The Pennsylvania State University
The Graduate School
The College of Engineering

AN ONTOLOGY OF THE USES OF BUILDING INFORMATION MODELING

A Dissertation in
Architectural Engineering
By
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Submitted in Partial Fulfillment
of the Requirements
for the Degree of
Doctor of Philosophy
December 2013

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ABSTRACT

Building Information Modeling (BIM) does not change the purpose for performing a task related to delivering a facility – only the means by which the purpose is achieved. Currently, no common language exists for the purposes of implementing BIM. This lack of a common language makes it challenging to precisely communicate with others the purposes for implementing BIM. The goal of this research is to create that common language by developing a BIM Use Ontology. A BIM Use (Use) is defined as *a method of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives.* The BIM Use Ontology (the Ontology) provides *a shared vocabulary that is applied to model (or express) the BIM Uses, including the type of objects (or terms), and concepts, properties, and relationships that exist.*

The methods performed to develop the BIM Use Ontology included: 1) defining domain and scope, 2) acquiring domain knowledge, 3) documenting domain terms, 4) integrating domain terms, 5) evaluating (refining and validating) the BIM Use Ontology, and 6) documenting the BIM Use Ontology. Overall, the BIM Use Ontology classified over 550 BIM terms into a defined ontological structure. Before the BIM Use Ontology was finalized, this structure was validated through competency questions, term mapping, industry interviews, and focus group meetings. The research methodology implemented to develop the BIM Use Ontology was designed based on the following criteria: clarity, comprehensiveness, extendibility, minimal bias, and minimal ontological commitment.

The BIM Use Ontology primarily classifies the BIM Uses based on the purpose of implementing BIM on a facility or within an organization; and secondarily classifies BIM Uses based on characteristics of the BIM Use. The BIM Use Ontology classifies BIM Uses into five primary BIM Use Purposes: 1) Gather, 2) Generate, 3) Analyze, 4) Communicate, and 5) Realize. After the BIM Use Purpose is determined, an implementer can identify more detailed BIM Use Characteristics such as facility element, facility phase, author discipline, or level of development. Depending upon a particular implementation of BIM, the process, information, infrastructure, maturity, benefits, and references are determined. The characteristics make the BIM Use Ontology applicable and usable by industry. The BIM Use Ontology provides a structure for the purposes by which BIM can be implemented during the life-cycle of a facility.

The BIM Use Ontology provides the fundamental terminology and organizational structure for the purposes for which BIM is implemented throughout the life-cycle of a facility. The BIM Use Ontology can be applied within procurement language and BIM planning to define exact requirements of various parties. The BIM Use Ontology can also be applied to standardize process and information exchanges. This standardization is critical to the *U.S. National BIM Standard*. Overall, the BIM Use Ontology allows for better communication of the purposes for implementing Building Information Modeling throughout the life of a facility.

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This dissertation is organized into the following chapters:

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2. Literature Review: Provides an overview of ontologies, Building Information Modeling, BIM Planning, and other BIM resources.
3. Methodology: Provides a detailed understanding of the methodology applied to develop the BIM Use Ontology including the defining domain and scope, acquiring knowledge, documenting domain terms, integrating domain terms, evaluating (refining and validating), and documenting the BIM Use Ontology
4. BIM Use Purposes and Objectives: Documents the purposes for implementing BIM including to gather, generate, analyze, communicate, and realize.
5. BIM Use Characteristics: Documents the characteristics of a BIM Use including facility element, facility phase, facility discipline, and level of development.
6. Application of the BIM Use Ontology: Presents a method for applying the BIM Use Ontology for BIM Planning on a project.
7. Summary and Conclusion: Revisits the goals of the research and how the BIM Use Ontology accomplishes those goals. Discusses the contributions, research limitations, and future work of this research.

