM on a project, it is critical for the project team to perform detailed and comprehensive planning.

This research establishes a Process Mapping Procedure for planning BIM implementation on a project. This Procedure provides an opportunity for the project team to map the implementation process for the various uses of BIM on a project. By mapping the detailed process, key information exchanges can be identified, and a method for documenting and planning these information exchanges is presented.

The process maps aim to specifically address which organizations will be using BIM on the project, what will they be performing with BIM applications, and how will they share information between the primary BIM Uses. Each project team member should develop detailed process maps for each BIM Use. Additionally, an information exchange documentation method was created to assist project teams in the accurate definition of key BIM deliverables. Information elements included in this method include information delivery schedule, responsible party, and information content for the BIM deliverables. A procedure has been documented to assist in the completion of process maps and information exchange worksheet.

The BIM Process Mapping Procedure was validated through the creation of template process maps, quasi-experiments, and a case study assessment. The survey results from the quasi-experiments show that the Procedure was adequately detailed to create process maps. The focus group discussion following the case study indicated a comprehensive Procedure. Overall, the

BIM Process Mapping Procedure can increase the level of planning for a project by familiarizing the team with the strategies and processes of their team members to achieve a more informed and effective transition of information between responsible parties.

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Chapter 1

Introduction to the Research

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.

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.

1.2 BIM Project Execution Planning Procedure

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. In order 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 (BIM Plan) 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 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.

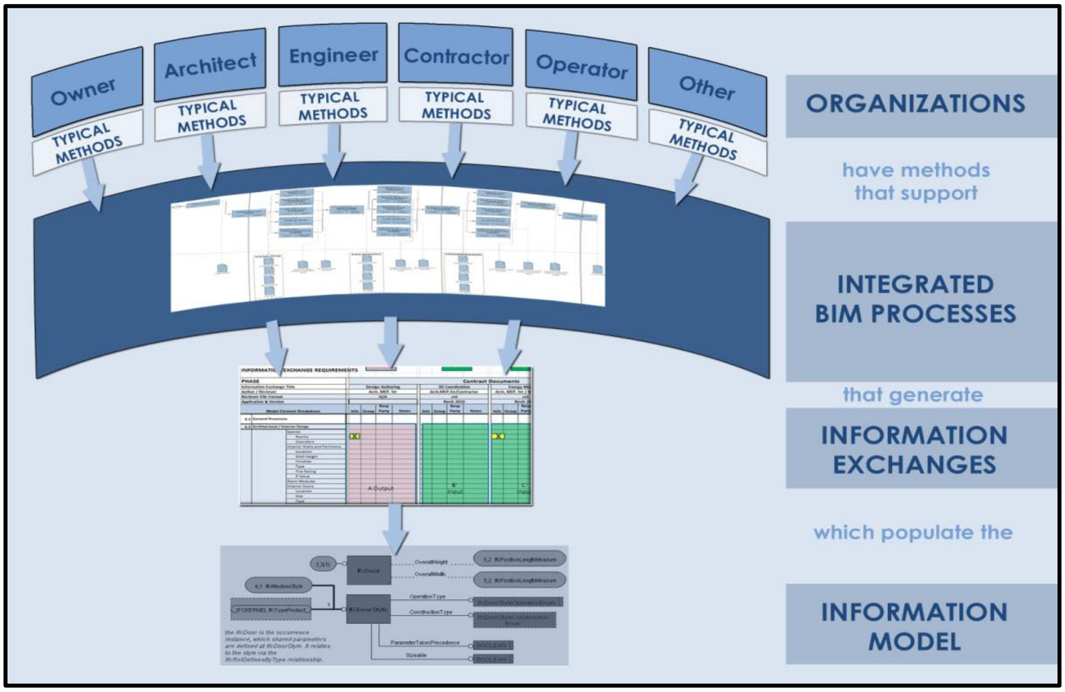

Figure **1-1**: BIM Project Execution Planning Process

1.3 Scope of Work

This research is focused on a specific area within a larger research context. The larger research project is focused on designing a method to create a BIM Plan. The BIM Project Execution Plan is being developed as a four step Procedure[1], refer to Figure 1-2:

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.

[1] For more information, please visit the website: http://www.engr.psu.edu/ae/cic/BIMEx/

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.

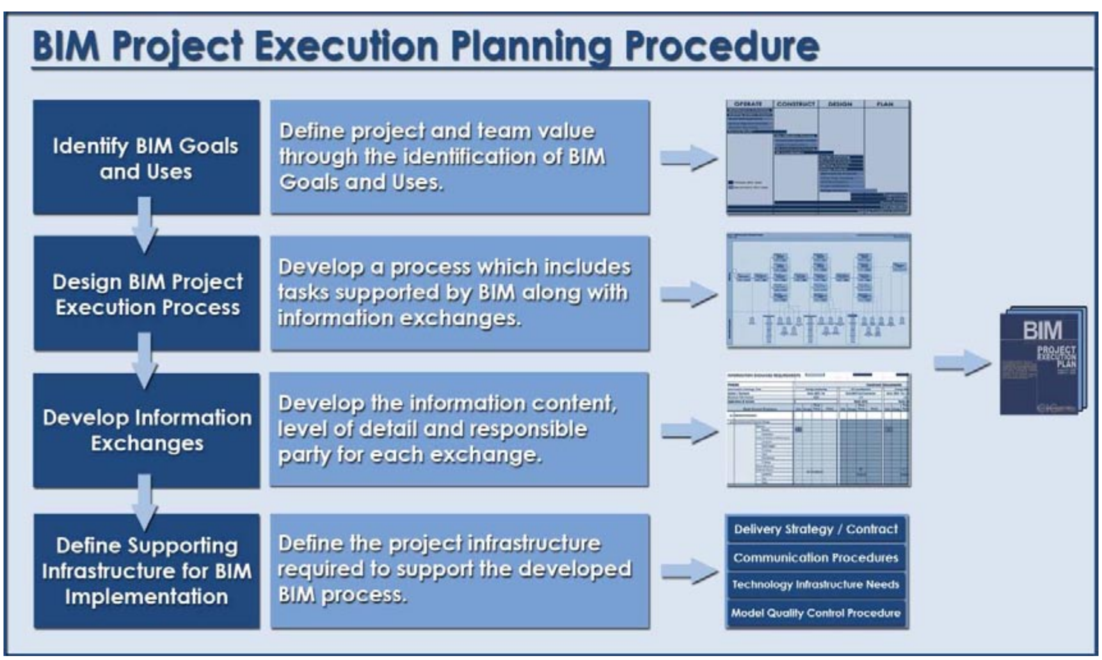

Figure **1-2**: BIM Project Execution Planning Procedure

This research is focused on Steps 2 and 3 of the Procedure: the creation and development of a BIM Execution Process, and defining the Information Exchanges. The research establishes a complete documentation to create the PM and complete the IE worksheet. Quasi-experiments were conducted to establish the clarity and comprehensiveness of the Procedure to create BIM PMs. Finally, the procedure was tested on a case study project. BIM PMs and IEs were created for the project and the results were shared with the project team. A focus group discussion was then held to record their feedback on the BIM Plan.

1.4 Research Goal

The research aims at developing a BIM Process Mapping 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 IE (Step 3). BIM PMs allows 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 IE establishes the information which is necessary to execute each BIM Use.

The goal of the research is to create a technique which allows the team to efficiently perform these two steps. The following goal is the focus of this research:

Develop a BIM Process Mapping Procedure for BIM execution on a project, which guides the project team to specifically answer "what" information needs to be exchanged, "when" during the construction project, and "who" is responsible for the information creation.

1.5 Research Objectives

To achieve this goal the following objectives were met.

1. *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.
2. *Validate the BIM Process Mapping Procedure*: Once the procedure to create PMs and IEs was established, it was necessary to validate it. To accomplish this task, quasi-experiments, template maps, and a case study validation were completed.

1.6 Research Contributions

The contributions of this research are:

- Documentation of the development and definition of a BIM Process Mapping Procedure for planning the implementation of BIM on a project;
- Template PMs for five BIM Uses on a project. These Template Maps can be used by the project teams for the creation of project specific PMs; and
- Documentation of the BIM Execution Plan on a case study project.

1.7 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.

1.8 Thesis Organization

This Chapter identified the goals, objectives and contributions of this research effort. The scope of work along with the BIM Project Execution Planning Procedure was also presented. The steps which were followed to complete this research are listed and elaborated in Chapter 2. The various techniques employed during the research to obtain valuable data related to the BIM Process Mapping Procedure is also discussed in Chapter 2. Chapter 3 provides an overview of the literature and establishes the background of this study. The procedure to develop the PM along with the process mapping components and the representation in the Business Process Modeling Notation is discussed in Chapter 4. Chapter 4 also discusses the structure of the IE worksheet, its components and a workable procedure to complete the worksheet. In Chapter 5, the results of the quasi-experiments conducted are produced along with the results of the questionnaire survey and lessons learned from the content analysis of the maps. Chapter 6 discusses the case study evaluation of the BIM Ex Procedure and the results of the focus group discussion. Finally, in Chapter 7, the conclusions of this research are discussed along with suggestions for future work.

Chapter 2

Research Methodology

Sections 1 and 2 of this chapter introduce the research and then discuss the research process, in chronological order, which will be adopted for this study. The third section of the chapter describes the different research techniques adopted to achieve the research goals and objectives.

2.1 Research Introduction

Many researchers and practitioners have documented that BIM is a new approach in 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.

2.2 Research Process

This study utilizes qualitative and quantitative research methods performed through literature review, surveys and case study evaluations for developing and assessing the Process Maps (PMs) and Information Exchanges (IEs) for BIM Project Execution. The following steps define the research process adopted to accomplish the objectives of the study, (see Figure 2-1).

RESEARCH PROCESS

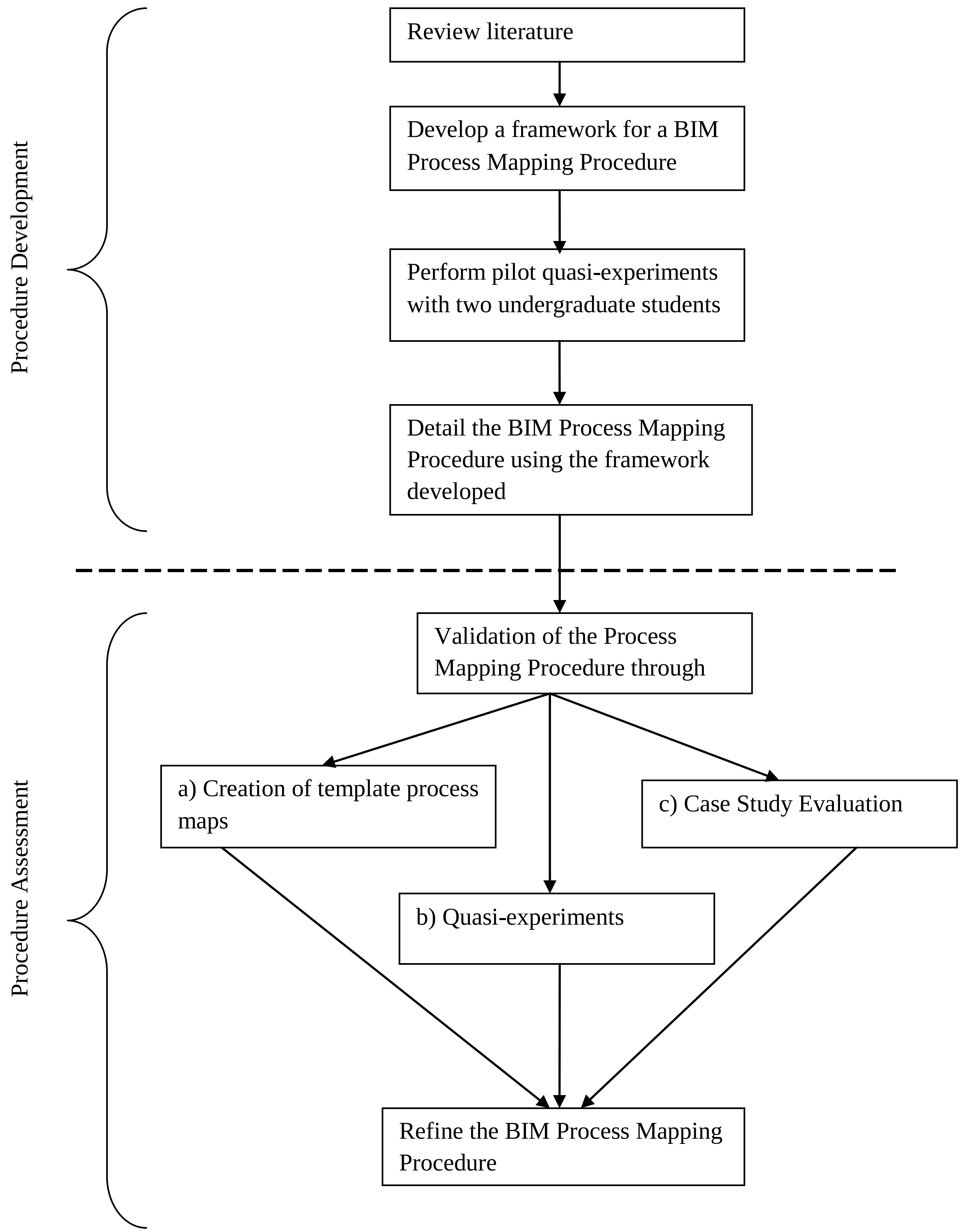

Figure **2-1**: Research process for BIM Process Mapping Procedure development and assessment

2.2.1 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. A summary of this literature is presented in Chapter 3.

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; documentation is reported in Chapter 4.

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.

2.2.2 BIM Process Mapping Procedure Assessment

Having established a BIM Process Mapping Procedure, the next task was to validate it. 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 Research Techniques

2.3.1 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.

2.3.1.1 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.

2.3.1.2 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 (refer to Chapter 5), and redefined the Procedure to more clearly define the topic in an attempt to address most of these observed irregularities.

2.3.2 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.

2.3.2.1 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 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.

2.4 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. The details of the case study evaluation have been documented in Chapter 6.

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 for the following BIM Uses: Programming (Plan), Energy Analysis (Design), 3D Coordination (Construct), Record Modeling (Operate) and Cost Estimation (Multiphase). The Template PMs have been included in Appendix A.

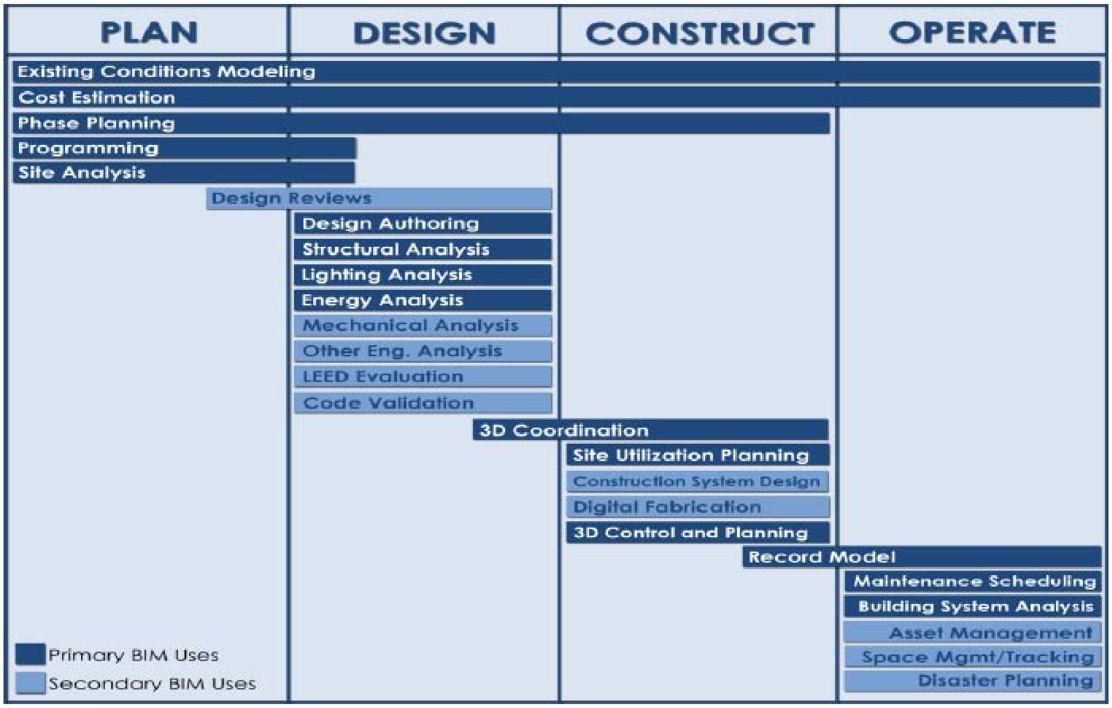

Figure **2-2**: BIM Uses throughout a building lifecycle

2.5 Chapter Summary

This Chapter presented the research process and techniques that the researcher had employed to define, develop and assess the BIM Process Mapping Procedure. 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 Process Mapping Procedure was developed, it was necessary to validate the research through various techniques. Quasi-experiments, development of Template PMs, and the implementation of the Procedure on a case study project were adopted for the assessment and evaluation of the BIM Process Mapping Procedure.

Chapter 3

Literature Review

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.

3.1 The Need for BIM Process Integration

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.

3.2 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.

3.2.1 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.

3.2.2 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. In 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 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 3-1, was subdivided into managing, planning, design, construction and operations of a facility.

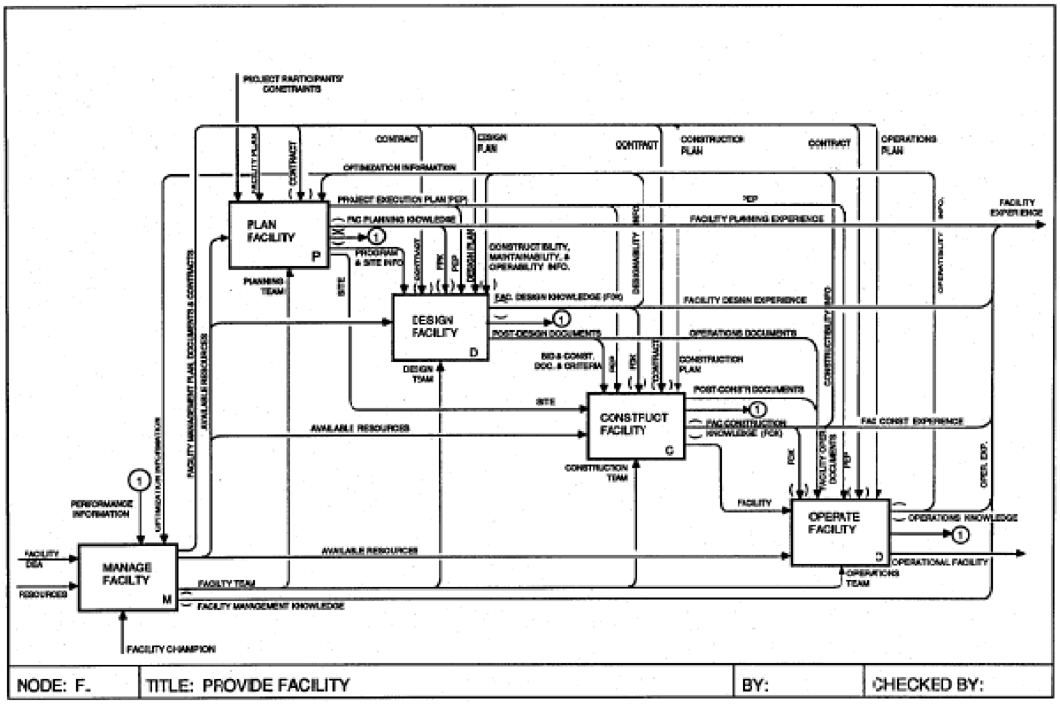

Figure **3-1**: Provide Facility (Sanvido et al. 1990)

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 3-2, consists of boxes and arrows with the activity represented by a rectangular box and the flow of a process with arrows.

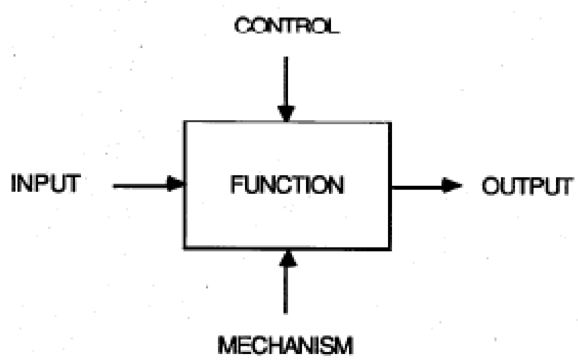

Figure **3-2**: IDEF0 box and arrow graphics (Sanvido et al. 1990)

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 Protocol2. The Generic Design and Construction Process Protocol essentially breaks down the design and construction process into 10 distinct phases, shown in Figure 3-3. 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).

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

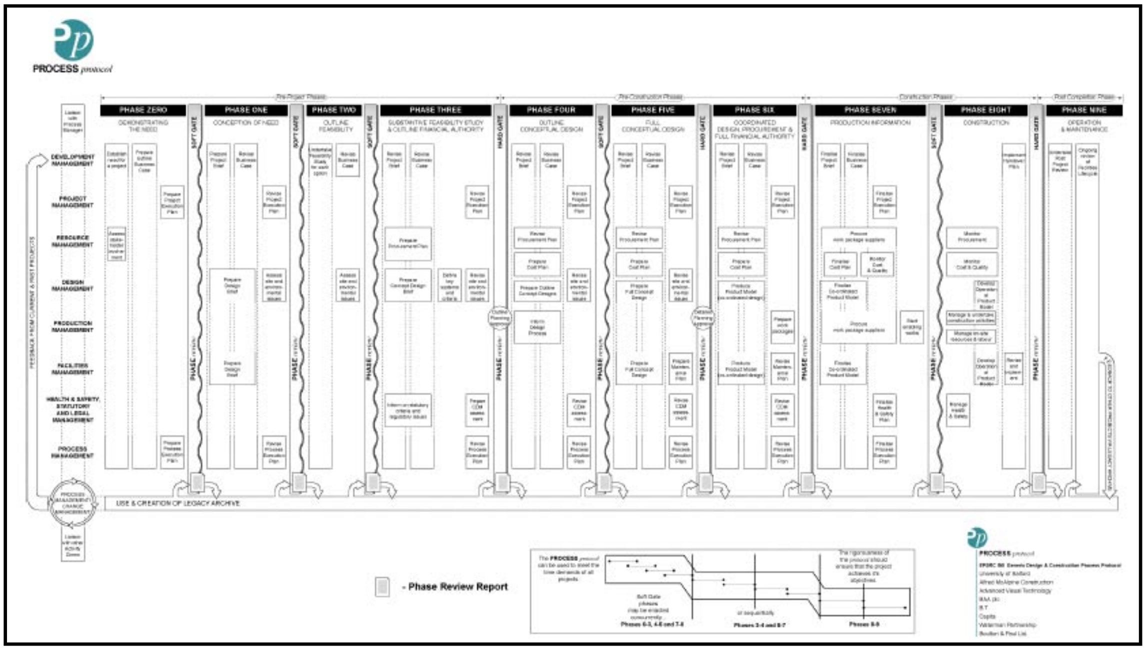

Figure **3-3**: The Generic Design and Construction Process Protocol model (Kagioglou et al. 2000).

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 3-4.

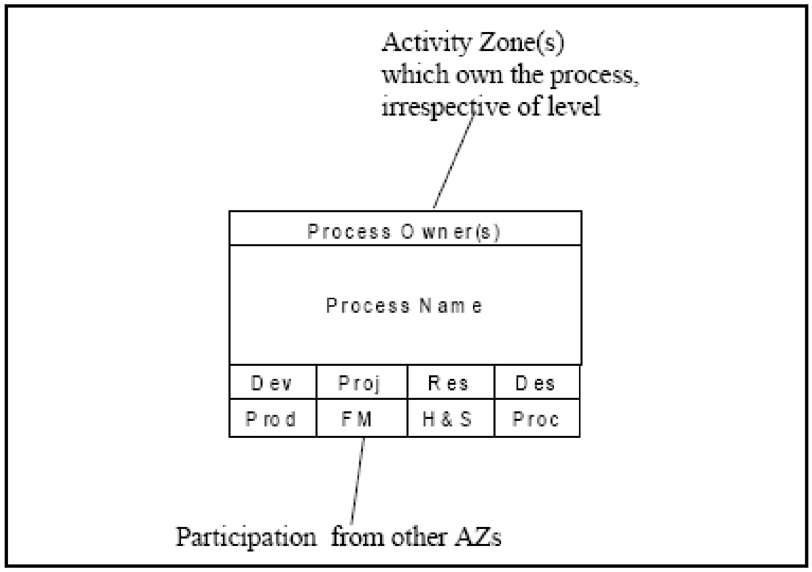

Figure **3-4**: Process map template for the Process Protocol (Fleming et al. 2000)

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.