The chapters of this dissertation are followed by the appendices, which include the BIM Use Ontology, BIM Use terms, a comparison of the BIM Use Ontology to the BIM Uses documented in the *BIM Project Execution Planning Guide*, a comparison of the BIM Use Ontology to other international BIM Uses and other appendices to support this research.

Note: This dissertation quotes a number of definitions; this is done intentionally to prevent the unnecessary creation of additional definitions through slight variations in definition, which could alter the meaning.

ACKNOWLEDGEMENTS

First of all, I would like to thank those on my doctoral committee: John Messner, Chimay Anumba, Robert Leicht, and Ute Poerschke. John, my advisor, helped to establish the direction that my research would take. His work in the area BIM planning allowed me to not only become knowledgeable in this area of research, but allowed me to contribute to forwarding the communities effort. Chimay's knowledge gained from his countless research publications allowed him to assist me with the creation of my research process. He helped tremendously to ensure that this research has the necessary vigor to be considered substantial. Rob's drive and dedication as a new member of the architectural engineering department provided a push for me to do more and never settle for good enough. Finally, Ute provided guidance as to when enough is enough and as well as understanding the broader impact of the research within this document.

Additionally, I would get like to thank some other individuals for supporting me and reviewing my work. These individuals include Robert Holland, Kurt Maldovan, Steve Hutsell, Van Woods, Deke Smith, Dianne Davis, Mark Butler, Rachel Riopel Wiley, Shawn Foster, James Vanderzant, Jason Reece, Grace Wang, Kerry Joels, Brigitta Foster, Greg Ceton, Adam Lega, Jan Reinherdt, Peirce Reynoldson, John Grady, and Connor Christian. Their hours of review and conversation have allowed me to move from concepts to a concrete ontology. Thank you to my colleagues and friends of Ashwin Ramesh, Eric Nulton, Steven Ayer, Sonali Kumar, Dragana Nikolic, Natalie Bryner, Heather Howard, Charles Miller, Mairav Mintz, Robert Carter, and Robert Fraga have reviewed this work in detailed and provided me with the support to continue pushing myself.

Moreover, I would like to thank my friends and family for putting up with me while I completed this effort. I know it was not always smooth as we had hoped or to the plan which was established, but you all still supported me through it all. I would also like to thank my parents, Ron and Rosalie. They got me started with this journey by contributing towards my undergraduate degree and gave me the support I needed to continue on four and half more years after the initial five years. Most of all I would like to thank my wife, Brittany. She supported me through all the highs and lows. I know that it did not always go to plan. (I think this was to be completed before you were my wife). Thanks for putting up with all those hours I was locked away completing my work and answer the questions that never seemed to make sense. I hope it all makes sense now.

To all of you, it was your support, more than myself, has made this effort possible.

CHAPTER 1: INTRODUCTION

This research is intended to provide a common language (in the form of an ontology) for the purposes of implementing BIM. An ontology will provide for a common understanding in the industry upon which the implementation of BIM may be normalized. It is important to understand that BIM is no different than any other activity in the life of a facility and should be implemented for a purpose. It is that purpose that this research strives to understand and define. This research is designed to foster better communication within the industry by documenting the BIM Uses and the purpose for implementing BIM throughout the life of a facility. The uses or purposes for implementing BIM are documented within the BIM Use Ontology.

Building Information Modeling (BIM) has been defined as "*the act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes.*" (buildingSMART alliance 2007). To foster better communication within the industry, it is important to define a consistent language to describe the focused implementation of BIM on a capital facility or a facility. A BIM Use can be defined as "*a method of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives.*" (Computer Integrated Construction Research Program 2013b)

BIM Uses can be classified based on the purpose for implementing BIM throughout the life of a facility. In addition to the purpose alone, several other characteristics can be defined to properly identify and communicate a BIM Use. These purposes and characteristics (see Figure 1-1) can be defined at varying levels depending upon the specificity required for different applications of the BIM Uses.

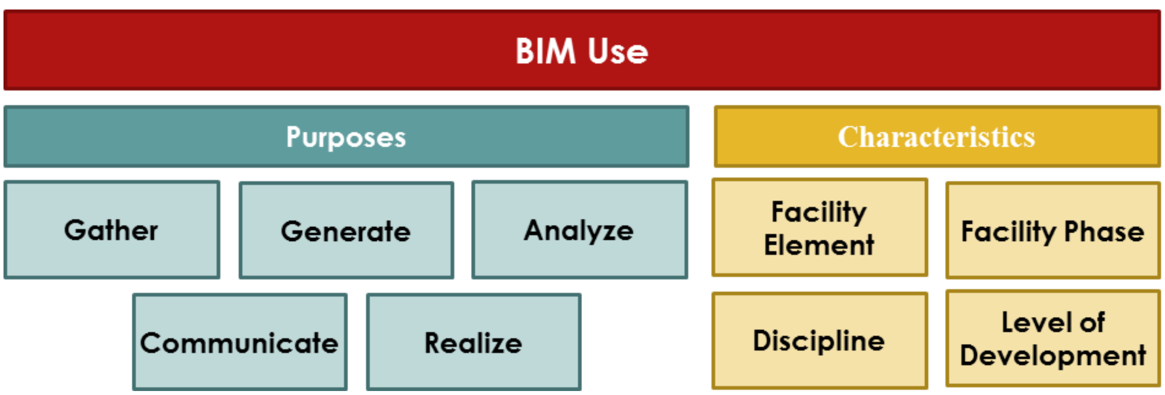


Figure 1-1: The Components of a BIM Use

A BIM Use Purposes communicates the primary objective of implementing the BIM Use. The BIM Use Purposes, shown in Figure 1-2, fall into five primary categories: gather, generate, analyze, communicate, and realize. Within primary BIM Use Purpose categories, there are numerous subcategories that further specify the BIM Use Purposes.

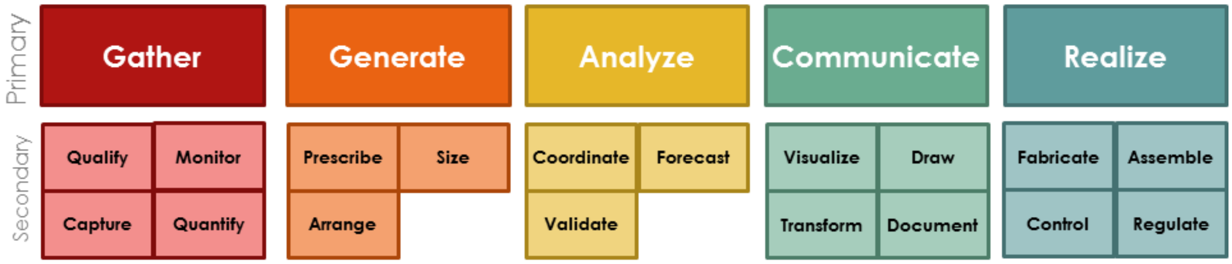


Figure 1-2: The BIM Use Purposes

The BIM Use Characteristics allow a user to further define the BIM Use based on common facility and project attributes: facility element, facility phase, discipline, and level of development. By determining these factors, as shown in Table 1-1, a particular BIM Use can be focused toward a specific approach.

Table 1-1: BIM Use Characteristics

Characteristics	Description
Facility Element	The system of the facility on which the BIM Use will be implemented.
Facility Phase	The point in the facility's life-cycle at which the BIM Use will be implemented.
Discipline	The party by whom the BIM Use will be implemented.
Level of Development	The degree of reliability to which the BIM Use will be implemented.

Implementing characteristics allow the user to define a very specific instance of the BIM Use for implementation for a specific facility at a specific time. Each implementation of BIM Use will include the following items: a process, information, infrastructure, level of maturity, potential impacts, and references to support that specific approach. These characteristics are often shared between multiple BIM Use Purposes.