3.3.1 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 3-5 (Bjork 1992).

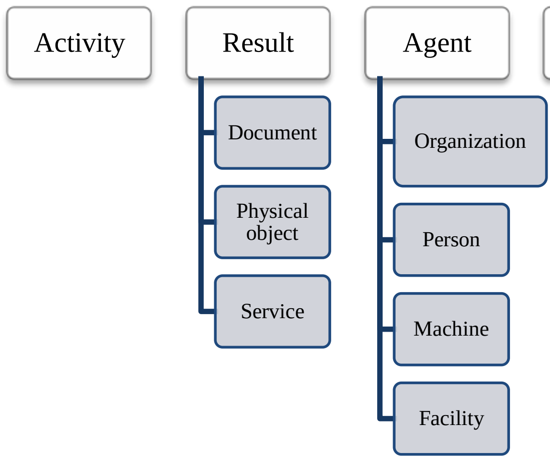

Figure **3-5**: Subtypes of the construction process entity (Bjork 1992)

Bjork (1995) also provided an EXPRESS-G representation of some of these objects in a generic construction process, as shown in Figure 3-6.

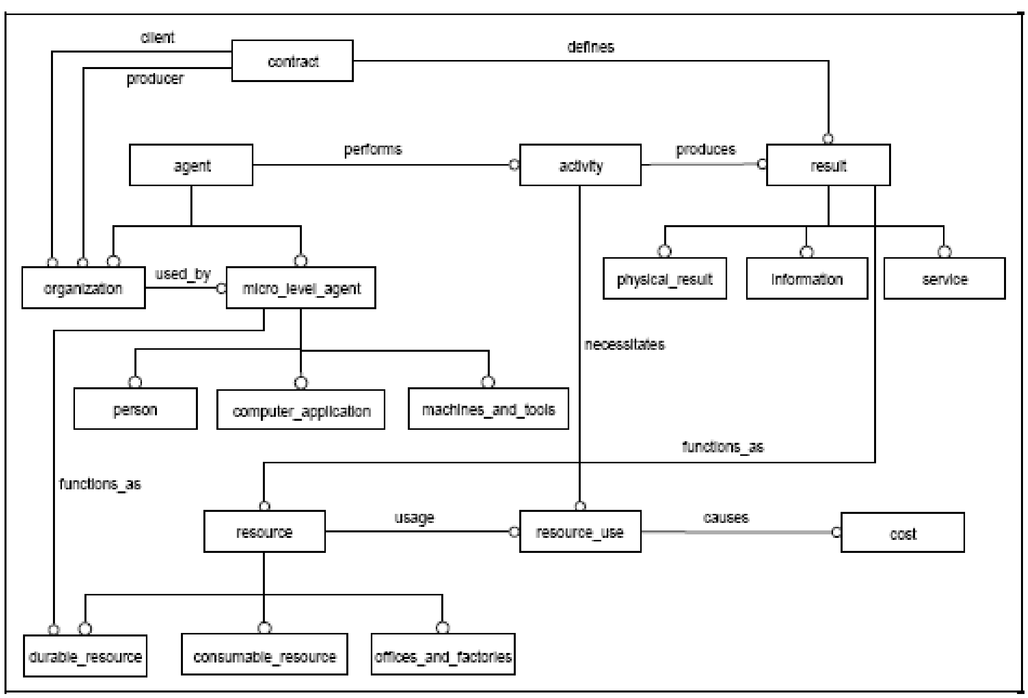

Figure **3-6**: A model of generic construction categories, showing some of their internal relationships (Bjork 1995)

3.3.2 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 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[3] (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).

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

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:

- 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.

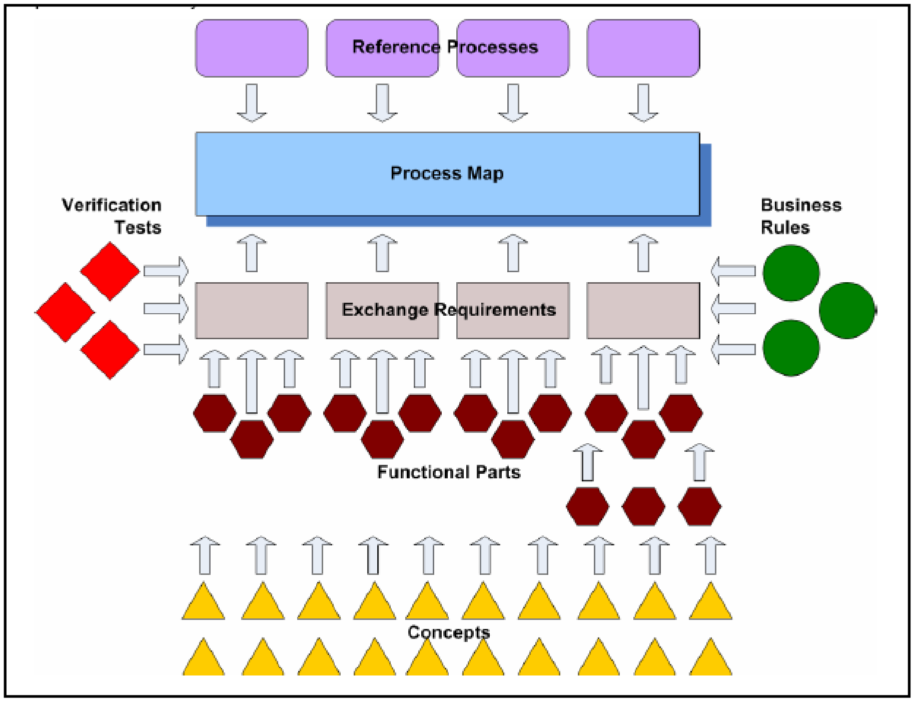

Figure **3-7**: IDM technical architecture (Wix 2007)

The three main components of an IDM are Process Map (PM), Exchange Requirements (ER) and Functional Parts (FP), refer to Figure 3-7. 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 3-8 for a sample PM for Electrical Engineering.

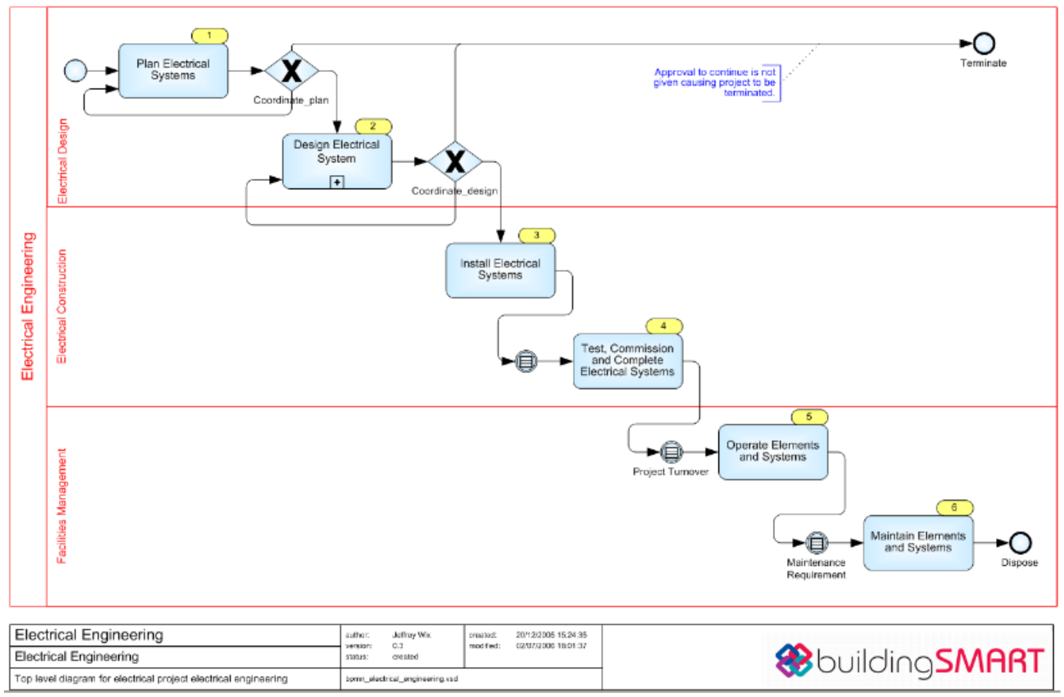

Figure **3-8**: PM for the business process: Electrical Engineering[4].

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):

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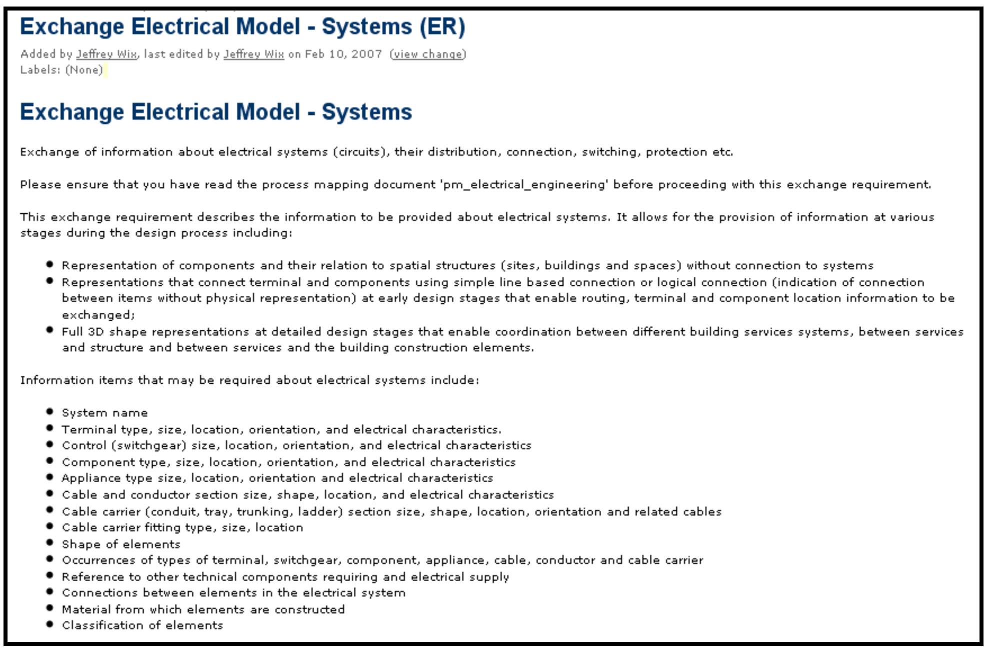
[4] For a complete reference to the available PMs within the IDM, please refer to http://idm.buildingsmart.no/confluence/dashboard.action

- 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 3-9.



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 **3-9**: 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[5].

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

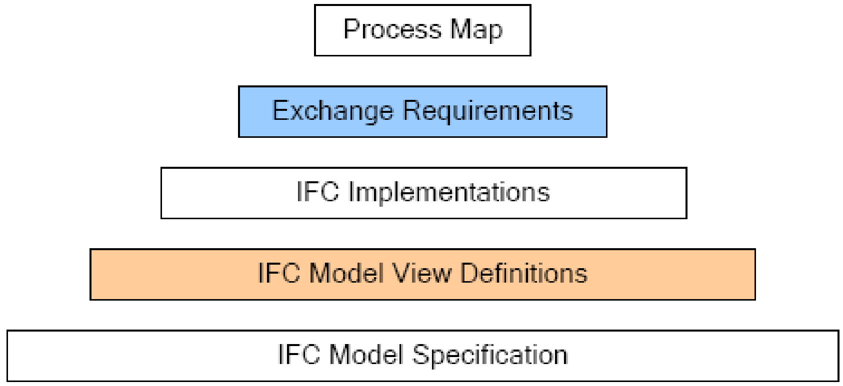


Figure **3-10**: IDM/MVD interoperability frame (Hietanen 2006).

Figure 3-10 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 Execution Guide for BIM

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.

3.5.1 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 and Muncey 2008).

3.5.2 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 3-11 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 **3-11**: Model Element Table (American Institute of Architects 2008).

3.5.3 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).

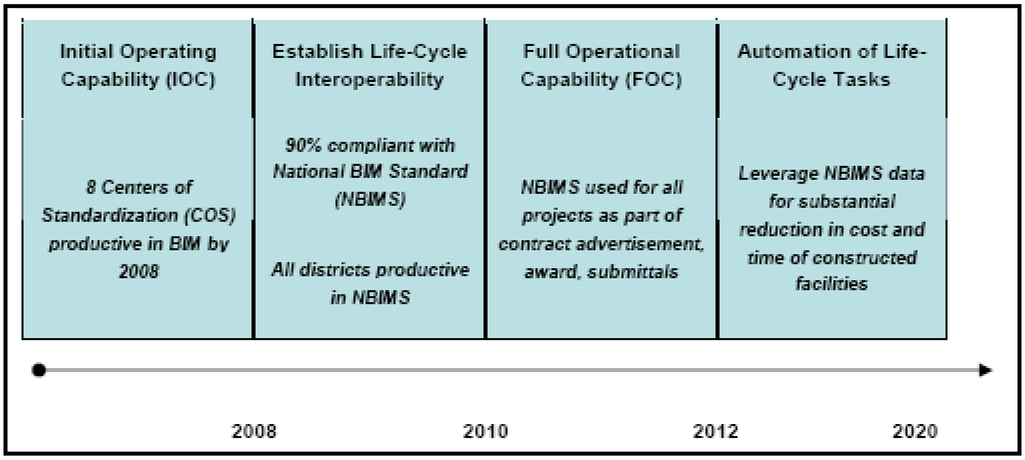


Figure **3-12**: Long term strategic goals for BIM (Brucker et al. 2006).

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 3-12). 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.

3.6 Chapter Summary

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.

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.

Chapter 4

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.

4.1 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.

4.2 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). A brief introduction of BPMN is contained in Chapter 3.

4.2.1 Key Process Mapping Elements

The key elements 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.

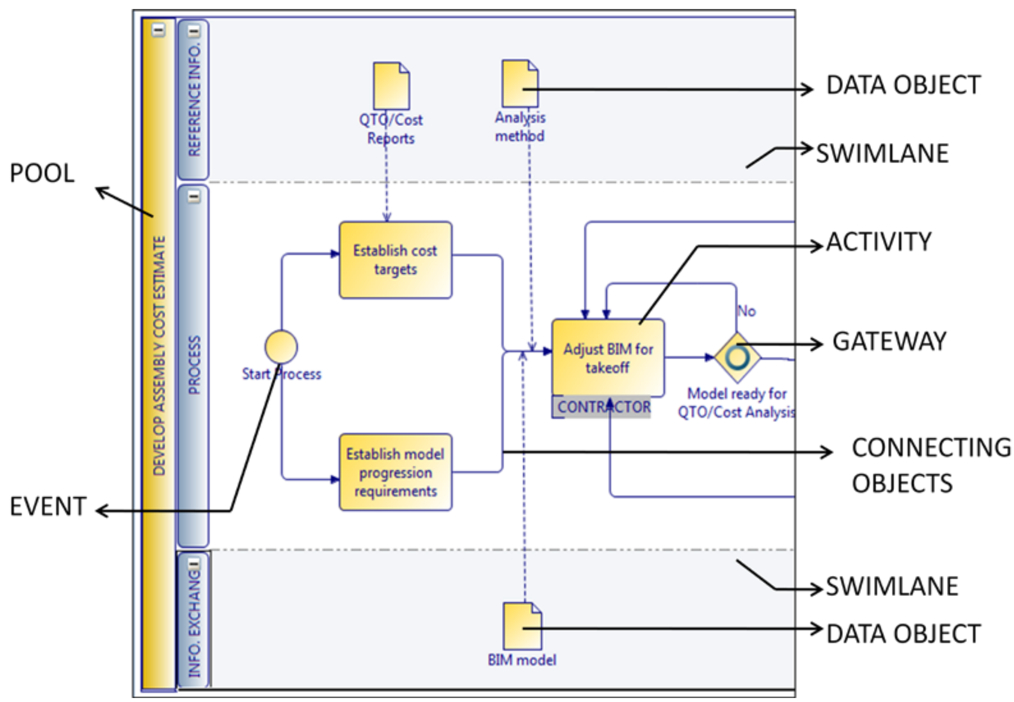


Figure **4-1**: Key process mapping objects

4.2.2 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 the section 4.3.
- *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.*

4.2.3 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 4-2 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.

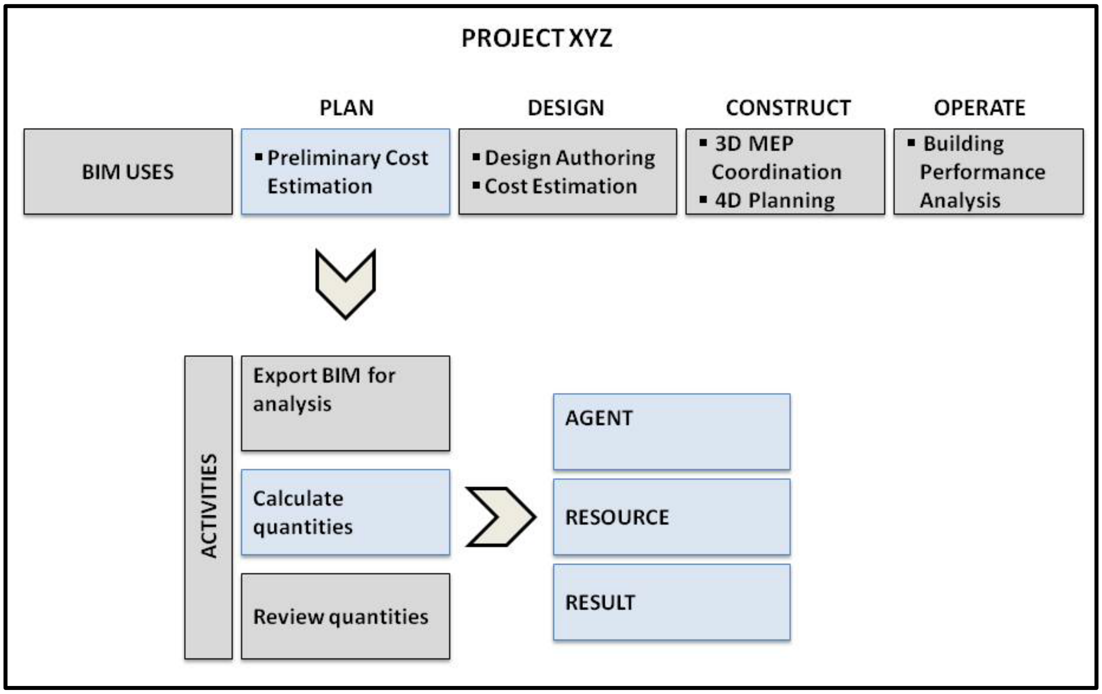


Figure **4-2**: Strategy to develop a process map for a BIM Use

4.2.4 Planning the Information Requirements for an Activity

To plan each activity of a BIM Use the following information is required; refer to Figure 4-3:

- 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.

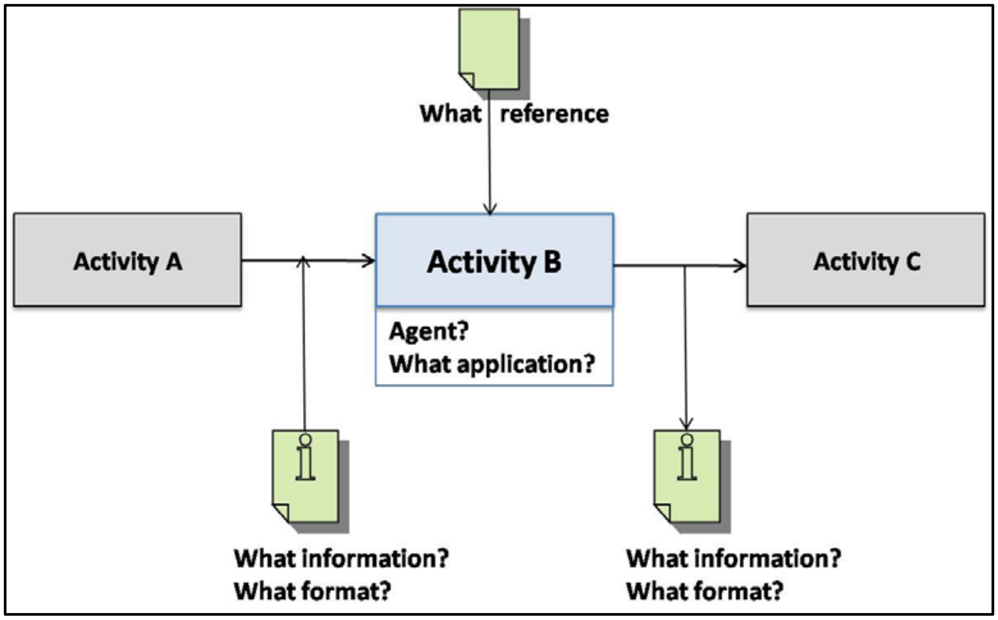


Figure **4-3**: Planning the information requirements for an activity

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.

4.2.5 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 4-4.

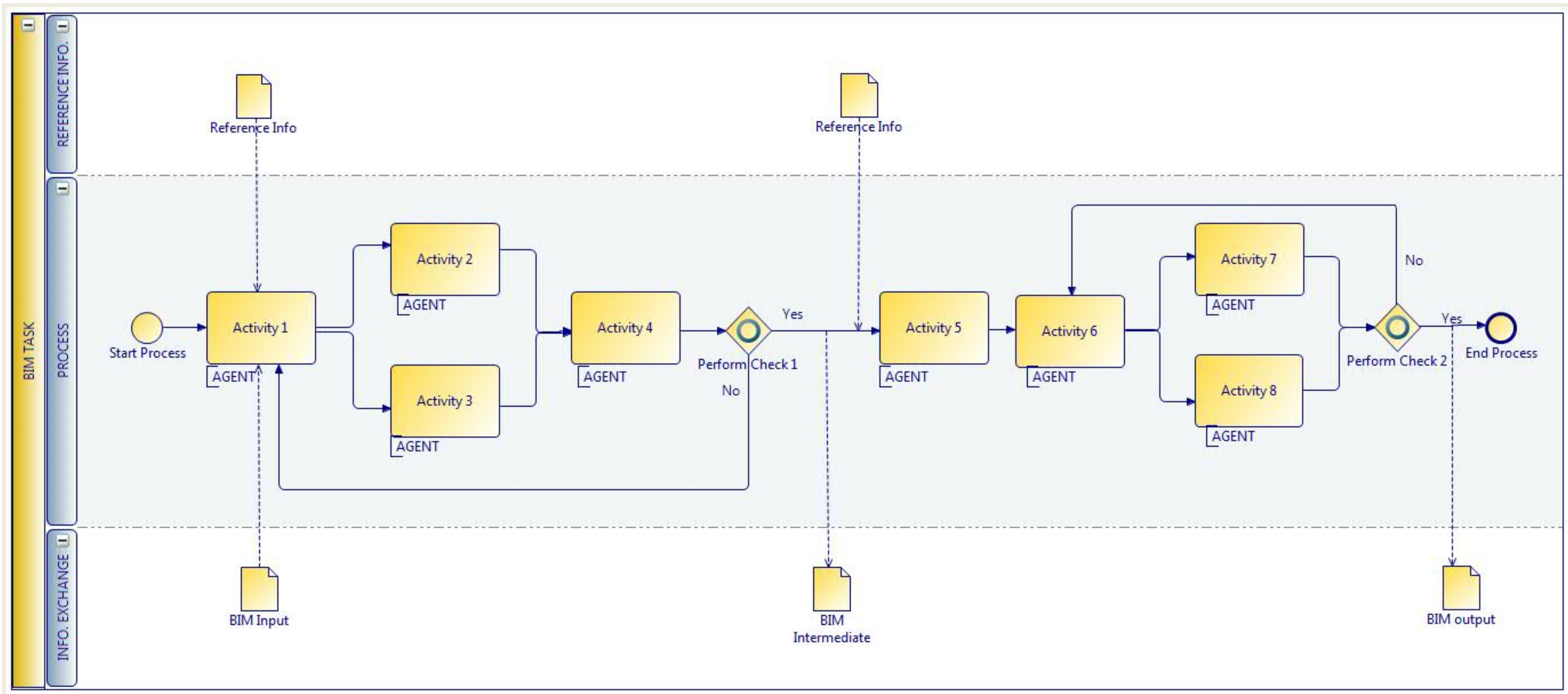


Figure **4-4**: Process Mapping Procedure represented in BPMN format.