Each BIM Use Purpose and Characteristic includes the term itself, a term definition, a term description, and term synonyms. These elements are considered the metadata about the term or attributes.

The BIM Use Ontology can be applied during the development of a BIM Project Execution Plan (BIM PxP) or to better allow for the establishment of requirements. Outside of BIM, the BIM Use Ontology can be applied to understand the flow of information throughout the life-cycle of a facility. The pattern of gather, generate, analyze, communicate, and realize repeats itself over and over again in the activities performed by project teams. If not using BIM, but "traditional" processes, the principles discussed in this dissertation still apply because BIM does not change the fundamental purposes for which methods are applied. A goal this research is that the

Architectural, Engineering, Construction, and Owner (AECO) Industry no longer refers to this technology and processes as BIM but rather simply as ways to improve the life-cycle of the facility. Because when this occurs, BIM will truly become normalized and standardized throughout the industry.

1.1 IMPORTANCE OF A BIM USE ONTOLOGY

The need for research in this area was identified during the development of the *BIM Project Execution Planning Guide* in 2009. When developing the *BIM Project Execution Planning Guide*, the research team documented approximately twenty-five BIM Uses (the number of uses varies from 24 to 26 depending on the version). Examples of these BIM Uses include Existing Conditions Modeling, Design Authoring, Design Reviews, 3D Coordination, Energy Analysis, and Record Modeling. In general, these BIM Uses were organized by facility phase (plan, design, construct, and operate). Organizing BIM Uses by phase has many drawbacks. First, each Use of BIM does not reside within one single facility phase. In fact, most can occur in multiple facility phases. However, every BIM Use can be applied during any phase of the life-cycle of a facility. Second, the current structure has few levels, categories, or classes of BIM Uses. Furthermore, this structure is not easily adaptable to changes, such as adding new Uses. Even the terms and definitions of each BIM Use have not been standardized, and they varied from version to version of the *BIM Project Execution Planning Guide* (the Guide). While the Guide made progress towards standardizing a list of terms and definitions, the terms have not been accepted uniformly and groups implementing the BIM Uses often customize the BIM Uses to suit their needs.

These types of issues are not only found within the *BIM Project Execution Planning Guide,* but also other industry guides. Few publications employ a standard list of BIM Uses. Of those publications that list the BIM Uses, the lists vary greatly from one publication to the next. Moreover, even fewer publications categorize the uses into classes and class hierarchies. This lack of a standard list prevents facility team members from clearly planning and communicating "what" they will achieve through the application of BIM on a facility. Therefore, there is a need to create an ontology that presents a standard list and definition of the BIM Uses, and organizes the BIM Uses in classes and a class hierarchy. While the BIM Uses defined in the *BIM Project Execution Planning Guide* moved the industry in the right direction, a more structured and specific categorization of BIM Uses will enable project teams and organizations to develop more effective plans.

1.1.1 Purpose of the BIM Use Ontology

The purpose of the BIM Use Ontology is to overcome the problems in communicating specific BIM Uses throughout the life-cycle of a facility. This purpose of the BIM Use Ontology includes:

- to create a common vocabulary for communication among the industry;
- to create a knowledge framework for the BIM Uses;
- to standardize terminology, meaning of concepts, components of tasks; and
- to allow for reuse of BIM Use knowledge.

To meet these objectives, this Ontology is developed to answer the following competency questions:

- What are the specific BIM Uses?
- What are the definitions of the BIM Uses?
- What are the important attributes of each BIM Use?
- What are the classes of BIM Uses?
- What is the hierarchy of the BIM Uses?
- What is the relationship(s) of one BIM Use to other BIM Uses?

(These questions are answered in section 3.5.1.1)

1.1.2 Goal of the BIM Use Ontology

The goal of this research is to improve the communication of the BIM Uses implemented throughout the life of a facility. This goal is accomplished through the development of an ontology of the Uses of Building Information Modeling. The BIM Use Ontology enables the communication of BIM Uses. The BIM Use Ontology contains standard terms, definitions, descriptions, attributes, relationships, classes, and class hierarchies of the BIM Uses. A BIM Use is defined as *a method of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives.* The term BIM Use has also been referred to as a BIM application, a BIM strategy, a BIM implementation strategy, BIM solution, or a BIM use case. "*An ontology provides a shared vocabulary, which can be used to model a domain, that is, the type of objects and/or concepts that exist, and their properties and relations*."(Arvidsson and Flycht-Eriksson 2008). Therefore, the BIM Use Ontology provides a shared vocabulary which is utilized to model (or express) the BIM Uses, including the type of objects (or terms), and concepts, properties, and relationships that exist in relation to the methods of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives.

1.1.3 Domain of the BIM Use Ontology

Establishing a firm understanding of the domain is one of the essential steps of creating an ontology. The domain defines the purpose of an ontology (Jones et al. 1998), which includes how and by whom an ontology will be applied. The BIM Use Ontology is within the domain of Building Information Modeling. More specifically, the domain of the BIM Use Ontology is the BIM Uses applied throughout a facility's life-cycle. This Ontology is to be applied by members of the Architectural, Engineering, Construction, and Owner (AECO) community to define purposes for which they are implementing BIM.

1.1.4 Scope of the BIM Use Ontology

Establishing the scope of an Ontology is as important as establishing the purpose and domain (Jones et al. 1998). The scope of the ontology defines what is included or excluded from the BIM Use Ontology. In other words, the scope defines which terms, or in this case which BIM Uses, are included in the BIM Use Ontology. Defining the scope of the BIM Use Ontology is particularly challenging. What exactly qualifies as a BIM Use? Do Computerized Maintenance Management Systems (CMMS) applied by operations personnel qualify? Do Computer Aided Drafting (CAD) systems qualify? This question can also be extended to project accounting and document management system software. Often, software vendors or contractors brand a technology BIM for marketing benefit, even if it is not truly BIM. The answer to the question of what qualifies as a BIM Use is a method of applying BIM that interacts with the facility elements and facility data from a model. For example, an accounting system using data derived directly from a BIM model is BIM, while a stand-alone accounting system with no connection to data within the model is not a BIM system. Another example is a schedule system that is directly linked to facility data and/or geometry compared to a system that is completely independent of the model elements. The direct tie to the virtual elements of the facility is the determining factor to identify an implementation to be a BIM Use.

With that said, the scope of the BIM Use Ontology includes all of the methods of applying BIM which employ information directly tied to the facility model(s), and are currently being implemented within organizations, projects, and/or the facility. Moreover, when the BIM Use Ontology was developed, the research focused only on classifying the BIM Uses that are presently being implemented during the life-cycle of a facility or the BIM Uses that have been thoroughly documented in literature. While the BIM Use Ontology provides the framework for classifying new BIM Uses, the BIM Use Ontology was not developed through hypothesizing new BIM Uses; rather classifying the BIM Uses that already exist.

1.2 CURRENT STATE OF RESEARCH IN THE DOMAIN OF BIM USES

To this date, no one has documented a comprehensive system that properly classifies BIM Uses. A number of groups have developed a generic list, such as the Uses in the *BIM Project Execution Planning Guide*. Other lists on BIM Uses include the BIM Uses documented in industry publications such as *the AGC Contractors' Guide to BIM* (The Associated General Contractors of America 2006), *the BIM Handbook* (Eastman et al. 2008), *the VA BIM Guide* (Department of Veterans Affairs 2010), *the GSA BIM Guide Series* (General Services Administration 2007), *the BuildingSMART Data Dictionary* (BuildingSMART International, Ltd 2013), and *Tetralogy of BIM* (buildingSMART alliance 2013). However, these lists of BIM Uses are not comprehensive and include some overlap issues – like the BIM Uses within the *BIM Project Execution Planning Guide*. The current work in this area, including the *buildingSMART Data Dictionary* and the industry guidelines, focuses on defining the terms themselves with little regard to whether they are processes or products, and with little regard to structure or organization of the terms. Currently, there is a lack of generally accepted structure for the fundamental purposes for implementing BIM.