4.2.6 Process Mapping Representation in BPMN format

A template PM for a BIM Use, as shown in the Figure 4-5, 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.

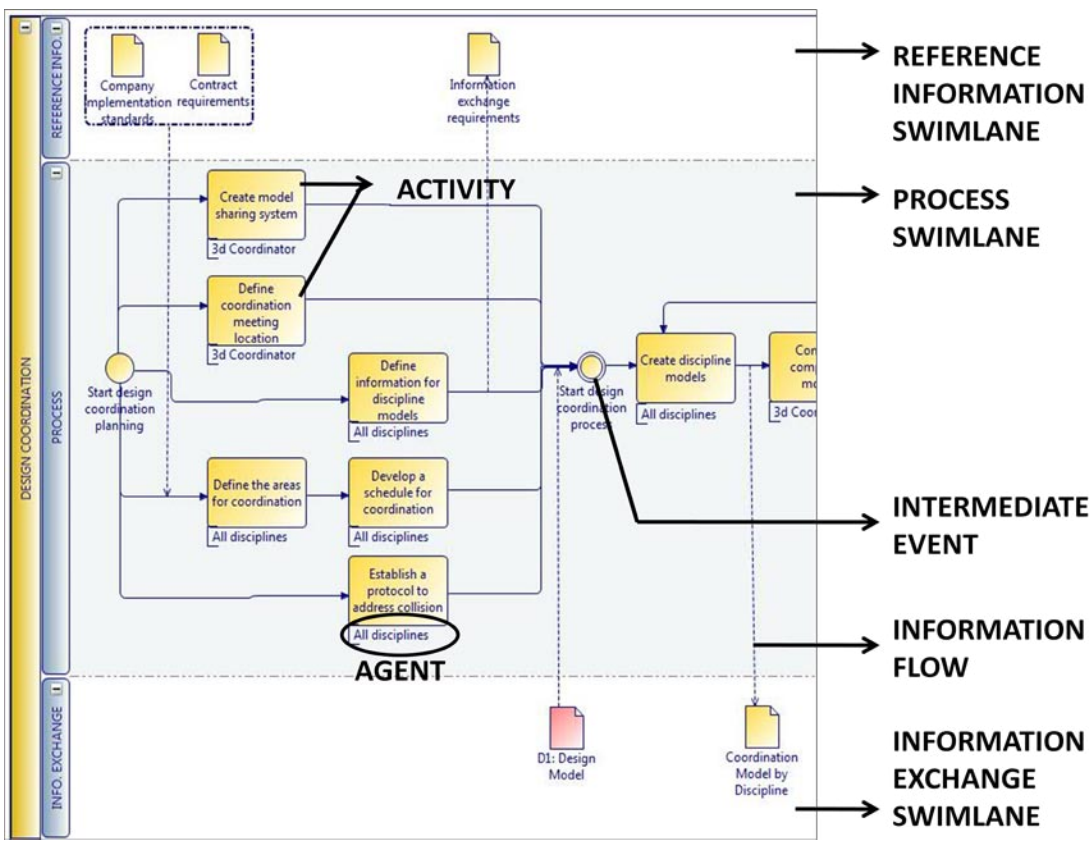


Figure **4-5**: Terminology used for BIM process mapping (adopted from BPMN)

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 4-6. All the other PMs are included in Appendix A.

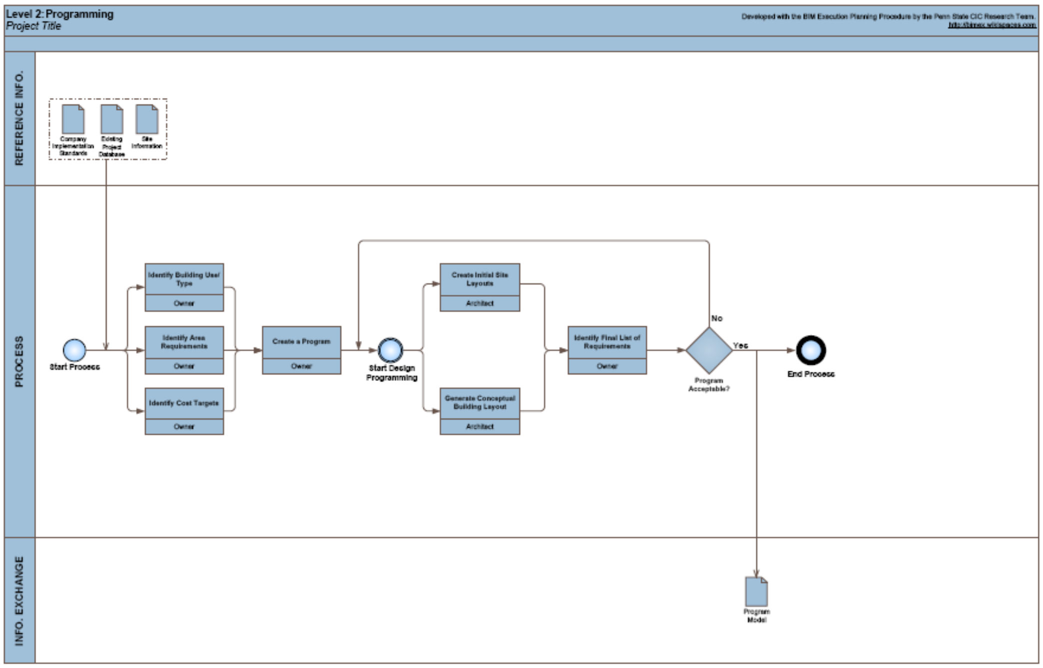


Figure **4-6**: Template process map for Programming

4.2.7 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 4-7.

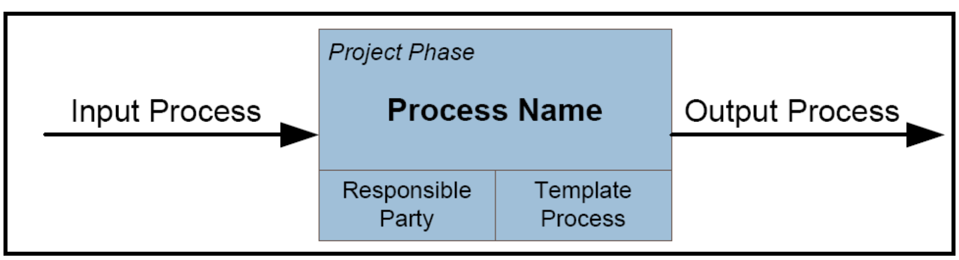


Figure **4-7**: Information required to create a BIM Overview Map

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 4-8. 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.

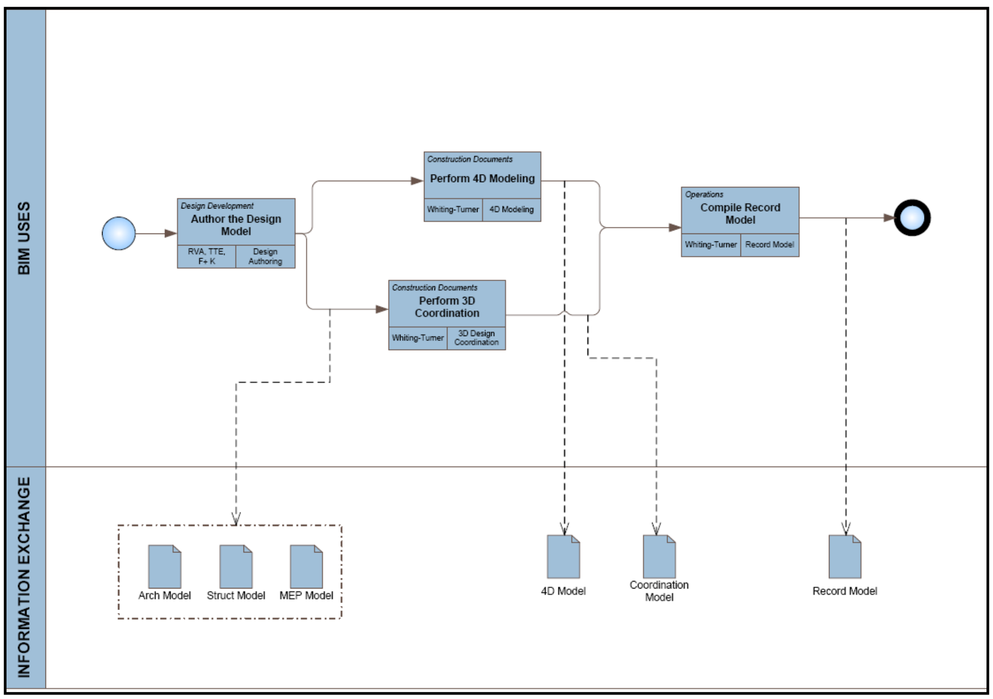


Figure **4-8**: Sample BIM Overview Map

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. To assist in the creation of the project maps, a Process Mapping Procedure has been provided in Section 4.2.5. 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.

For a project, the Detailed BIM Use Maps should be developed for each of the BIM Uses defined in the Overview Map.

4.3 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 a '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.

4.3.1 IE 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 4-1.

Table **4-1**: 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 4-2.

Table **4-2**: Legend for Responsible Party.

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 referred.

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 interoperablity 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 the Appendix B.

4.3.2 Structure of the IE

In the IE template worksheet (refer to Figure 4- 9), 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 **4-9**: Structure of the Information Exchange

4.3.3 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.

4.4 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 5

Assessing the BIM Process Mapping Procedure

This chapter presents the evaluation method for assessing the procedure developed for creating the process maps (PMs). The data and the data collection processes are described in this chapter. The data collection was based mainly upon the quasi-experiments conducted at the Pennsylvania State University. Content analysis of the maps produced also provided valuable data regarding the gaps in the procedure. The results of the questionnaire surveys and the content analysis are discussed in this chapter.

5.1 Process Mapping Task

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.

5.1.1 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, refer to Appendix C.

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.

5.1.2 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 survey is included in Appendix C.

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.

5.1.3 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.

5.2 Process Mapping Outcomes and Analysis

5.2.1 Questionnaire Survey

This section shows a selection of the results of the questionnaire responses to the quasi-experiment performed. A copy of the questionnaire survey and the detailed results is attached as Appendix C. 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 (Figure5-1). 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 5-2, 5-3, and 5-4). 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 5-5). However, some of the students were unsure if the swimlanes helped them in understanding the task (Figure 5-6).

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 hrs per participant.

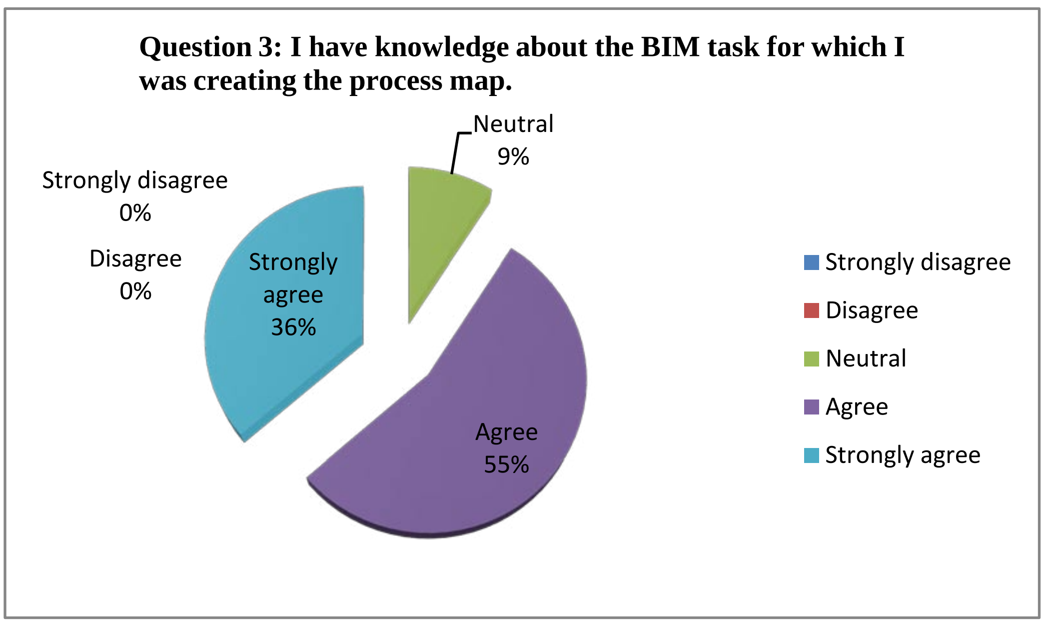


Figure **5-1**: Knowledge about the BIM task

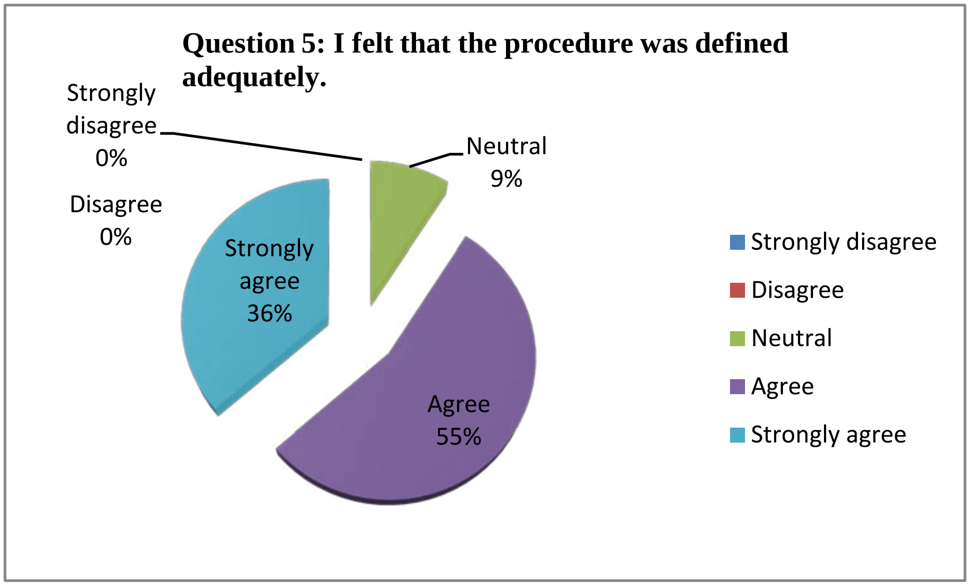


Figure **5-2**: Procedure was defined adequately

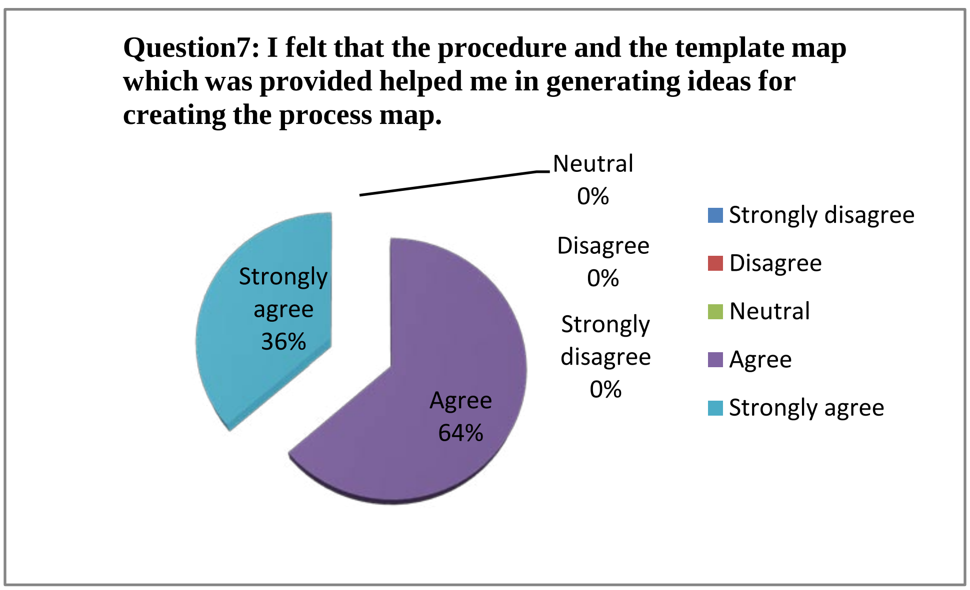


Figure **5-3**: Generating ideas for creating a process map

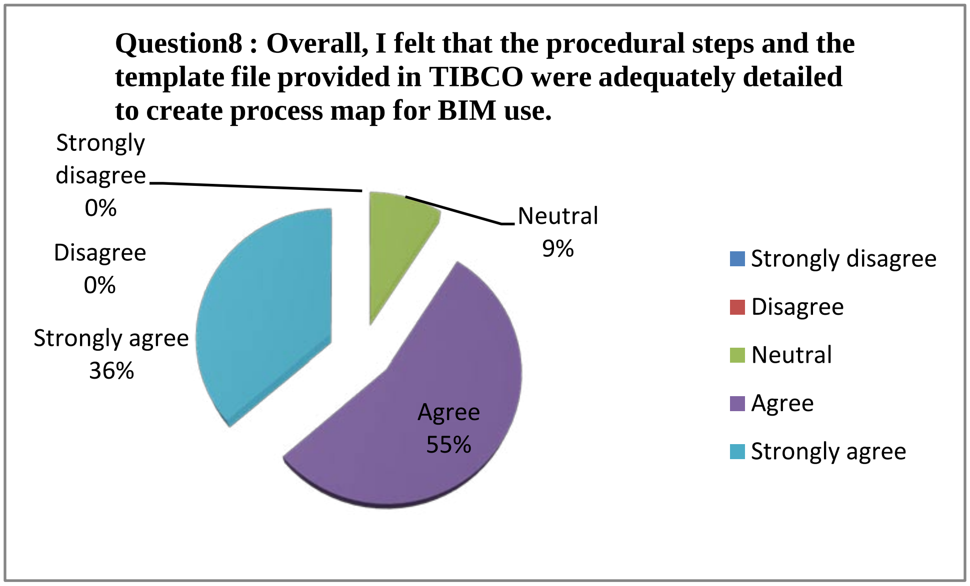


Figure **5-4**: Creating a process map from the procedure and the template file

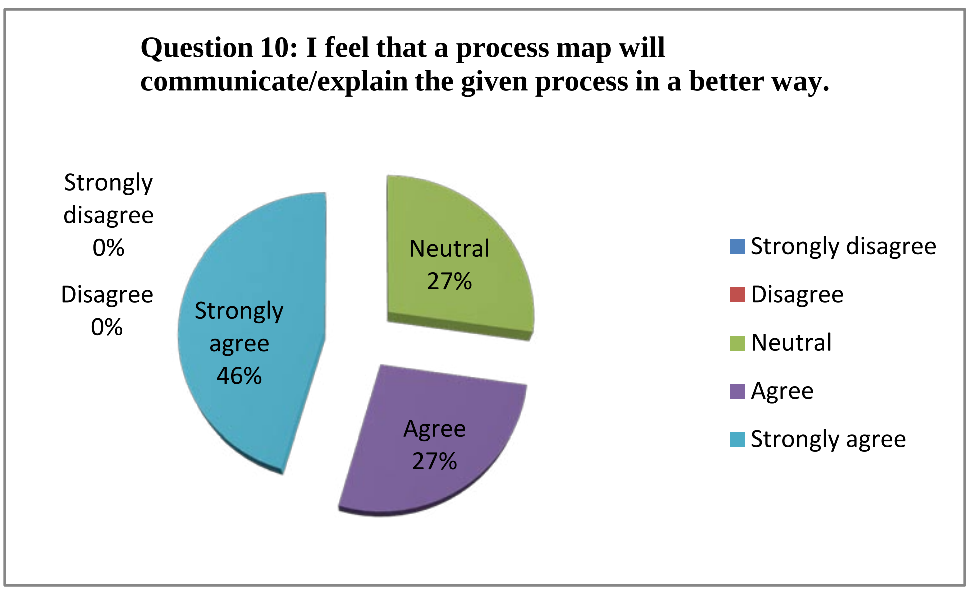


Figure **5-5**: Communicate the process

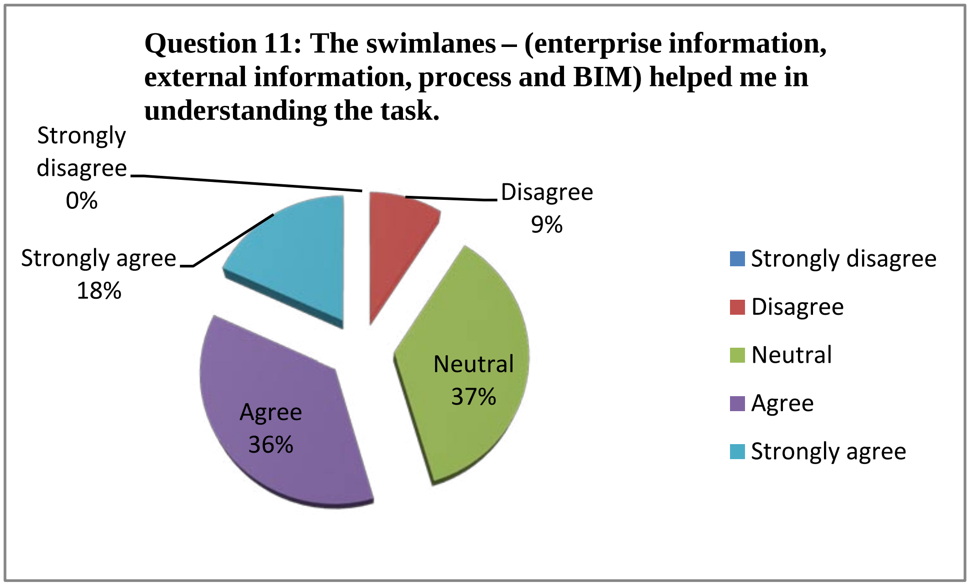


Figure **5-6**: Swimlanes

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."

5.2.2 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 (Refer to Figure 5-7, 5-13, 5-14, 5-15, 5-16).
- Information not placed in the correct swimlane (Refer to Figure 5-8, 5-9, 5-10, 5-14).
- The information displayed is not appropriately detailed (Refer to Figure 5-11, 5-12).
- The template maps not having an expected format (Refer to Figure 5-14, 5-15, 5-16).

In Figure 5-7, 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.

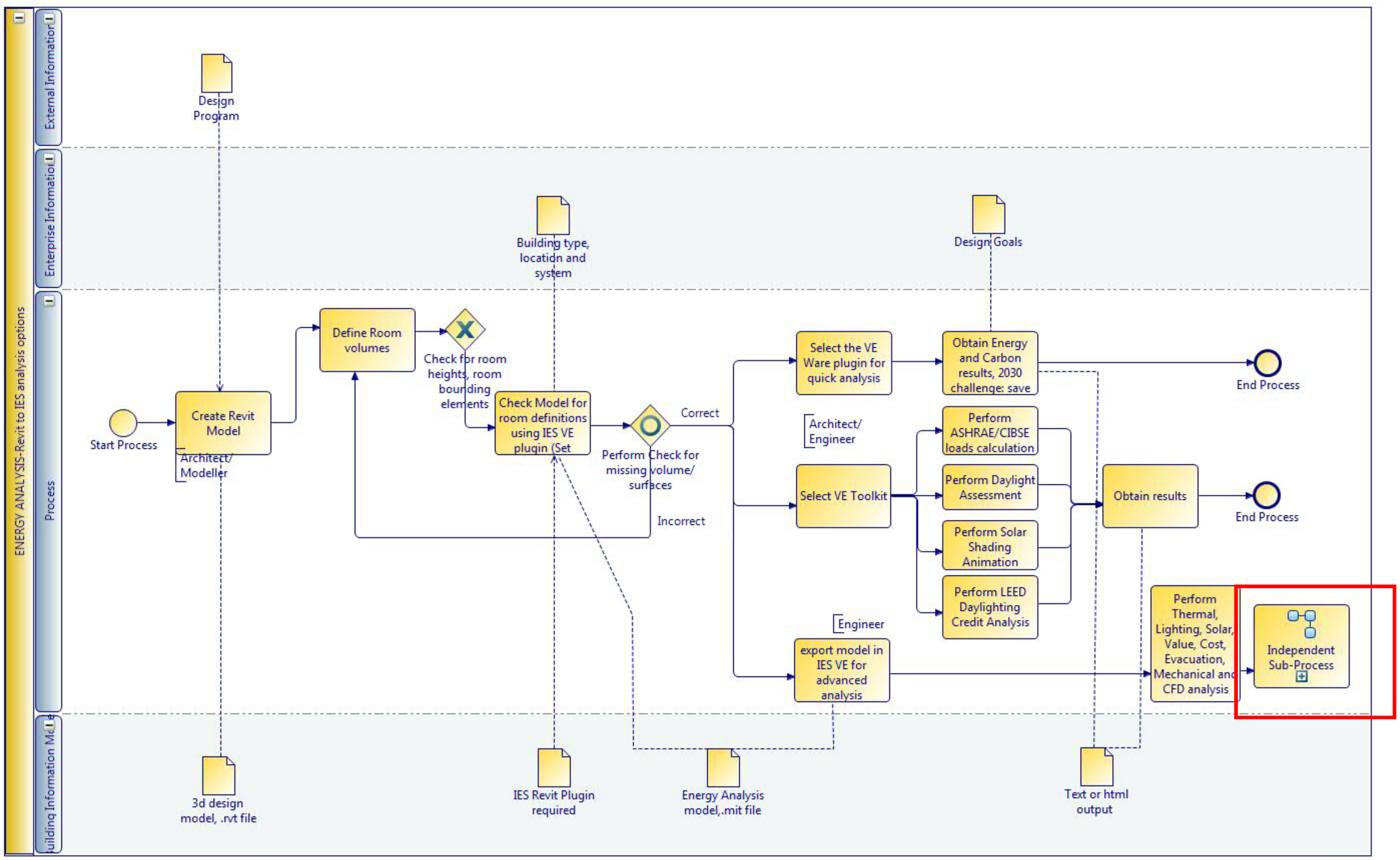


Figure **5-7**: The process map must have an end process to symbolize the end event.