1.3 COMPONENTS OF AN ONTOLOGY

To accomplish the purpose of this research, a BIM Use Ontology was developed. The standard components of an ontology, which were used within the BIM Use Ontology, are presented in Table 1-2.

Table 1-2: Components of an Ontology
(Gruber 1995)

Component	Description	Synonyms
Terms	*A word or expression that has a precise meaning in some uses or is peculiar to a science, art, profession, or subject.* (Merriam-Webster 2013a)	Names, Words
Definition	*An exact statement or description of the nature, scope, or meaning of something*(Merriam-Webster 2013a)	Description, Explanation
Attribute	*A quality or feature regarded as a characteristic or inherent part of someone or something,* (Oxford Dictionary 2013a)	Property, Characteristic
Classes	*A group, set, or kind sharing common attributes* (Merriam-Webster 2013b)	Types, Concepts
Class Hierarchy	*An arrangement or classification of things according to relative importance or inclusiveness* (Oxford Dictionary 2013b)	Structure, Organization

1.4 APPLICABILITY AND BENEFITS OF THE BIM USE ONTOLOGY

The BIM Use Ontology can and should be applied to provide the standardized fundamental terminology and organizational structure for the BIM Uses throughout the life-cycle of a facility. The primary purpose for implementing the Ontology is to provide for better communication for why and how BIM is being implemented. This will allow the industry to have a common and standardized language where none currently exists. The overall applications and benefits of the BIM Use Ontology are illustrated in Figure 1-3: Applications of the BIM Use Ontology.