Embedded sub-process is not a part of the template map provided (refer to Figure 5-8 and Figure 5-9). If there is information that has to be represented in the process map, it should be included in the 'Reference Information' swimlane.

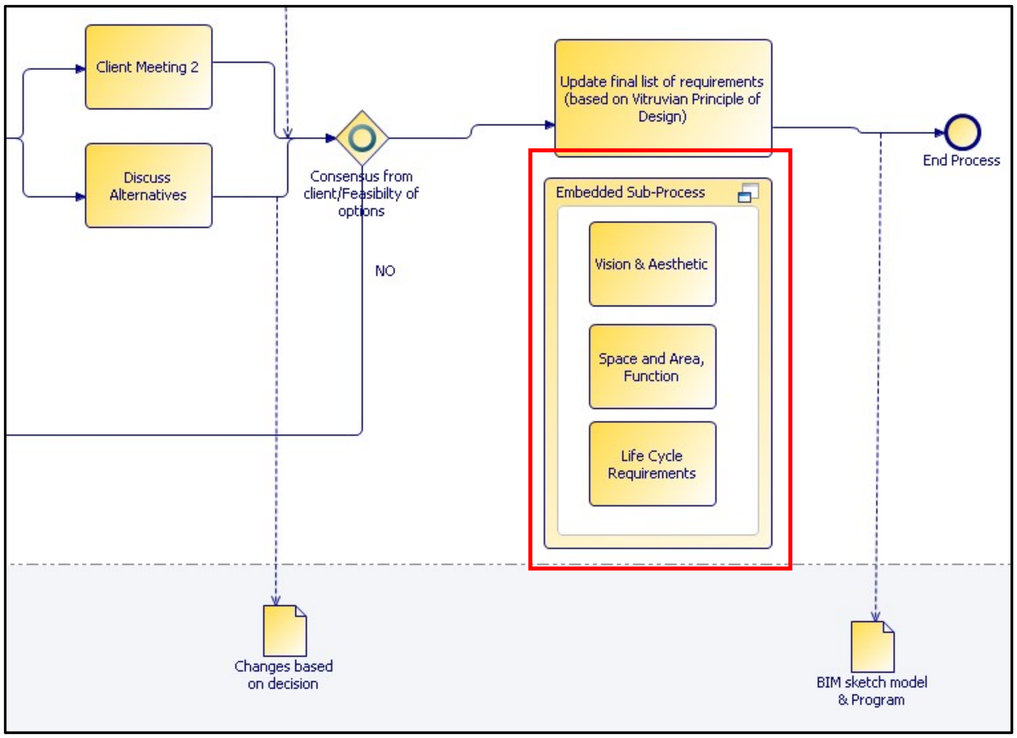


Figure **5-8**: Embedded process should not be used as part of template map

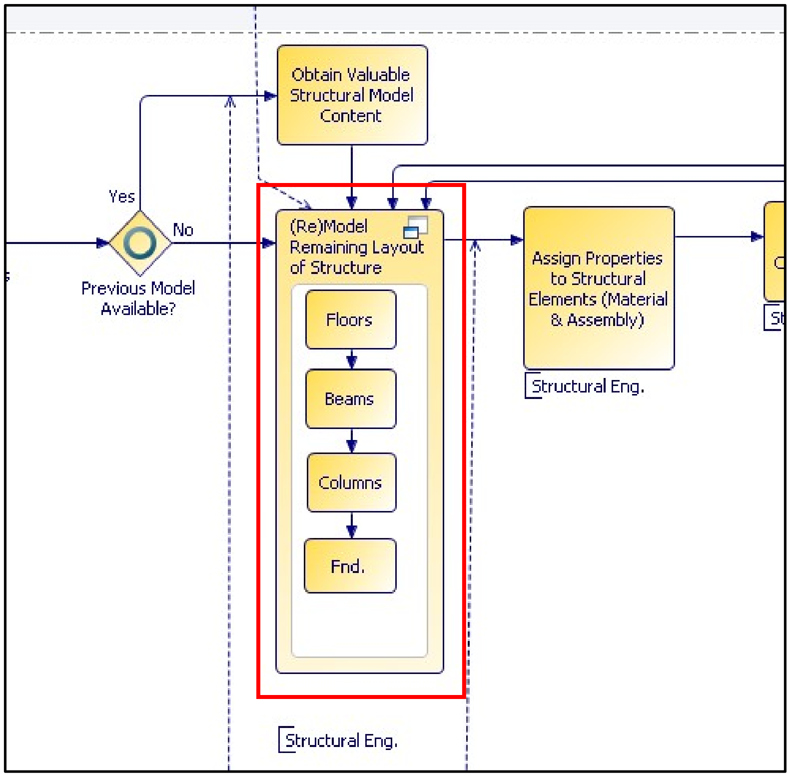


Figure **5-9**: Incorrect use of embedded process

In Figure 5-10, ‘Verify tolerances’ is an activity and should be a part of the ‘Process’ swimlane instead of being included in the ‘Reference Information’ swimlane.

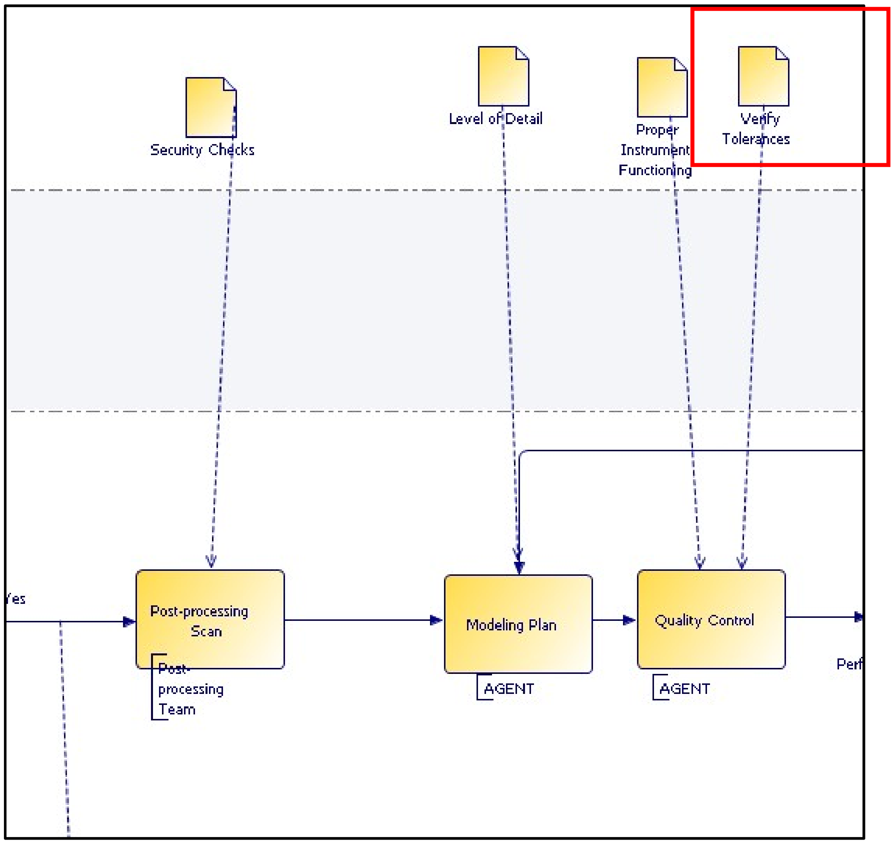


Figure **5-10**: Incorrect use of swimlane

The information represented in a PM should be adequately detailed for others to understand. In Figure 5-11, 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.

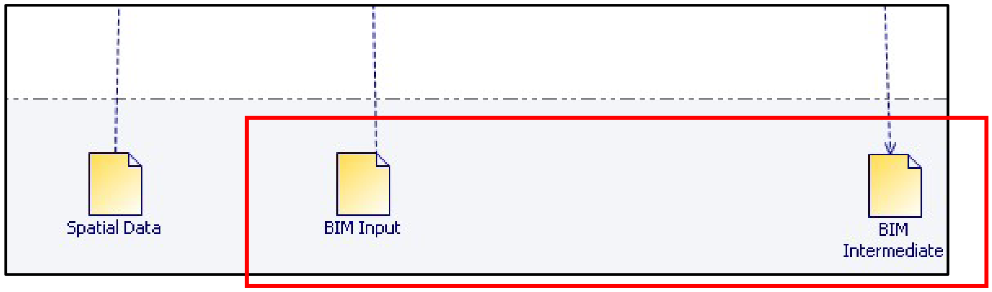


Figure **5-11**: The level of detail of the BIM deliverable is not appropriate

In Figure 5-12, it is unclear what information architect or the contractor is providing.

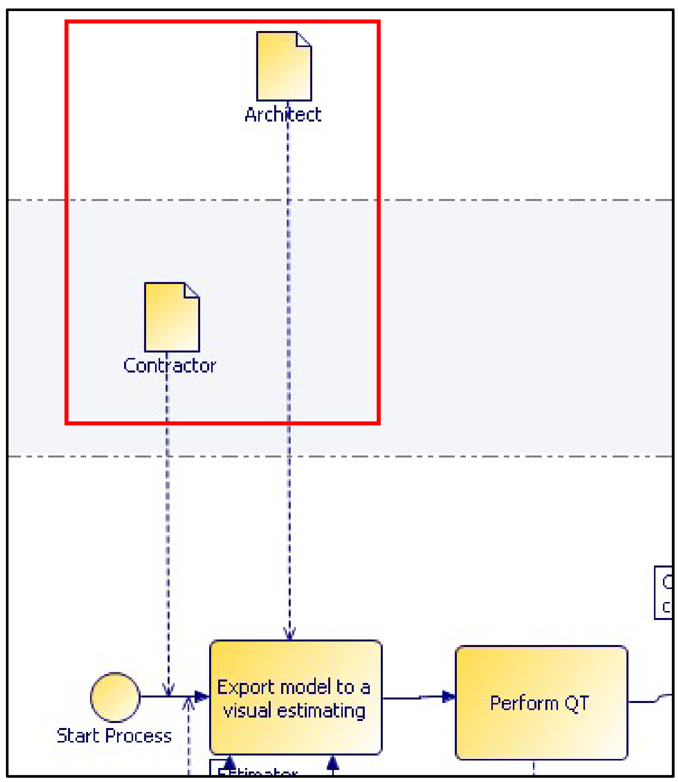


Figure **5-12**: The reference information has to be detailed

As seen in Figure 5-13, 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.

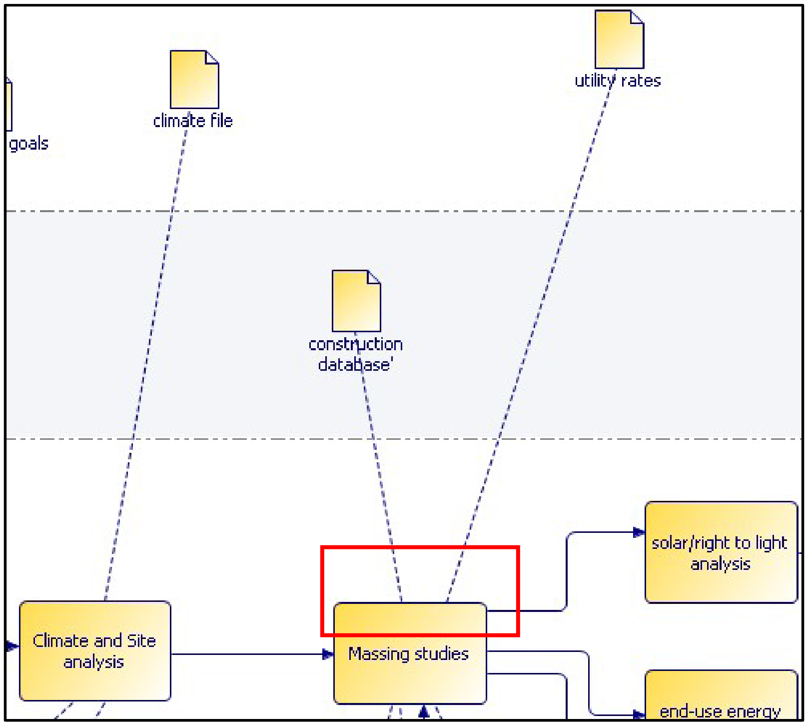


Figure **5-13**: Information flow missing

A BIM deliverable cannot convert to another BIM deliverable in the ‘Information Exchange’ swimlane (refer to Figure 5-14). There needs to be an appropriate process to occur for such a transformation.

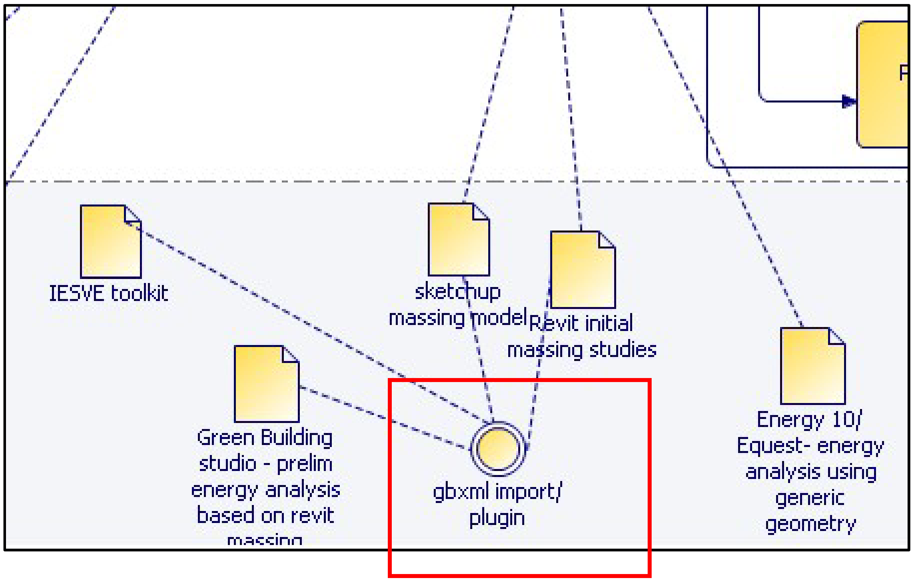


Figure **5-14**: Incorrect use of intermediate event

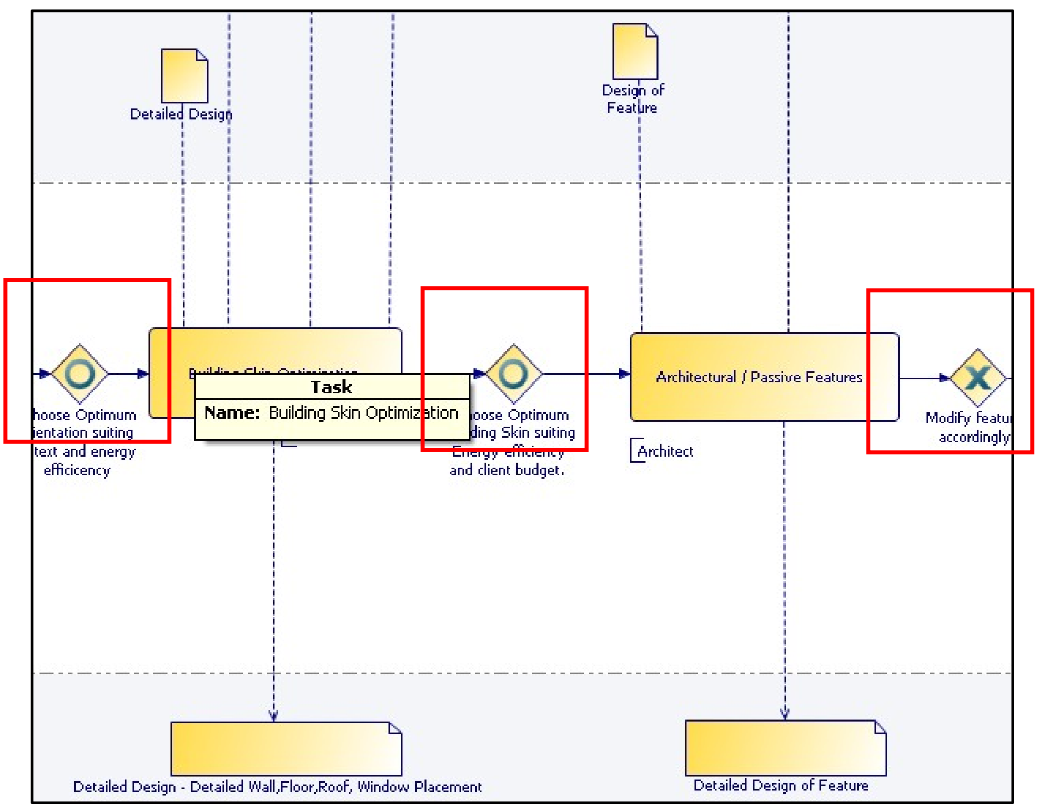


Figure **5-15**: Incorrect use of symbols

In Figure 5-15, a decision making symbol should be followed by a minimum of two choices to demonstrate that there is an either/or situation.

In Figure 5-16, 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.

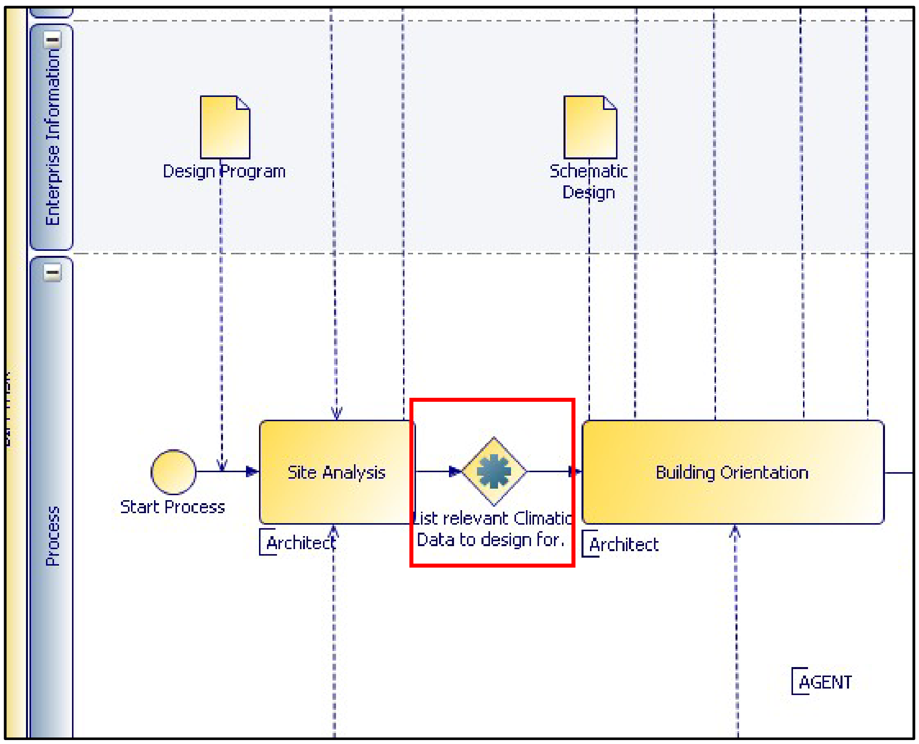


Figure **5-16**: Incorrect use of symbols

5.3 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' swimlane. 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 6

Case Study Evaluation

This chapter introduces the case study project used in this study. The latter part of the chapter discusses the project Process Maps (PMs) and the Information Exchanges (IEs) developed for the project. The goal of the case study was to validate the BIM Project Execution Planning Procedure through the mapping of a project which is using BIM for defined purposes.

6.1 Millennium Science Complex Project Overview

The study focuses on the BIM implementation for Penn State’s new Millennium Science Complex (MSC), a state of the art research facility for interdisciplinary research between the Life Sciences and the Material Sciences faculty and students. The Millennium Science Complex will include a western wing for life sciences and a northern wing for materials sciences. The structure will cantilever over a new plaza and garden at the intersection of the wings, one of the building's signature features (Penn State Live 2008). Also, aligning with the University's environmental initiatives and aiding in achieving LEED certification (Leadership in Energy and Environmental Design), green roofs will be used to reduce storm water runoff while enhancing energy efficiency.

This project, a new 275,600 square foot facility, will house laboratories, office and support spaces. The building is currently under construction at the University Park Campus and is scheduled for completion in the summer of 2011.

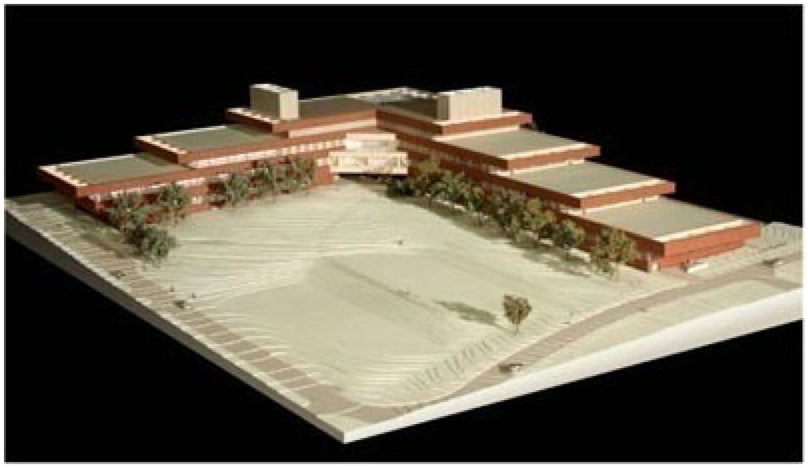


Figure **6-1**: Image of the model of the Millennium Science Complex project (Source: http://www.opp.psu.edu/planning-construction/projects/Millennium_Science_Complex)

6.1.1 Project Organization

The building was designed by Rafael Viñoly Architects and Thornton Tomasetti Engineers for The Pennsylvania State University; and the general contractor is Whiting-Turner Contracting Company. Detailed guidelines were created to pre-qualify mechanical, electrical, plumbing, fire protection, structural steel and building envelope subcontractors for their capabilities to collaborate using 3D tools. The guidelines included the ability to produce 3D content using software compatible with Revit 2009 and/or Navisworks. This was important because the structural steel design drawings provided by the A/E were in Revit 2009. The MEP/FP subcontractors selected for this project include Farfield (HVAC), Herre and McClure (Plumbing), Biter (Electrical), Kinsley (Structural Steel), and Comunale (Fire protection).

6.1.2 MSC Project BIM goals

The MSC project team is using BIM technology for envelope and MEP coordination and 4D automated scheduling. The project team is currently also investigating the delivery of a digital as-built record model to Penn State for facility maintenance, but precise details still need to be defined.

6.1.3 Modeling Responsibilities

The architect, structural engineer and mechanical engineer were responsible for providing the 3D model for the architectural, structural and mechanical scope of work. The subcontractors used this content as a reference to model their scope of work. The General Contractor was responsible for coordinating the MEP and envelope design process, as well as coordinating an installation sequence using 4D modeling. The design coordination process included conflict detection and a conflict resolution process.

In line with the project goals of reducing waste processes; duplication of work was avoided by using the 3D models created by the subcontractors to develop a fully coordinated MEP model that could be used for fabrication and construction. Table 6-1 shows the modeling responsibilities for the MSC project.

Table **6-1:** Modeling Responsibilities for the MSC Project

Company	**Role**	**Modeling Responsibility**	**3D Software (for design authoring)**
Rafael Viñoly Architects	Architect	Architectural model in 3D including interior partition, ceiling and lab casework models.	Revit Architecture 2009
Thornton Tomasetti Engineers	Structural Engineers	Structural model in 3D	Revit 2009
Flack + Kurtz	Mechanical Engineers	Preliminary model of penthouse and shaft.	Revit MEP 2009
Kinsley	Steel Subcontractors	Create 3D steel shop drawing model	SDS2
High Concrete Group	Concrete Cladding Contractor	Create 3D precast model	Tekla Structures
Whiting Turner	General Contractor	3D architectural model design updates	Revit Architecture 2009 and 2010
Farfield	Mechanical Subcontractor	HVAC piping, ductwork and equipment model	
Herre Brothers	Plumbing Subcontractor		
Biter	Electrical Subcontractor		
Comunale	Fire Protection Subcontractor		
Logical Automation	Controls		
McClure	Plumbing Subcontractor	Underground plumbing model	
L S Fiore	Drywall Subcontractor	Create 3D model of the interior partitions and ceiling, focusing on structural framing and supports such king studs, kickers, braces, wires etc.	Revit Architecture 2010
Fisher Scientific	Lab Casework Subcontractor	In-wall strapping and accurate location for all laboratory equipment and support	Revit Architecture 2010
D-M Products	Curtain Wall Contractor	Curtain wall design	AutoCAD 3D
EPI	Miscellaneous Steel Subcontractor	3D miscellaneous metal design	Revit Architecture 2010
Mohawk	Metal Panel	Metal Panel design in 3D	Revit Architecture 2010

6.1.4 Data Collection

The researcher attended about ten/twelve of the weekly design coordination meetings starting from the BIM coordination kickoff meeting held in the last week of April 2009. The BIM coordinator for the MSC project also made the necessary documentation available for the case study. Most of the data was collected through the discussions during the coordination meetings and the available documentation.

6.1.5 Data Analysis

The collected data was methodologically analyzed and linked to the BIM Project Execution Planning Procedure to produce a set of PMs and corresponding IEs. This documentation was later approved by the project manager for the interpretation and accuracy.

The MSC project was the first project on which the BIM Project Execution Planning Procedure was tested. The approach taken here was to historically map the collected data and produce a BIM implementation plan using the BIM Project Execution Planning Procedure. The aim was to:

- Validate if all the relevant BIM issues were addressed in the BIM Project Execution Planning Procedure;
- Create project PMs using the template maps and the process mapping procedure discussed in Chapter 4; and
- Map information exchanges for BIM deliverables using the IE template discussed in Chapter 4.

The next section elaborates on the MSC BIM Project Execution Planning Process.

6.2 MSC BIM Project Execution Planning Process

The BIM Project Execution Planning Procedure[6] is a structured method for a project team to design the execution strategy for BIM on a project. This procedure includes four main steps. These steps are:

1. Identify BIM goals and uses
2. Design BIM project execution process
3. Develop information exchanges
4. Define supporting infrastructure for BIM implementation

The scope of this study includes documentation for step 2 and 3 in detail.

6.2.1 Identify BIM Goals and Uses

The project team of the Millennium Science Complex was already far along in the delivery process when the Penn State team joined to develop an execution plan. Table 6-2 identifies the BIM Uses which the project team and the owner had already selected, and the responsible party leading that BIM Use.

Table **6-2**: Identify BIM Uses

BIM Uses	Responsible Party	Identified BIM Deliverable
Design Authoring	Rafeal Viñoly Architects Thornton Tomasetti Engineers Flack + Kurtz	Architecture Model Structural Model Mechanical Model
3D MEP Coordination	Whiting Turner	Coordination Model
4D Modeling	Whiting Turner	4D Model
Record Modeling	Whiting Turner	Record Model

[6] For a detailed description of BIM Project Execution Planning Process, please refer the website: http://www.engr.psu.edu/ae/cic/BIMEx/

6.2.2 Design BIM Project Execution Process

6.2.2.1 MSC Project: Level 1 Process Map

The Level 1 map, refer to Figure 6-2, defines the overall BIM Uses that have been employed for the project, which are 4D modeling, 3D MEP coordination and record modeling. The responsible parties for Design Authoring were Rafeal Viñoly Architects, Thornton Tomasetti Engineers, and Flack + Kurtz who were responsible for Architecture Model, Structural Model, and Mechanical Model Information Exchanges respectively.

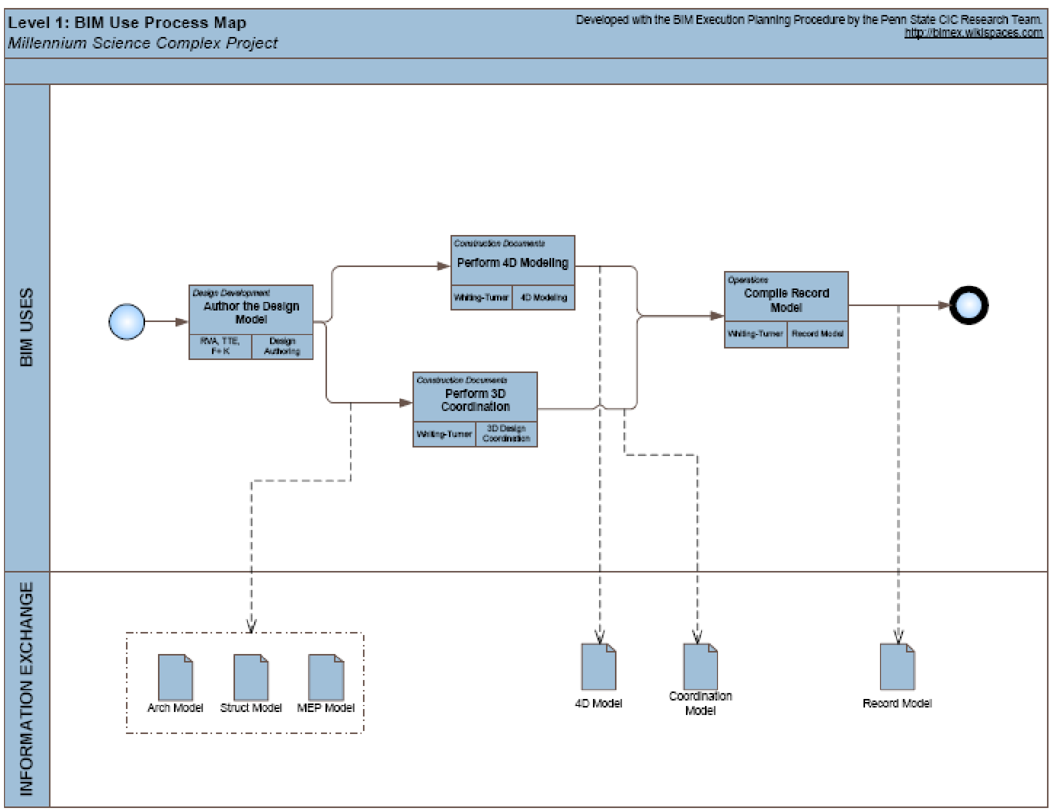


Figure **6-2**: MSC Project Level 1 BIM Overview Map

6.2.2.2 Level 2 Detailed BIM Use Process Maps

Detailed BIM Use PMs must be created for each identified BIM Use on the project to clearly define the sequence of the various activities to be performed. For this case study project, the Detailed BIM Use PMs were created for design authoring, 4D modeling, 3D design coordination and record modeling, refer to Appendix D.

6.2.3 Develop Information Exchanges

In this step, the project team identifies the modeling requirements, responsible parties, and schedule for the information exchanges identified in the BIM Overview Map.

The process of creating the MSC project Information Exchange worksheet was to accurately fill out the IE template defined in Chapter 4. The objective was to map the information content and grouping requirements as it was delivered on the project. The following Information Exchanges were, thus, detailed for the respective BIM uses:

- Design Authoring: Architecture Model, Structural Model, Mechanical Model
- Design Coordination: Coordination Model
- 4D modeling: 4D Model
- Record Modeling: Record Model

The MSC Project IE worksheet can be referred in Appendix D.

6.2.4 Define Supporting Infrastructure for BIM Implementation

As part of the BIM Execution Planning Procedure, this step aims to open discussion in the following four major areas:

1. Delivery strategy/contract
2. Communication procedures
3. Technology infrastructure needs
4. Model quality control procedure

Since, the objective of the case study project was to validate the process mapping technique and the IE worksheet, detailing this step was beyond the scope of this work.

6.3 MSC BIM Project Execution Assessment: Focus Group

The focus group discussion lasting one hour and a half produced good feedback on the different steps of the BIM Project Execution Planning Procedure, and the current implementation plan of the MSC project. Some of the important discussions topics are summarized below:

1. **What do you think of the BIM Project Execution Planning Procedure? Do you see yourself doing it?**

   One of the important strategies in creating a BIM Implementation Plan is to define the role and responsibility of the project team members upfront in the project. One of the suggestions was to add a 'mission statement' to the Implementation Plan to ensure that all parties are clearly aware of the opportunities and responsibilities associated with the incorporation of BIM into the project workflow. It was also discussed that it is critical to review this 'mission statement' at every step of the procedure to ensure that the process is being implemented as envisioned.

2. **Discussion on creating the BIM – PMs, the second step of the Procedure.**

It was discussed during the focus group meeting that for a project team with none/limited BIM experience, the map is extremely important because "you realize right away that the output of one is input to the other, so the downstream person is really the one defining what you should do. Although, this might get unreasonable quickly, so it is important to work with the architect and designers while they are developing the model." The PMs assist in creating this definition as a structured process.

The PM created for BIM Use 'Record Modeling' was utilized to understand the as-built model as a final output by the MSC project team. It was suggested that a record model is a compilation of information which has been collected throughout the delivery of construction.

3. Discussion on creating a BIM IE: the third step of the procedure.

The focus group participants were of an opinion that this step represents an opportunity where the teams can decide what information can be collected in a model. It was referred to as "a menu or shopping list". The participants displayed familiarity with the concept of IE, and discussed that the same topic was covered as a responsibility matrix in the current MSC VDC Plan. However, one of the suggestions was to look into AIA E202 document to compare if the information breakdown column could be completed using the Level of Detail guidelines. The reason mentioned was that a lot of people in the construction industry are getting fairly acquainted with the AIA's requirements. The challenge of the LOD, however is the melding of the geometric LOD with other attribute of data. For example, a LOD 100 or 200 does not clearly explain whether the "R Value" on a wall should be included in the energy model or not. The approach in the present

IE worksheet is to maintain the separation of geometric accuracy versus the attribute property of the information structure.

One of the other discussion points in regards to the IE was that it is essential to customize the Model Element Breakdown list on the left hand side depending on the complexity of the building, type of building and contracting structure.

4. How do you think the project contracting structure affects the BIM Implementation Plan?

The participants were of the opinion that it affects a great deal, "because the scope of works for the sub-contractor packages to fill in the gaps." It was noted that, "over the years the owners have leaned on designers to cut their fees or not raise the fees, and one of the ways is to convince the downstream guy to pick up some of the tasks. It is because of this reason that the designers submit more of a concept or diagrammatic drawings as opposed to a model which places a big burden on a contractor to model things to make sure that the ducts and pipes all fit."

5. How long does it take to create a BIM Implementation Plan? Who should take the lead in it?

Currently the contractors are extracting the ability to use a BIM model from what may be available but may not be passed on by the designers. In the case of MSC Project, the architect was not going to pass on the BIM model, which was used as a visualization tool. So, the team had to work to extract it from them. "If it's truly collaborative it'll happen in the beginning but we like to take the lead because we are looking both upstream and downstream and so we like to drive this. If the architect or the engineers decide that they are going to drive the bus, that'll work too as long as everybody works together. We are the guys driving hard to fit the schedule so we are kind of used to making these things happen so we'll step up."

6. **What are some lessons learned by the current implementation plan of the MSC?**

   "Our goal is that we are trying to be proactive with this because you don't want to hit a road block during construction which is incredibly expensive." Since contractually the parties are set up at arm's length to each other the BIM Execution Plan is seen as an opportunity to bridge this gap. However, it was discussed that initially it was difficult to get the model from the architect and the designer as it was viewed as their visualization tool which added a lot of burden on the contractors and subcontractors. One of the current problems that the contractor is facing is to establish the content of the record model which would be useful to the owner and the facility management team. It was also discussed that the more the project team meets, it is better for the process. Our goal is that we are trying to be proactive with this because you don't want to hit a road block during construction that's incredibly expensive."

Chapter 7

Conclusions

In this chapter, first a summary of the research is presented. This is followed by a description of the contributions and limitations of this research. Then several suggestions for future work in this area are provided. Concluding remarks are presented in the final section.

7.1 Research Summary

This research is a part of the BIM Project Execution Planning Procedure, developed through the buildingSMART alliance ™ project, a part of the National Institute of Building Sciences. 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 out the BIM execution strategy on a project. This project 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.

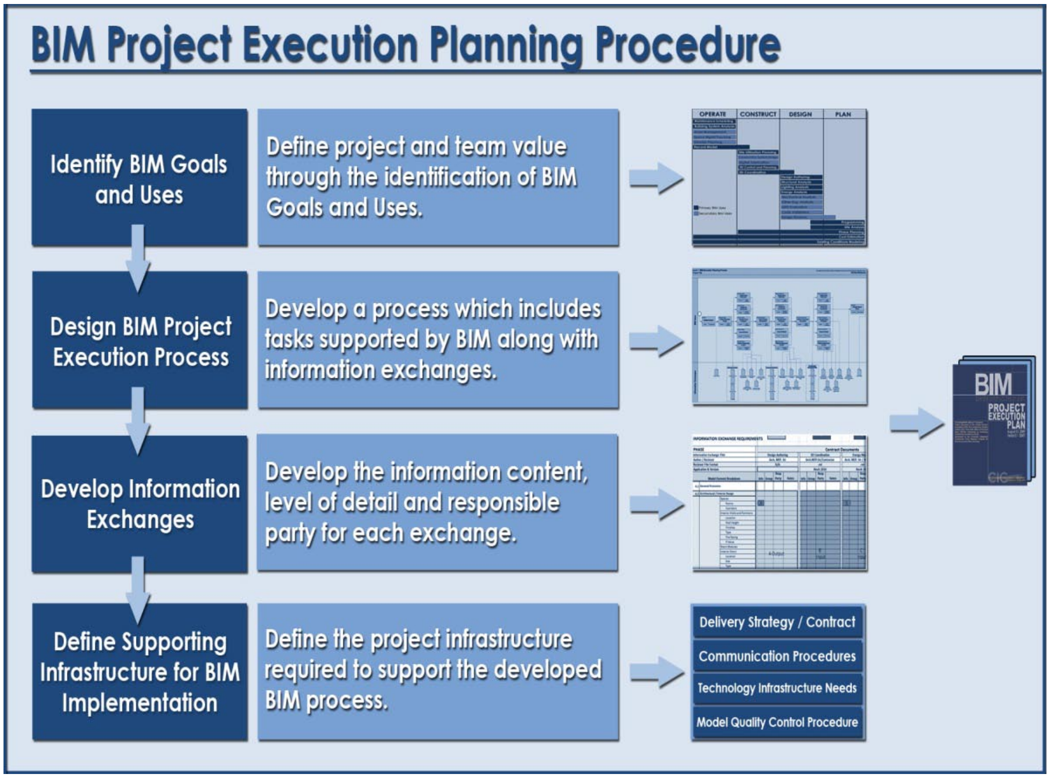


Figure **7-1**: The BIM Execution Planning Procedure (The Computer Integrated Construction Research Program 2009)

This thesis focuses on documenting the process mapping section of the project. A process mapping procedure has been created to assist the project teams to create Detailed BIM Process Maps for the identified BIM Uses. First, an Overview Map showing the relationship of BIM Uses is developed (see Figure 7-2). This Process Map (PM) also shows the information flow throughout the project lifecycle. Next, Detailed BIM Use PMs are created for each identified BIM Use to clearly define the sequence of various activities to be performed. These maps also identify the responsible parties for each activity, reference information content, and the information exchanges which will be created and shared with future projects. To assist in the creation of the detailed maps, template process maps have been created for the primary BIM Uses. It is realized 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 the project teams to achieve the project and company goals.

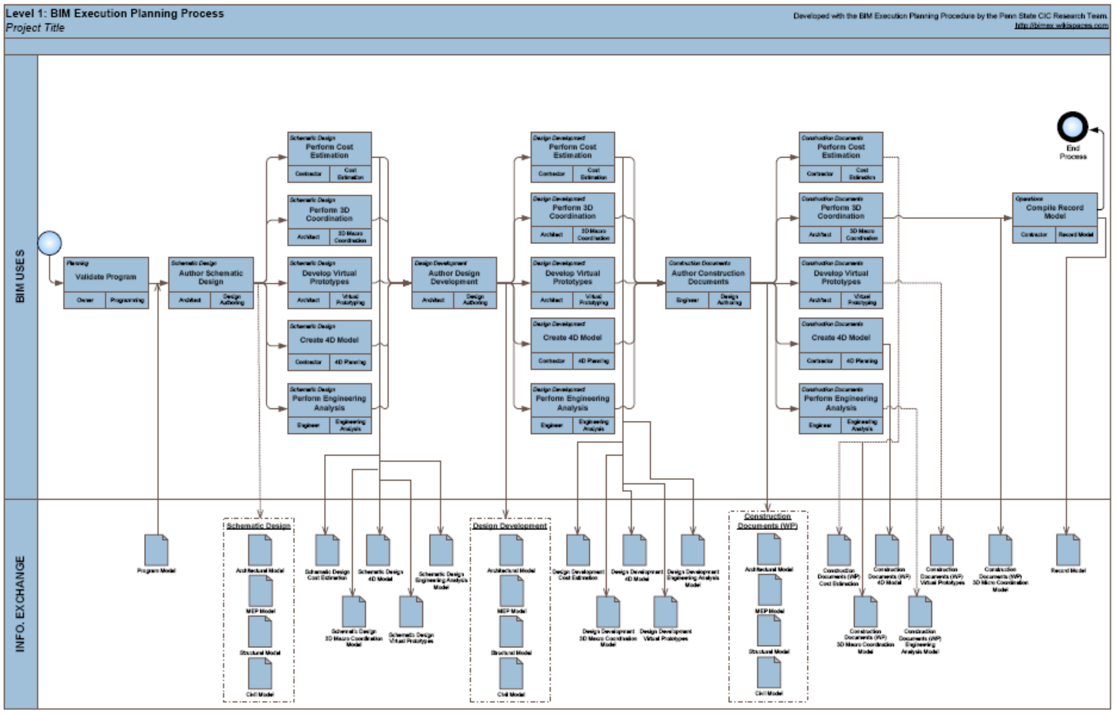


Figure **7-2**: Overview BIM Use Map

Further, a procedure has been defined to complete the Information Exchange (IE) worksheet. The IE worksheet (see Figure 7-3) has been developed to clearly identify the information exchanges which occur among the project participants. In defining these exchanges, the team should understand what information is necessary for the delivery of each BIM Use. A procedure to complete this template has been documented in this research.

INFORMATION EXCHANGE REQUIREMENTS									
Information Exchange Title	Information Exchange 1			Information Exchange 2			Information Exchange 3		
Time of Exchange (SD, DD, CD, Construction)									
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									

Figure **7-3**: Portion of the Information Exchange Worksheet

Quasi-experiments were conducted in which participants were asked to create a BIM Use PM using the developed Procedure. Perception surveys and content analysis were used to judge the value of process mapping, ease in creating a PM, and gaps in the Procedure. The survey results indicated that the participants agreed that the Process Mapping Procedure and the template file provided in TIBCO were adequately defined, and it assisted in generating ideas for creating the PMs. The majority of the participants also agreed that the PM will help in communicating a given BIM Use more efficiently than traditional means.

A case study evaluation on the Millennium Science Complex was also performed. PMs on the different BIM Uses were created along with the corresponding IEs. A focus group discussion with key project team members was performed to obtain valuable feedback on the Project Execution Planning Procedure. The focus group discussion indicated a comprehensive Procedure. PMs were seen to be useful for a team member who is not familiar with the BIM Process. In addition, it was also seen as a valuable activity to standardize the Process. The

Information Exchange worksheet was observed as an important task to increase the predictability of the BIM model.

7.2 Research Contribution

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

7.2.1 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.

7.2.2 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.

7.2.3 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.

7.2.4 Pilot Case Study for Project Execution Procedure for BIM

The goal of the case study was to validate the BIM Project Execution Planning Procedure through the mapping of a project which is using BIM for defined purposes. An Overview Map was created which showed the sequence and interaction between the BIM Uses. The project was implementing BIM for the following four tasks: Design Authoring, 3D Coordination, 4D Modeling and Record Model. A Detailed Project PM was created for each of these BIM Uses. IE worksheet was also developed which clearly identified the contents of the different BIM deliverables.

7.3 Limitations

7.3.1 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 multi phase 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.

7.3.2 Limited Case Study Applications

The research only utilized the Millennium Science Complex 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 creating PMs and IEs. Additional case studies will also help in analyzing possible gaps in the process mapping procedure.

7.3.3 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.

7.4 Future Work

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

7.4.1 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.

7.4.2 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.

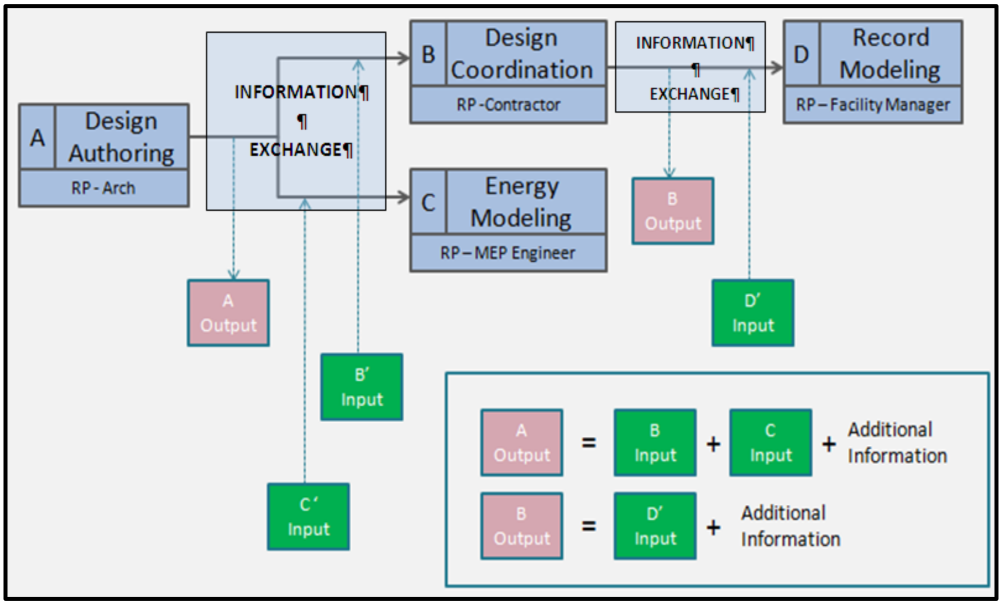


Figure **7-4**: Information Exchange concept

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 7-4). 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.

7.5 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 organization level.