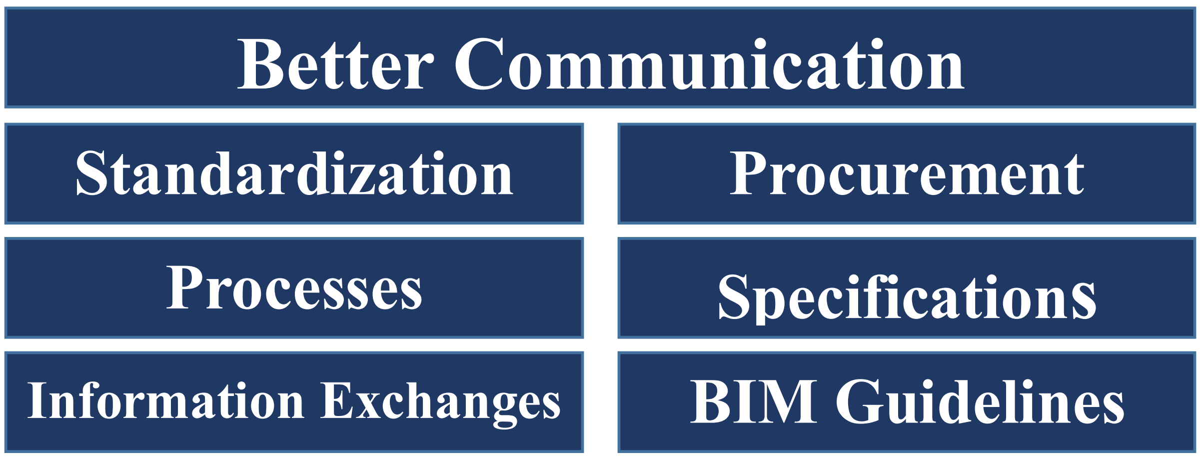


Figure 1-3: Applications of the BIM Use Ontology

This common language can lead to the standardization of processes and exchanges. One way the BIM Use Ontology can be applied is to structure the terminology used throughout Model View Definitions and Information Delivery Manuals. A Model View Definition (MVD) "*defines a subset of the IFC schema, that is need to satisfy one or many Exchange Requirements*" (Liebich 2011). The intent is for a MVD to be a technical exchange definition for employment by software developers (buildingSMART alliance 2007). An Information Delivery Manual (IDM) is "*the exchange definition written in non-technical prose for use by end-users. [It] describes the business process, stakeholders, exchange points, information requirements, and business rules.*" (buildingSMART alliance 2007). Therefore, it is possible to develop a corresponding information delivery manual for each instance of a BIM Use (or multiple IDMs depending upon the specific needs). Additionally, the BIM Use Ontology can be applied to provide for better communication of requirements within contract language and when planning for the Use of BIM. This lack of understanding of intent is one of the critical issues within contract language today. The BIM Use Ontology allows the industry to move toward performance based specifications and requirements. More extensively the BIM Use Ontology can be expanded to better understand the business practices of the Architectural, Engineering, Construction and Operations (AECO) Industry as a whole and may incorporate most of the business practices of planning, designing, constructing, operating, and managing a capital facility. The BIM Use Ontology allows for better communication of fundamental processes within the domain of Building Information Modeling.

CHAPTER 2: LITERATURE REVIEW

When developing the BIM Uses Ontology, it was critical to understand the background of ontology development, Building Information Modeling, and the relationship between the two. This includes research about ontologies themselves, as well as BIM Uses. Understanding both allowed for the proper application of both knowledge areas so that the BIM Use Ontology is applicable and usable by the AECO Industry to plan and understand the reasons for implementing BIM during the life of a facility.

2.1 ONTOLOGIES

Ontologies are part of our everyday life. The organization and structure of a deck of playing cards could be considered an ontology. A deck of cards can be organized by color, suit, or number. Each of these groups are really classes of cards. Ontologies are often applied to classify products we purchase every day. For example, the interaction with products on Amazon or other on-line stores are typically organized using several different ontological structures and classes. Even in the grocery store, the products are organized based on common attributes among them; otherwise we would have a very difficult time finding anything in the store. We can also quickly understand when there is little organization in a store. Moreover, the scientific community has been organizing the physical environment into ontologies and classes for years. We organize the world based on living or non-living; plant or animal; mammal, insect, amphibian, bird, fish, and reptile; and further breakdown of species. Language itself can be organized into an ontology including classes such as verbs, nouns, participles, interjections, pronouns, prepositions, adverbs, and conjunctions. All of these different ontologies have common elements, which include: standard terms, definitions, classes, attributes, and relationships. Ontologies allow for people to better understand the world around them, and provide a common understanding of information among people, which allow people communicate the understanding to each other.

2.1.1 DEFINITION OF ONTOLOGY

In recent years, the word ontology has taken on new meaning. The current application of the word in the science and technology field derives its meaning from classical philosophy. In the classical sense of the word, ontology simply “means a systematic explanation of existence;” (Gómez-Pérez 1999) or, in other words, an ontology is the “theory of existence". (Mizoguchi and Ikeda 1998). Barry Smith, as part of *the Blackwell Guide to the Philosophy of Computing and Information*, describes ontology as:

> *" a branch of philosophy is the science of what is, of the kinds and structures of objects, properties, events, processes and relations in every area of reality. 'Ontology' is often used by philosophers as a synonym of 'metaphysics' (a label meaning literally: what comes after the Physics'), a term used by early students of Aristotle to refer to what Aristotle himself called first philosophy'. Sometimes 'ontology' is used in a broader sense, to refer to the study of what might exist; metaphysics' is then used for the study of which of the various alternative possible ontologies is in fact true of reality. (Ingarden 1964) The term 'ontology' (or ontologia) was coined in 1613, independently, by two philosophers, Rudolf Göckel (Goclenius), in his Lexicon philosophicum and Jacob Lorhard (Lorhardus), in his Theatrum philosophicum. Its first occurrence in English as recorded by the OED appears in Bailey's dictionary of 1721, which defines ontology as 'an Account of being in the Abstract'* (Smith 2004).