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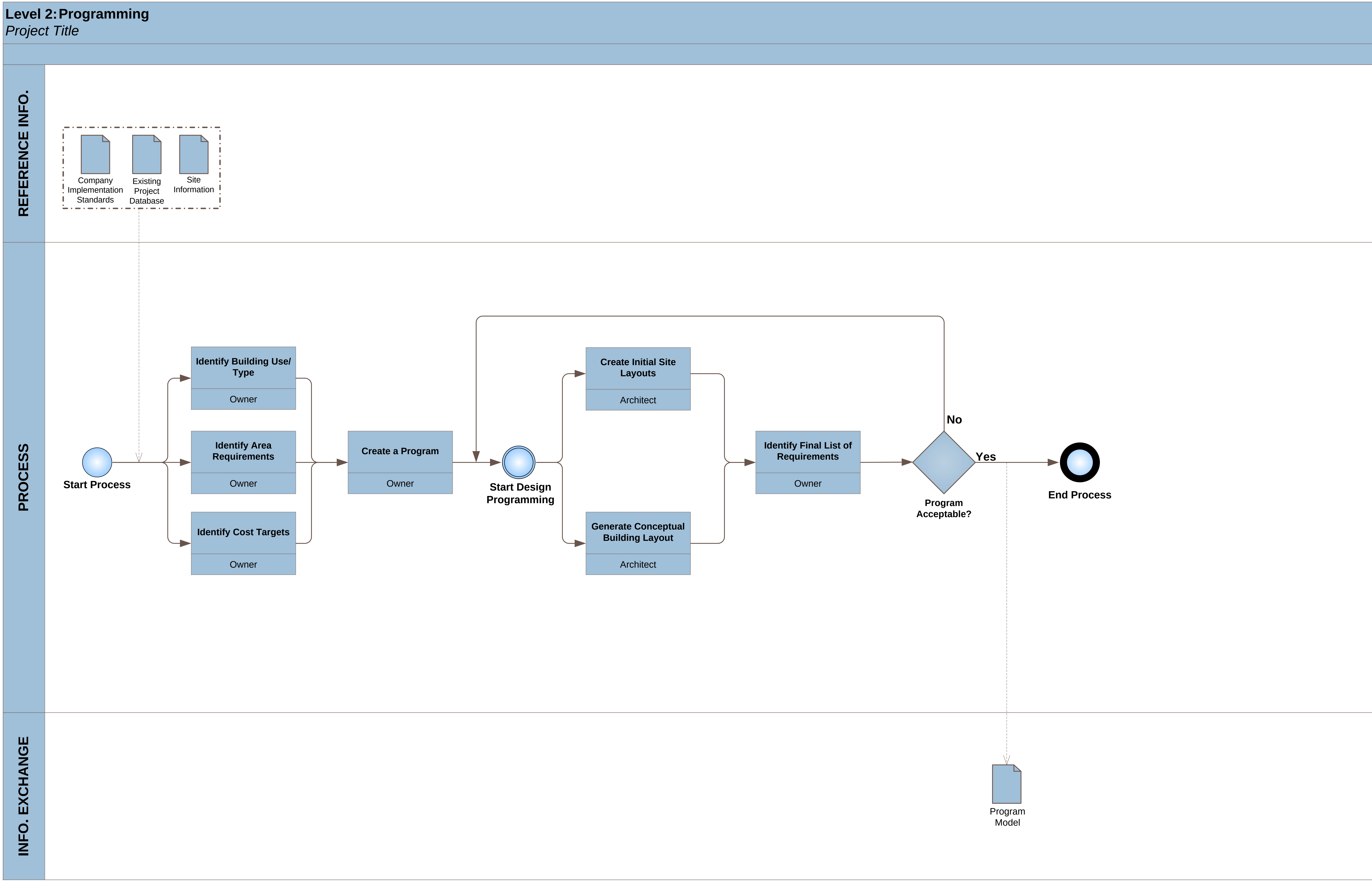
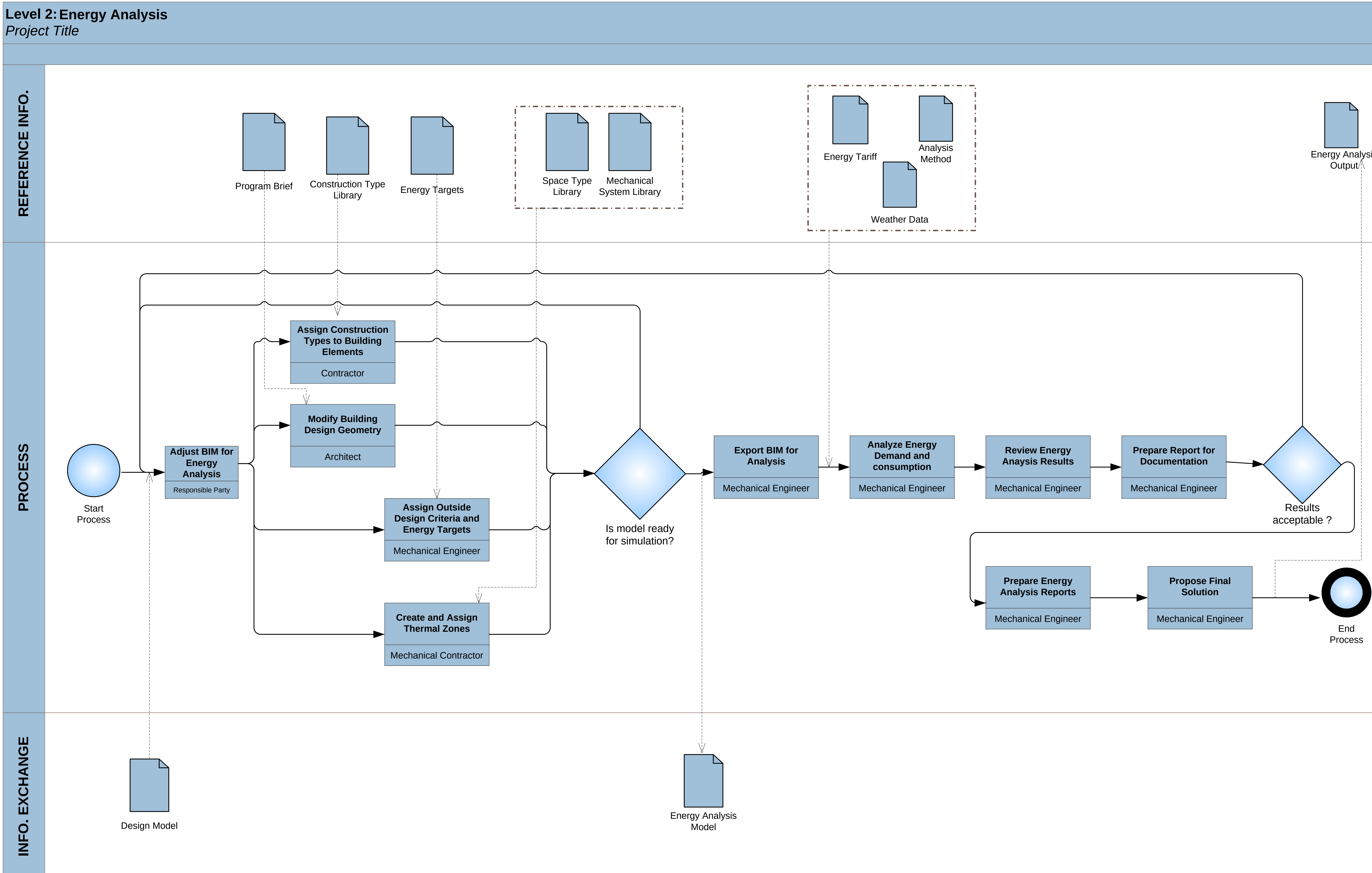
Appendix A

Template Process Maps

This Appendix contains the following Template Process Maps:

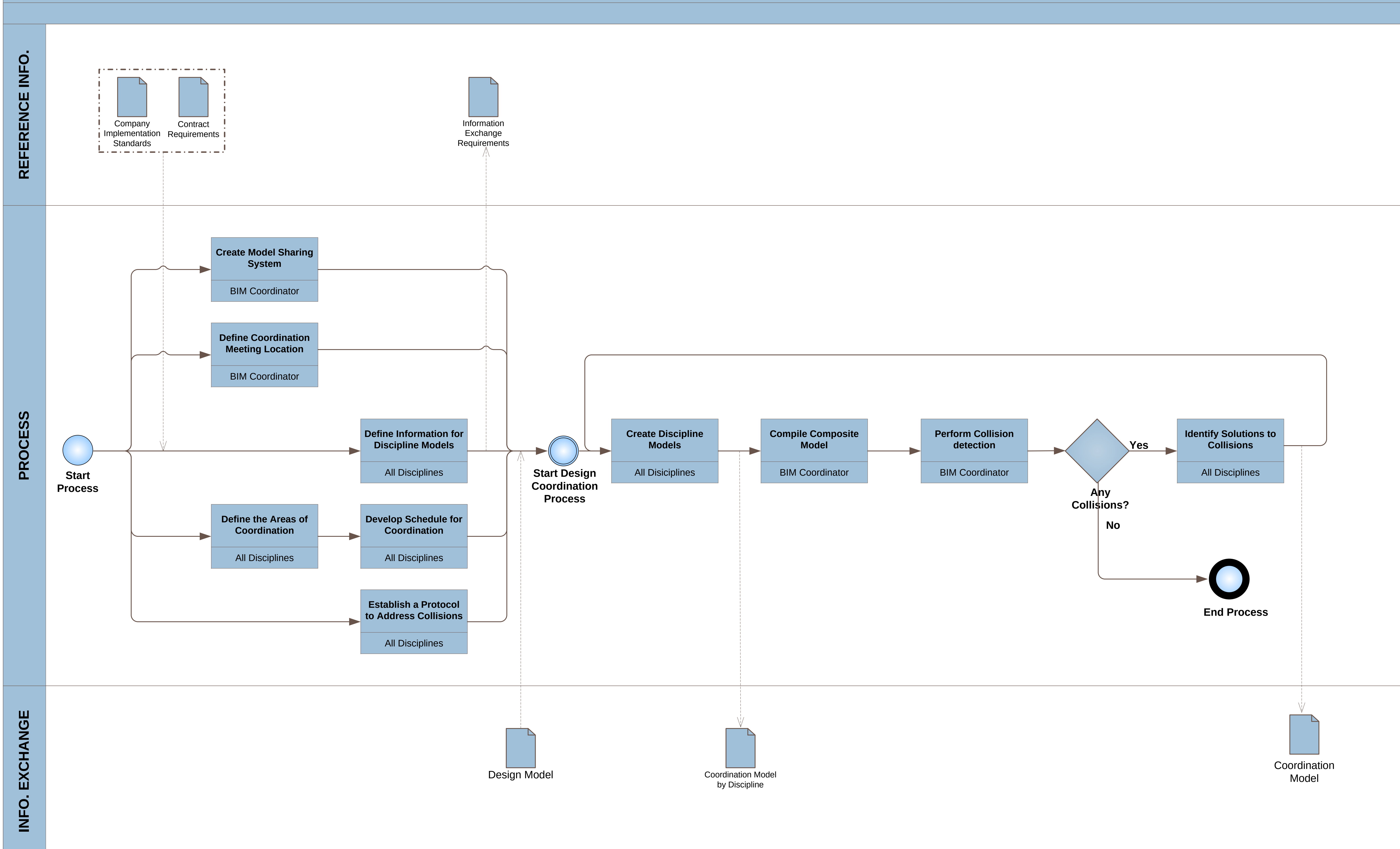
- Template Process Map for Programming;
- Template Process Map for Energy Analysis;
- Template Process Map for Design Coordination;
- Template Process Map for Record Model; and
- Template Process Map for Cost Estimation.

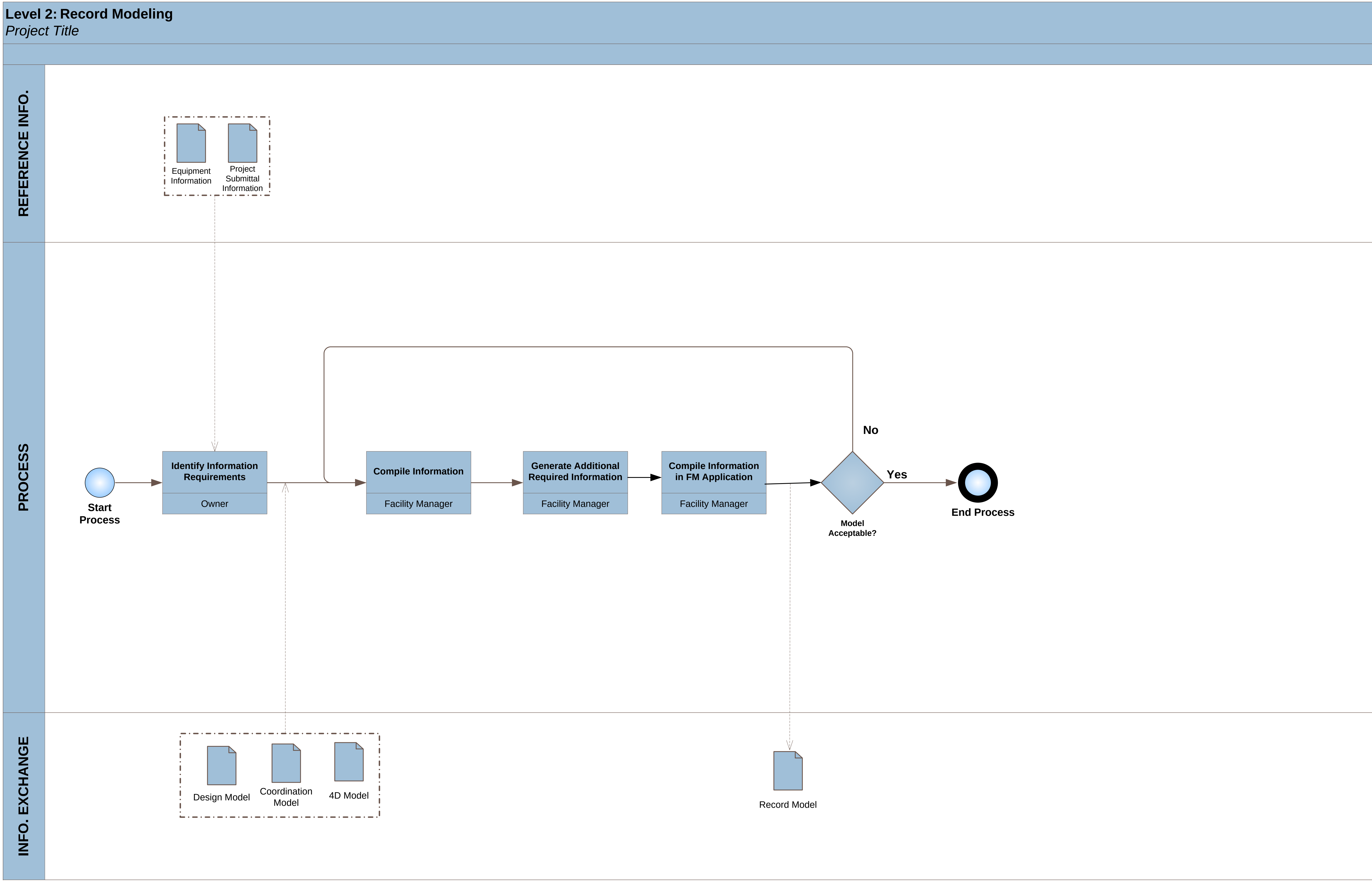

Level 2: Programming
Project Title
REFERENCE INFO.
Company Implementation Standards
Existing Project Database
Site Information
PROCESS
Start Process
Identify Building Use/ Type
Owner
Identify Area Requirements
Owner
Identify Cost Targets
Owner
Create a Program
Owner
Start Design Programming
Create Initial Site Layouts
Architect
Generate Conceptual Building Layout
Architect
Identify Final List of Requirements
Owner
No
Yes
Program Acceptable?
End Process
INFO. EXCHANGE
Program Model



Level 2: Energy Analysis
Project Title
REFERENCE INFO.
PROCESS
INFO. EXCHANGE
Program Brief
Construction Type Library
Energy Targets
Space Type Library
Mechanical System Library
Energy Tariff
Analysis Method
Weather Data
Energy Analysis Output
Start Process
Adjust BIM for Energy Analysis
Responsible Party
Assign Construction Types to Building Elements
Contractor
Modify Building Design Geometry
Architect
Assign Outside Design Criteria and Energy Targets
Mechanical Engineer
Create and Assign Thermal Zones
Mechanical Contractor
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
Results acceptable ?
Prepare Energy Analysis Reports
Mechanical Engineer
Propose Final Solution
Mechanical Engineer
End Process
Design Model
Energy Analysis Model

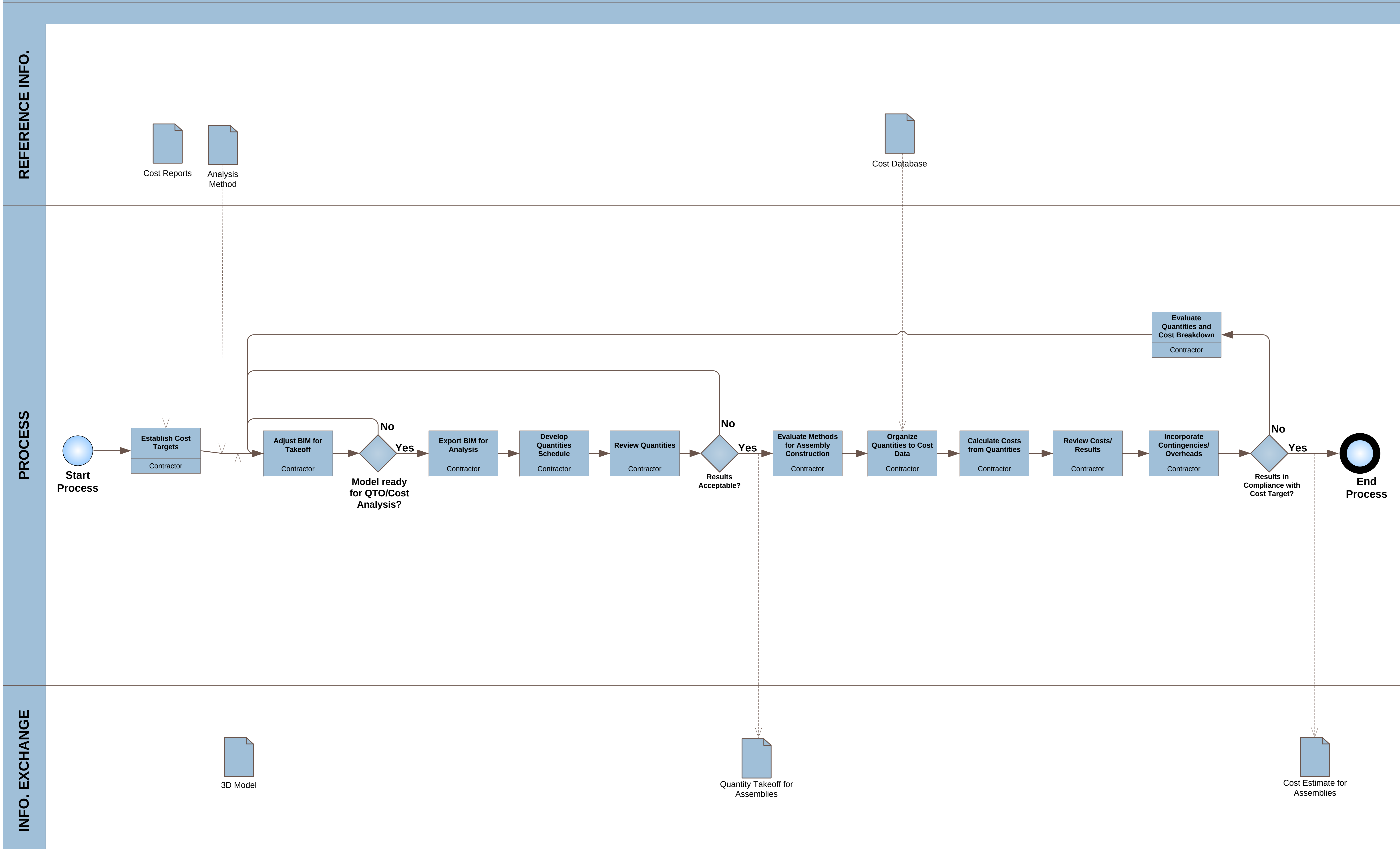
Level 2: Design Coordination
Project Title




Level 2: Record Modeling
Project Title
REFERENCE INFO.
Equipment Information
Project Submittal Information
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: Cost Estimation

Project Title



Appendix B

Template Information Exchange Worksheet

This Appendix contains the Template IE worksheet using the CSI UNIFORMAT II classification as the model element breakdown structure.

Table **B-1**: Legend for Information Content

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

Table **B-2**: Legend for Responsible Party

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

INFORMATION EXCHANGE REQUIREMENTS

			Information Exchange 1			Information Exchange 2			Information Exchange 3			Information Exchange 4		
Information Exchange Title														
Time of Exchange (SD, DD, CD, Construction)														
File Format														
Application & Version														
Model Element Breakdown			Info	Resp Party	Notes	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												
		Controls & Instrumentation												
		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												
		Movable 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													

Appendix C

Questionnaire Survey and Detailed Results

BIM Process Mapping Survey **Name: ___________________________**

This survey is conducted for the sole purpose of research and the data collected will be kept confidential. Please give your comments and provide your responses on a scale of 1-5 (1- strongly disagree to 5- strongly agree). Thank you for your time and cooperation!

1. What is your Academic Standing? (Check Appropriate Box)	***4th Year***	***5th Year***	***Graduate***	***Other (Please describe below)***	
2. What is your experience level in BIM? (Check appropriate box)	***None***	***Somewhat familiar***	***Familiar***	***Fairly well***	***Expert***

Please indicate the extent to which you agree to the following statements.

	Strongly Disagree	***Disagree***	***Neutral***	***Agree***	***Strongly Agree***
3. I have knowledge about the BIM task for which I was creating the process map.	1	2	3	4	5
4. I have been directly or indirectly involved in creating process maps before.	1	2	3	4	5
5. I felt that the procedure was defined adequately.	1	2	3	4	5
6. I felt that the procedure allowed me to model all the aspects necessary to understand the BIM Use.	1	2	3	4	5
7. I felt that the procedure and the template map which was provided helped me in generating ideas for creating the process map.	1	2	3	4	5
8. Overall, I felt that the procedural steps and the template file provided in TIBCO were adequately detailed to create process map for the BIM Use.	1	2	3	4	5

9. This activity helped me gain a better understanding of the given BIM use.	1	2	3	4	5
10. I feel that a process map will communicate/explain the given process in a better way.	1	2	3	4	5
11. The swimlanes – (enterprise information, external information, process and BIM) helped me in understanding the task.	1	2	3	4	5
12. I felt comfortable using TIBCO to create process maps.	1	2	3	4	5

13. What challenges did you have while creating the process map?

____
____
____
____
____
__

14. What additional steps/instructions will you like to see included in the procedure or the template file provided.

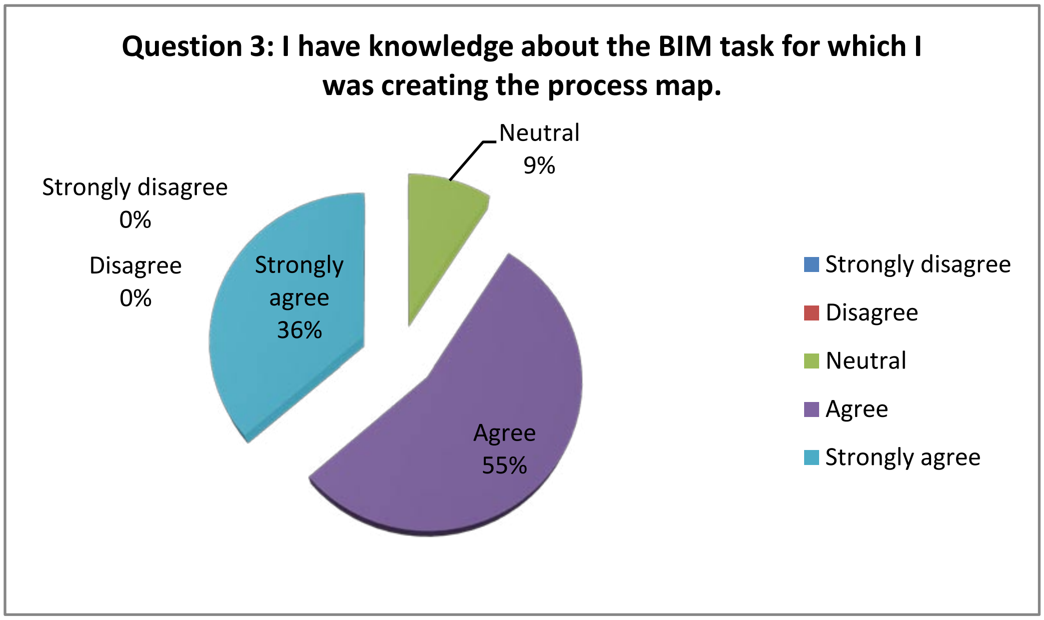
____
____
____
____
____

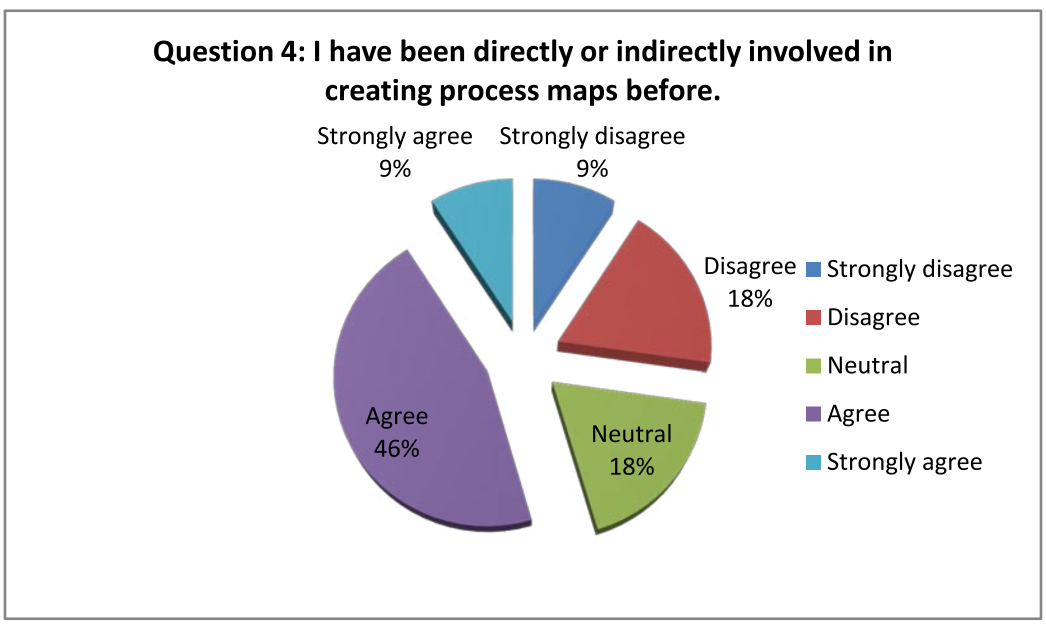
15. How long did it take you to a) Orient yourself to TIBCO _____________________________?
b) Develop this map____________________________________?

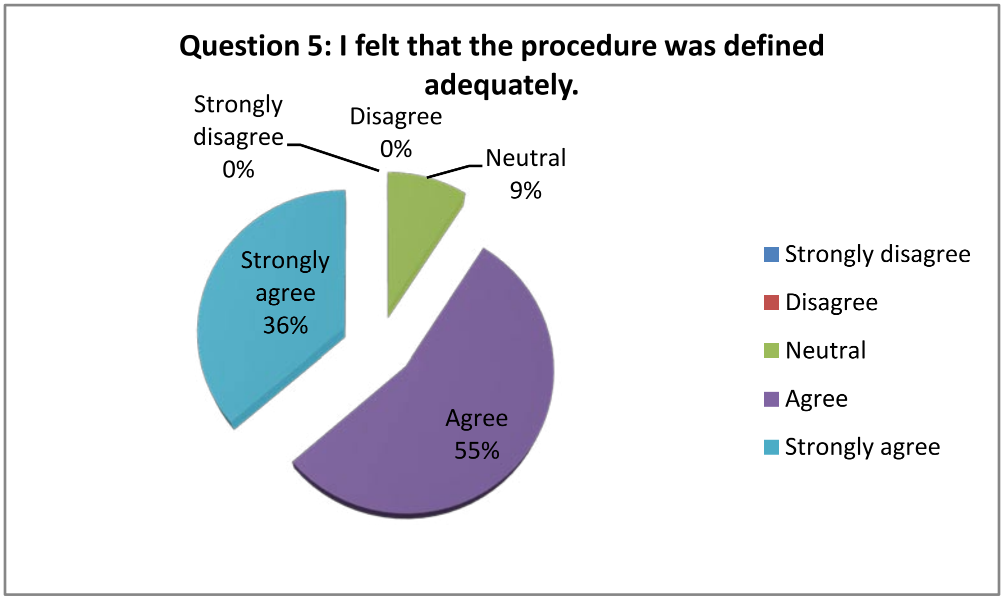
16. Please provide any additional comments.

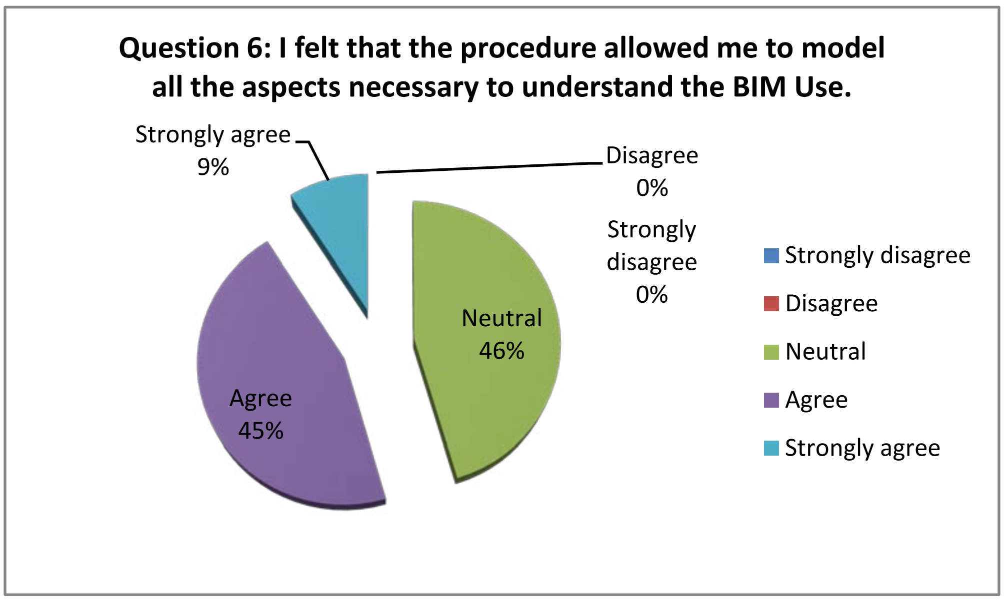
____
____
____
____
____
_

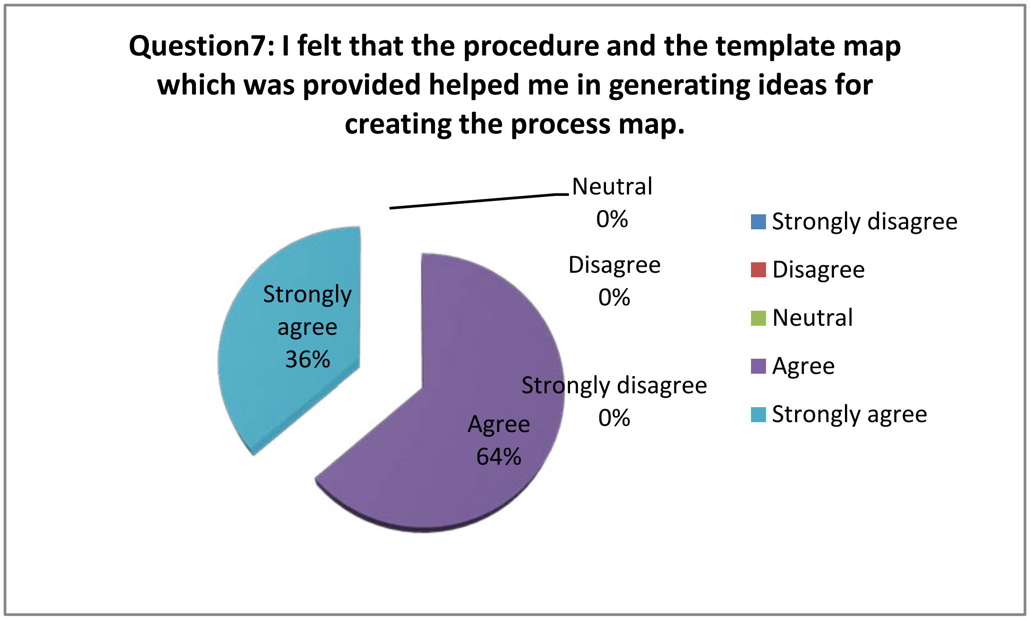
Detailed Survey results

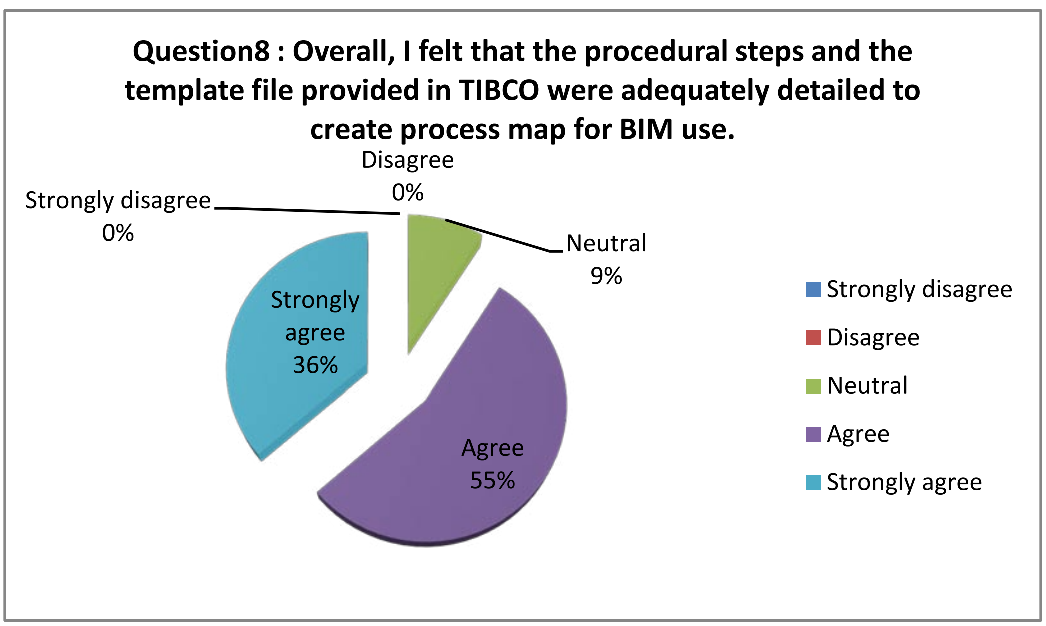


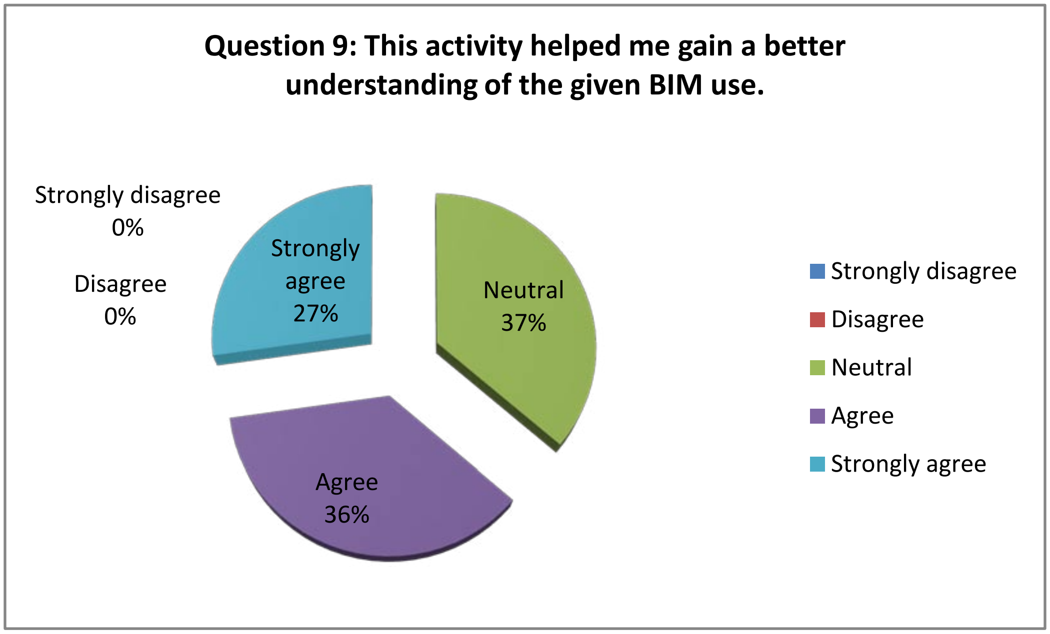


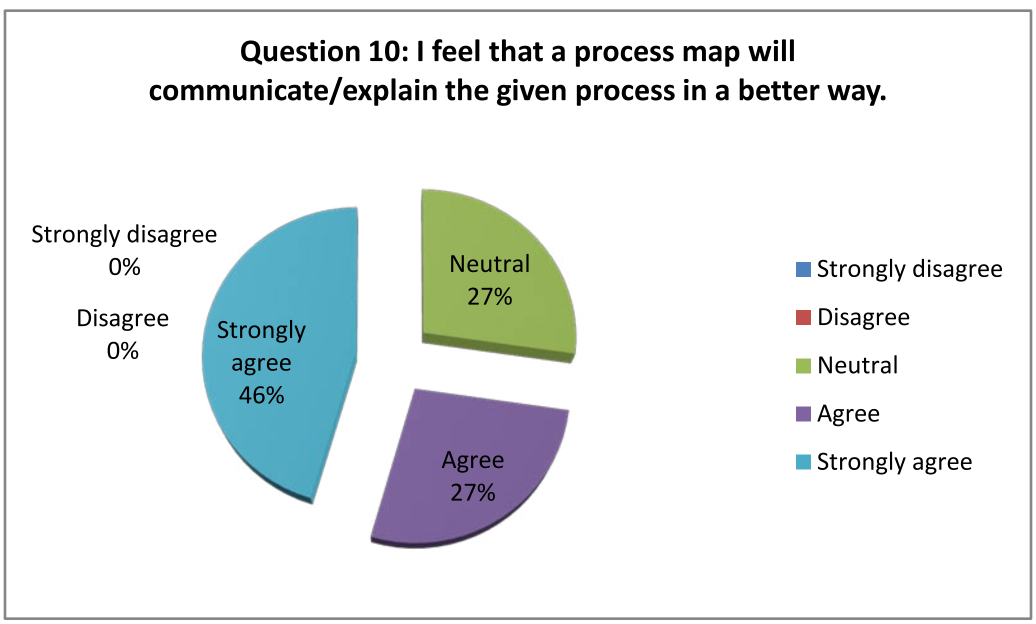

Question 5: I felt that the procedure was defined adequately.
Strongly disagree 0%
Disagree 0%
Neutral 9%
Strongly agree 36%
Agree 55%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree

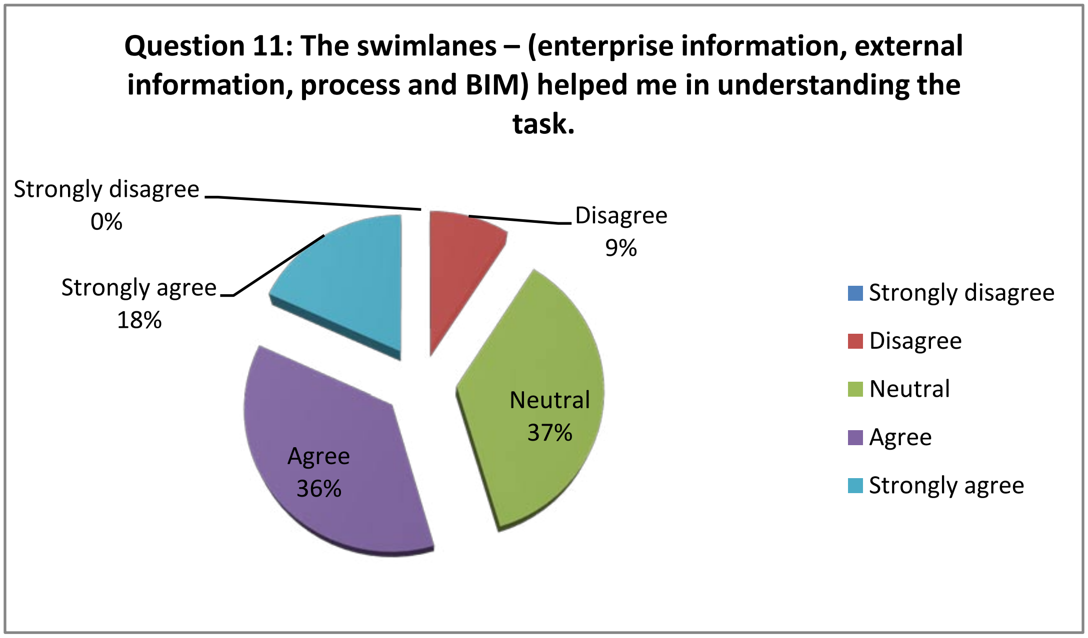

Question 6: I felt that the procedure allowed me to model all the aspects necessary to understand the BIM Use.
Strongly agree 9%
Disagree 0%
Strongly disagree 0%
Neutral 46%
Agree 45%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree

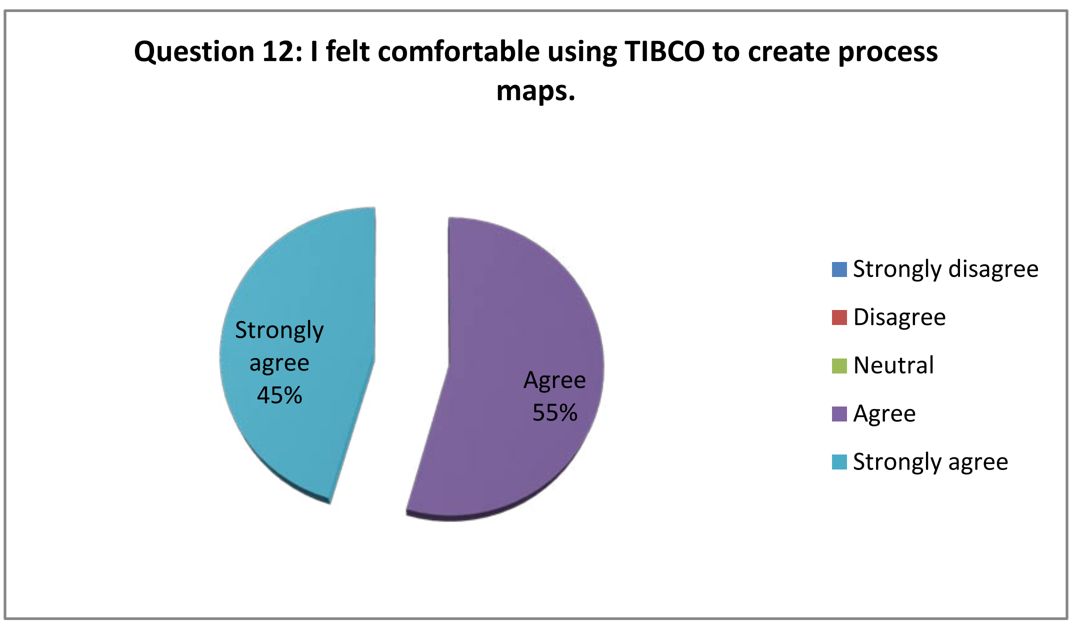

Question7: I felt that the procedure and the template map which was provided helped me in generating ideas for creating the process map.
Neutral 0%
Disagree 0%
Strongly disagree 0%
Strongly agree 36%
Agree 64%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree


Question8 : Overall, I felt that the procedural steps and the template file provided in TIBCO were adequately detailed to create process map for BIM use.
Disagree 0%
Strongly disagree 0%
Neutral 9%
Strongly agree 36%
Agree 55%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree

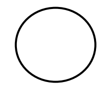
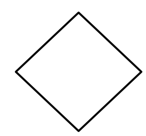
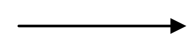
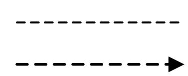
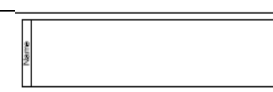

Question 9: This activity helped me gain a better understanding of the given BIM use.
Strongly disagree 0%
Disagree 0%
Strongly agree 27%
Neutral 37%
Agree 36%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree

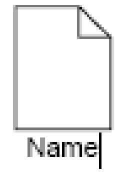

Question 10: I feel that a process map will communicate/explain the given process in a better way.
Strongly disagree 0%
Disagree 0%
Strongly agree 46%
Neutral 27%
Agree 27%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree


Question 11: The swimlanes – (enterprise information, external information, process and BIM) helped me in understanding the task.
Strongly disagree
0%
Disagree
9%
Strongly agree
18%
Neutral
37%
Agree
36%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree


Question 12: I felt comfortable using TIBCO to create process maps.
Strongly agree
45%
Agree
55%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree

Symbols used for Process Map Representation

Element	Description	Notation
Event	An event is something that "happens" during the course of a business process. These events affect the flow of the process and usually have a cause (trigger) or an impact (result). Events are circles with open centers to allow internal markers to differentiate different triggers or results. There are three types of Events, based on when they affect the flow: Start, Intermediate, and End.	
Activity	An activity is a generic term for work that company performs. An activity can be atomic or non-atomic (compound). The types of activities that are a part of a Process Model are: Process, Sub-Process, and Task. Tasks and Sub- Processes are rounded rectangles. Processes are contained within a Pool.	
Gateway	A Gateway is used to control the divergence and convergence of Sequence Flow. Thus, it will determine branching, forking, merging, and joining of paths. Internal Markers will indicate the type of behavior control.	
Sequence Flow	A Sequence Flow is used to show the order that activities will be performed in a Process.	
Association	An Association is used to associate information with Flow Objects. Text and graphical non-Flow Objects can be associated with Flow Objects. An arrowhead on the Association indicates a direction of flow (e.g., data), when appropriate.	
Pool	A Pool represents a Participant in a Process also acts as a "swimlane" and a graphical container for partitioning a set of activities from other Pools.	
Lane	A Lane is a sub-partition within a Pool and will extend the entire length of the Pool, either vertically or horizontally. Lanes are used to organize and categorize activities.	
Data Object	Data Objects are considered Artifacts because they do not have any direct effect on the Sequence Flow or	

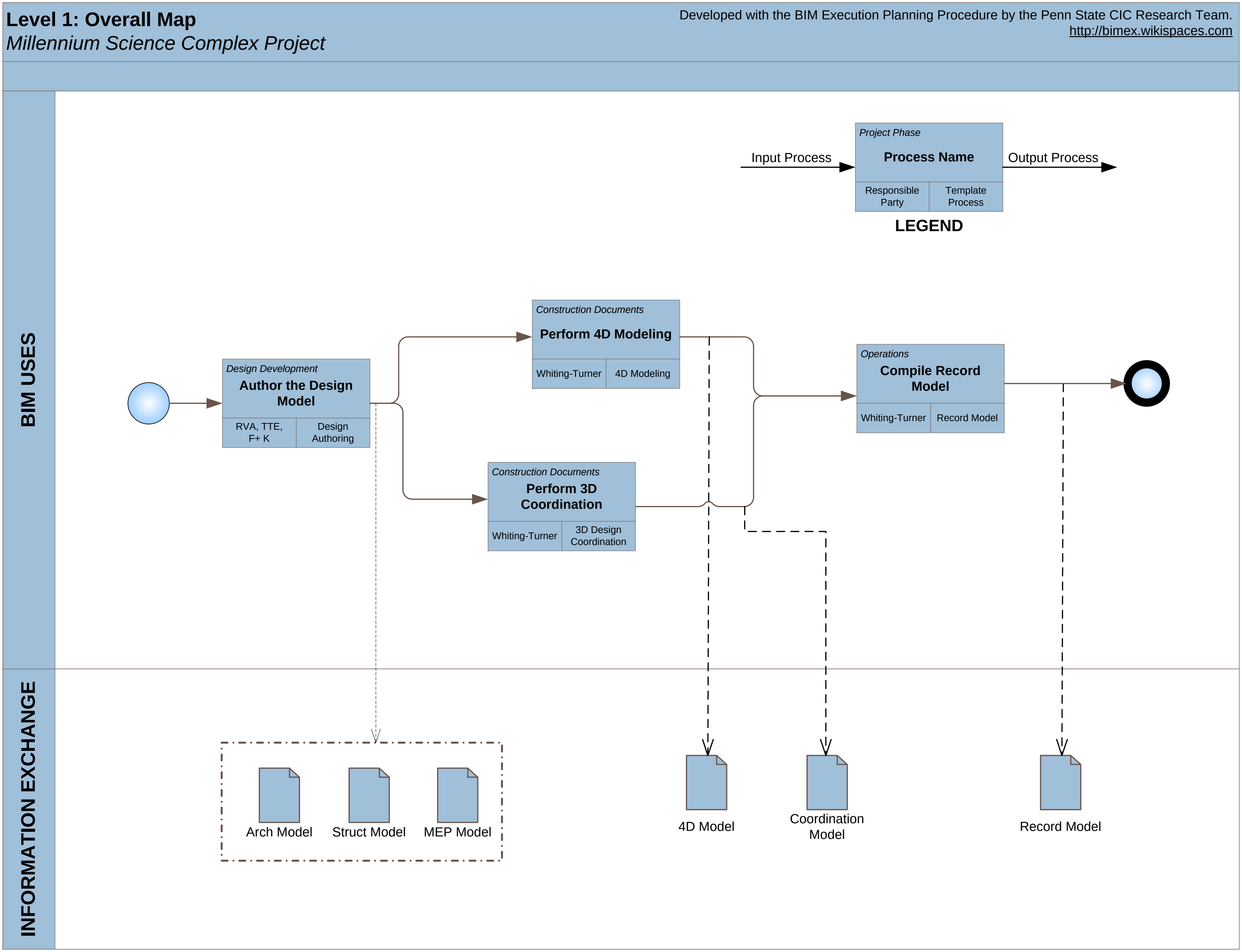
	Message Flow of the Process, but they do provide information about what activities require to be performed and/or what they produce.	
Group	A grouping of activities that are within the same category. This type of grouping does not affect the Sequence Flow of the activities within the group. The category name appears on the diagram as the group label. Categories can be used for documentation or analysis purposes.	

Appendix D

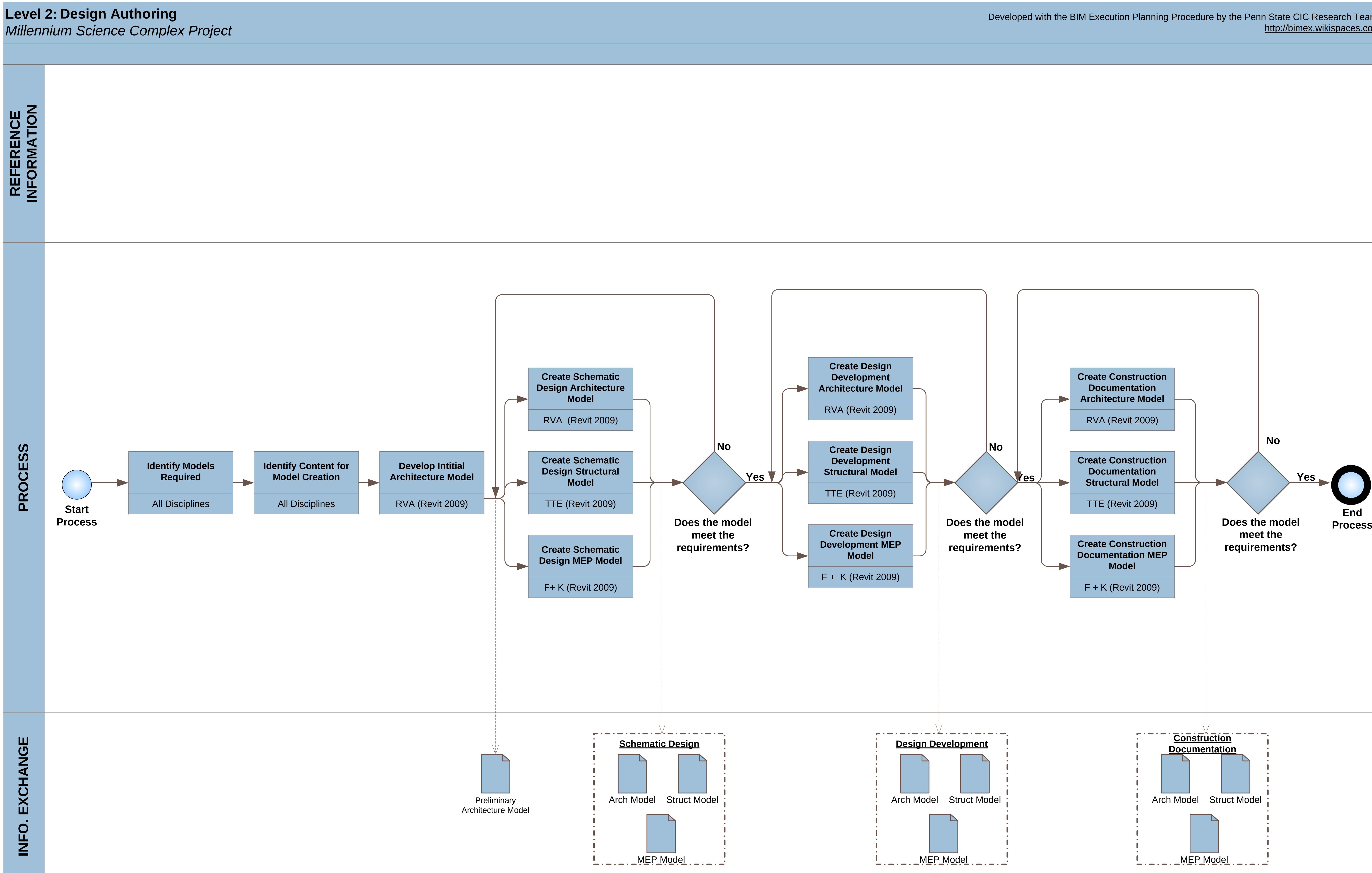
Case Study Process Maps and Information Exchange Worksheet

This appendix contains the PMs and the IE for the MSC Project.

- BIM Overview Map;
- Detailed BIM Use Process Map for Design Authoring;
- Detailed BIM Use Process Map for Design Coordination;
- Detailed BIM Use Process Map for 4D Modeling;
- Detailed BIM Use Process Map for Record Modeling; and
- IE for MSC Project



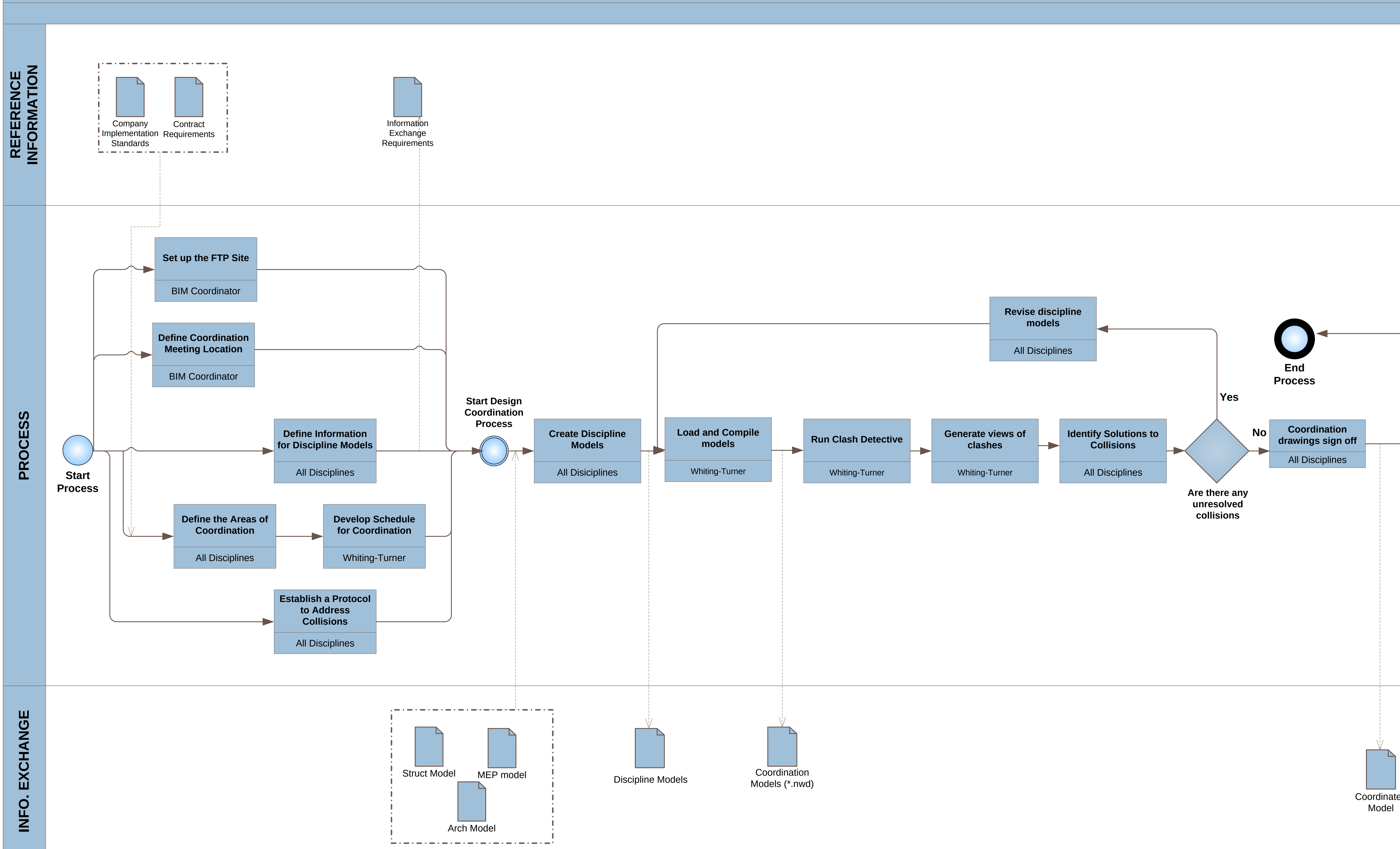
Level 1: Overall Map
Millennium Science Complex Project
Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com
BIM USES
Project Phase
Process Name
Input Process
Output Process
Responsible Party
Template Process
LEGEND
Design Development
Author the Design Model
RVA, TTE, F+ K
Design Authoring
Construction Documents
Perform 4D Modeling
Whiting-Turner
4D Modeling
Construction Documents
Perform 3D Coordination
Whiting-Turner
3D Design Coordination
Operations
Compile Record Model
Whiting-Turner
Record Model
INFORMATION EXCHANGE
Arch Model
Struct Model
MEP Model
4D Model
Coordination Model
Record Model

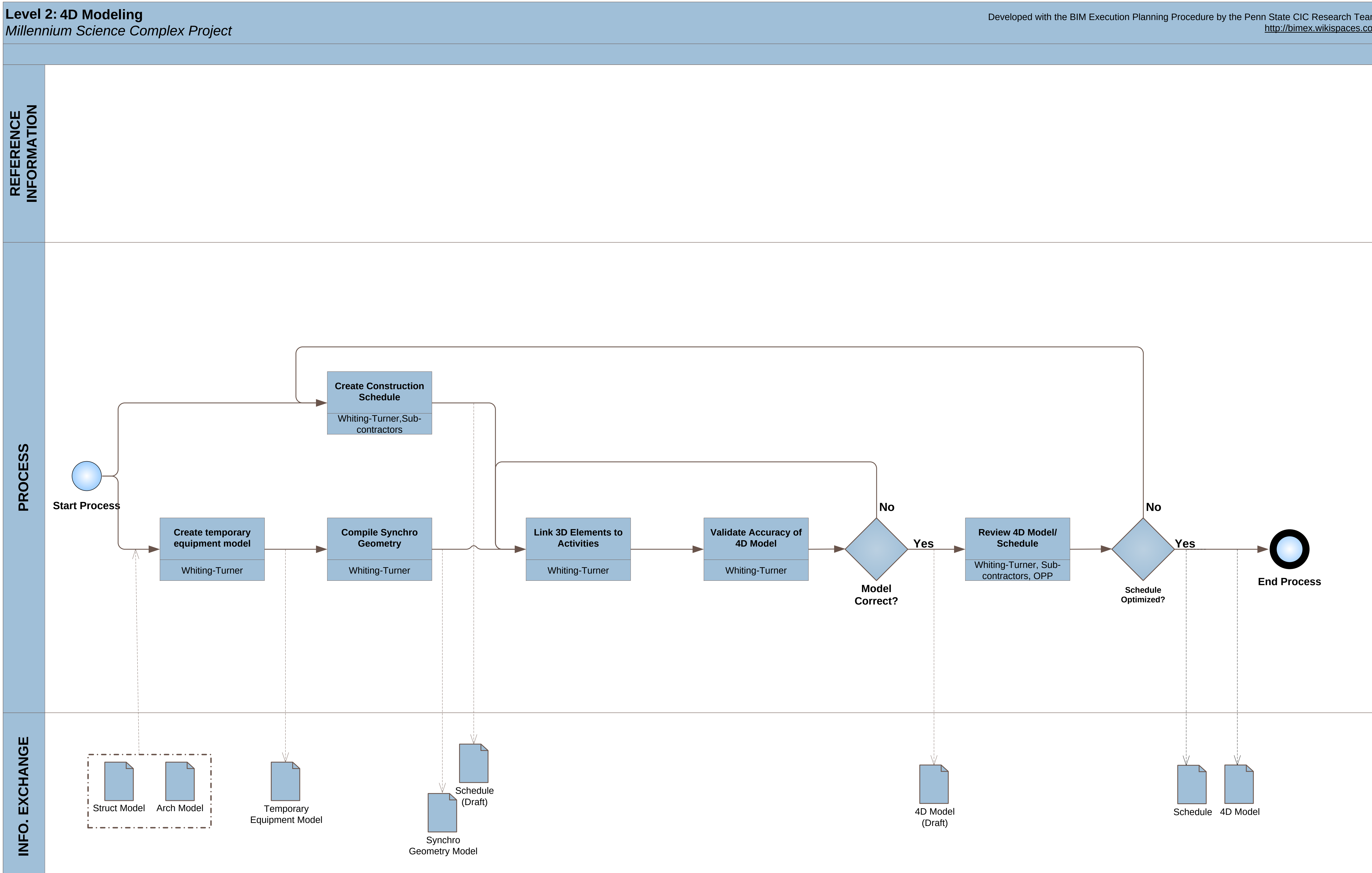

Level 2: Design Authoring
Millennium Science Complex Project
Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com
REFERENCE INFORMATION
PROCESS
INFO. EXCHANGE
Start Process
Identify Models Required
All Disciplines
Identify Content for Model Creation
All Disciplines
Develop Intitial Architecture Model
RVA (Revit 2009)
Create Schematic Design Architecture Model
RVA (Revit 2009)
Create Schematic Design Structural Model
TTE (Revit 2009)
Create Schematic Design MEP Model
F+ K (Revit 2009)
Does the model meet the requirements?
No
Yes
Create Design Development Architecture Model
RVA (Revit 2009)
Create Design Development Structural Model
TTE (Revit 2009)
Create Design Development MEP Model
F + K (Revit 2009)
Does the model meet the requirements?
No
Yes
Create Construction Documentation Architecture Model
RVA (Revit 2009)
Create Construction Documentation Structural Model
TTE (Revit 2009)
Create Construction Documentation MEP Model
F + K (Revit 2009)
Does the model meet the requirements?
No
Yes
End Process
Preliminary Architecture Model
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

Millennium Science Complex Project

Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com





Level 2: 4D Modeling
Millennium Science Complex Project
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
Create Construction Schedule
Whiting-Turner,Sub-contractors
Create temporary equipment model
Whiting-Turner
Compile Synchro Geometry
Whiting-Turner
Link 3D Elements to Activities
Whiting-Turner
Validate Accuracy of 4D Model
Whiting-Turner
No
Yes
Model Correct?
Review 4D Model/ Schedule
Whiting-Turner, Sub-contractors, OPP
No
Yes
Schedule Optimized?
End Process
Struct Model
Arch Model
Temporary Equipment Model
Schedule (Draft)
Synchro Geometry Model
4D Model (Draft)
Schedule
4D Model

Level 2: Record Modeling
Millennium Science Complex Project

Developed with the BIM Execution Planning Procedure by the Penn State CIC Research Team.
http://bimex.wikispaces.com

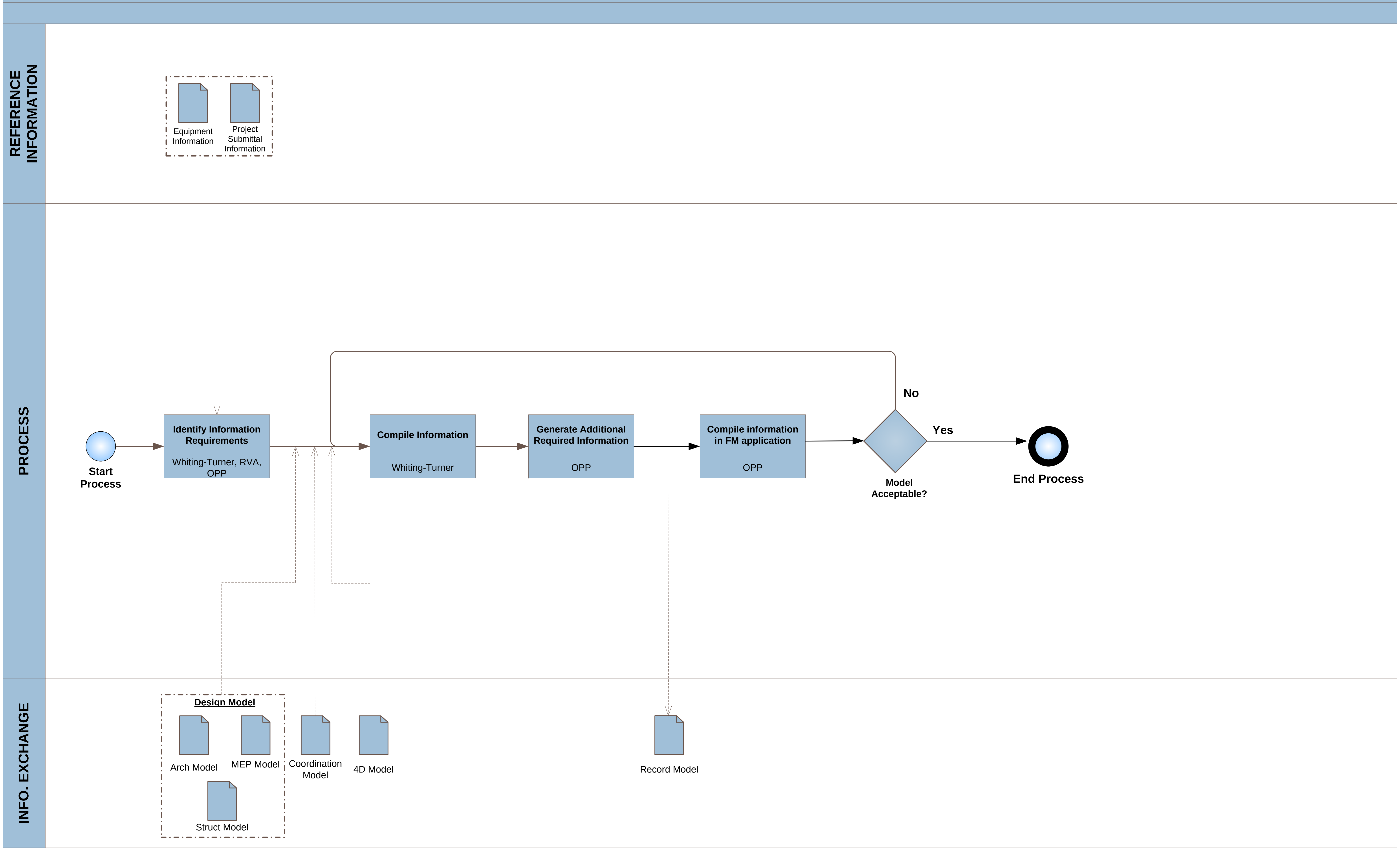


Table **D-1**: Legend for Information Content used for the Case Study

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

Table **D-2**: Legend for Responsible Party used for the Case Study

Legend	Responsible Party
RVA	Architect (Rafeal Viñoly Architects)
TTE	Structural Steel Engineers (Thornton Tomasetti)
Kinsley	Structural Steel Designers
Farfield	HVAC Piping/ductwork/equipment
WT	General Contractor (Whiting-Turner)
F&K	Mechanical Engineer (Flack + Kurtz)
McClure	Plumbing Sub-contractor
Biter	Electrical Sub-contractor
Herre	Plumbing Sub-contractor
Comunale	Fire Protection

INFORMATION EXCHANGE REQUIREMENTS

RVA	Architect (Rafeal Viñoly Architects)
TTE	Structural Steel Engineers (Thornton Tomasetti)
Kinsley	Structural Steel Designers
Farfield	HVAC Piping/ductwork/equipment
WT	General Contractor (Whiting-Turner)
F&K	Mechanical Engineer (Flack + Kurtz)
McClure	Plumbing Sub-contractor
Biter	Electrical Sub-contractor
Herre	Plumbing Sub-contractor
Comunale	Fire Protection

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

Information Exchange Title			Architecture Model			Structural Model			Mechanical Model			Coordination Model			4D Model		
Time of Exchange (SD, DD, CD, Construction)			DD			DD			DD			CD			DD,CD		
Reciever File Format			*.rvt			*.rvt			*.rvt			*.nwd					
Application & Version			Revit 2009			Revit 2009			Revit 2009			Navisworks 2010					
Model Element Breakdown			Info	Resp Party	Notes	Info	Resp Party	Notes	Info	Resp Party	Notes	Info	Resp Party	Notes	Info	Resp Party	Notes
A	SUBSTRUCTURE																
	Foundations																
		Standard Foundations	C	RVA		A	TTE		A	TTE		A	Kinsley		B	Kinsley	
		Special Foundations	C	RVA		A	TTE		A	TTE		A	Kinsley		B	Kinsley	
		Slab on Grade	C	RVA		A	TTE		A	TTE		A	Kinsley		B	Kinsley	
	Basement Construction																
		Basement Excavation	A	RVA		A	RVA		A	RVA		A	WT		B	WT	
		Basement Walls	A	RVA		A	RVA		A	RVA		A	WT		B	WT	
B	SHELL																
	Superstructure																
		Floor Construction	A	RVA		A	RVA		A	RVA		A	Kinsley		B	Kinsley	
		Roof Construction	A	RVA		A	RVA		A	RVA		A	Kinsley		B	Kinsley	
	Exterior Enclosure																
		Exterior Walls	A	RVA		A	RVA		A	RVA		A			B		
		Exterior Windows	A	RVA		A	RVA		A	RVA		A			B		
		Exterior Doors	A	RVA		A	RVA		A	RVA		A			B		
	Roofing																
		Roof Coverings	A	RVA		A	RVA		A	RVA		A	WT		B	WT	
		Roof Openings	A	RVA		A	RVA		A	RVA		A	WT		B	WT	
C	INTERIORS																
	Interior Construction																
		Partitions	A	RVA		A	RVA		A	RVA		A	WT		B	WT	
		Interior Doors	A	RVA		A	RVA		A	RVA		A	WT		B	WT	
		Fittings	A	RVA		A	RVA		A	RVA		A	WT		B	WT	
	Stairs																
		Stair Construction	C	RVA		A	TTE		A	TTE		A	Kinsley		B	TTE	
		Stair Finishes	C	RVA		A	TTE		A	TTE							
	Interior Finishes																
		Wall Finishes	A	RVA		A	RVA		A	RVA		A					
		Floor Finishes	A	RVA		A	RVA		A	RVA		A					
		Ceiling Finishes	A	RVA		A	RVA		A	RVA		A					
D	SERVICES																
	Conveying Systems																
		Elevators & Lifts										A	Farfield		A	Farfield	
		Escalators & Moving Walks															
		Other Conveying Systems															
	Plumbing																
		Plumbing Fixtures							A	F&K		A	Herre, McCLure				
		Domestic Water Distribution							A	F&K		A	Herre, McCLure				
		Sanitary Waste							A	F&K		A	Herre, McCLure				
		Rain Water Drainage							A	F&K		A	Herre, McCLure				
		Other Plumbing Systems															
	HVAC																
		Energy Supply							A	F&K		A	Farfield				
		Heat Generating Systems							A	F&K		A	Farfield				
		Cooling Generating Systems							A	F&K		A	Farfield				
		Distribution Systems							A	F&K		A	Farfield				
		Terminal & Package Units							A	F&K		A	Farfield				
		Controls & Instrumentation								F&K			Farfield				
		Systems Testing & Balancing							A	F&K		A	Farfield				
		Other HVAC Systems & Equipment															
	Fire Protection																
		Sprinklers										A	Communale				
		Standpipes										A	Communale				
		Fire Protection Specialties															
		Other Fire Protection Systems															
	Electrical																
		Electrical Service & Distribution										A	Biter				
		Lighting and Branch Wiring										A	Biter				
		Communications & Security										A	Biter				
		Other Electrical Systems										A	Biter				
E	EQUPMENT & FURNISHINGS																
	Equipment																
		Commercial Equipment															
		Institutional Equipment															
		Vehicular Equipment															
		Other Equipment															
	Furnishings																
		Fixed Furnishings										A					
		Movable 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																