Information sciences has moved ontology from the abstract to the more concrete. According to Thomas Gruber, a leader in the field of ontological research, ontology simply means "*an explicit representation of conceptualization*," (Gruber 1995) where conceptualization means to "*associate the names of entities in the universe of discourse with human-readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of the terms*." (Gruber 1995).

While Gruber's definition is often cited and is one of the primary sources for ontological research, the definition is not simply understood. Another definition is that "*an ontology is a hierarchically structured set of terms for describing a domain that can be used as a skeletal foundation for a knowledge base*." (Swartout et al. 1997) Yet another definition, and the clearest definition, is that of Arvidsson and Flycht-Eriksson, "*an ontology provides a shared vocabulary, which can be used to model a domain, that is, the type of objects and/or concepts that exist, and their properties and relations*." (Arvidsson and Flycht-Eriksson 2008).

However, one of the most complete definitions when pertaining to this research comes from Noy and McGuinness. According to Noy and McGuiness (2001), an ontology can be defined as *"a formal explicit description of the concepts in a domain of discourse, properties of each concept describing various features and attributes of the concept, and restrictions on slots"*. This definition sets the stage for the BIM Use Ontology. Ontologies organize the structure of the knowledge with a domain which makes it reusable (Chandrasekaran et al. 1999).

2.1.1.1 Comparison of Ontology to other forms of Vocabulary

When developing an ontology other terms are often discussed such as a dictionary and taxonomy. The following table, Table 2-1, discusses the differences between the dictionary, taxonomy, and ontology.

Table 2-1: Comparison of Dictionary, Taxonomy, and Ontology

Item	Description	Differences
Dictionary	*lists the words of a language (typically in alphabetical order) and gives their meaning, or gives the equivalent words in a different language, often also providing information about pronunciation, origin, and usage* (Oxford Dictionary 2013c)	A dictionary is different from an ontology and taxonomy in that is does not give structure for the terms that it contains.
Taxonomy	*the practice and science (study) of classification of things or concepts, including the principles that underlie such classification* ("Taxonomy" 2013)	A taxonomy is different from an ontology and a dictionary in that it does not give definition to the terms within it, rather may only contain the structure.
Ontology	*an ontology provides a shared vocabulary, which can be used to model a domain, that is, the type of objects and/or concepts that exist, and their properties and relations*." (Arvidsson and Flycht-Eriksson 2008)	An ontology is a combination of a dictionary and taxonomy within a specific domain, as an ontology establishes both a meaning for the terms and a classification system

2.1.2 Purpose and Benefits of Ontologies

There are many benefits to ontologies. An ontology makes understanding and processing data easier. According to Noy and McGuinness (2001), the five primary reasons for someone to develop an ontology are:

1. to create a common understanding of information among people,
2. to enable reuse of domain knowledge,
3. to make a domain's main assumptions explicit,
4. to separate domain knowledge from the operation knowledge, and
5. to analyze domain knowledge.

Another benefit is that an ontology can guarantee consistency between organizations (Gruber 1995). An ontology allows for organizations to share vocabulary in a consistent manner while not sharing proprietary knowledge within that vocabulary. Additionally, Gruber states, an ontology can be applied for a conceptual schema for databases, a backbone for the information of the users in a certain domain, answering competency questions, standardizing, transforming databases, knowledge reuse, and knowledge reorganization.

2.1.3 Components of Ontologies

A properly developed ontology consists of five elements. The elements, shown in Figure 2-1, include a) terms, b) definitions, c) attribute types, d) classes, and e) a class hierarchy. These elements are the basis for all ontologies (Gruber 1995).

Figure 2-1: Components of an Ontology
(Gruber 1995)

Ontology Component	Description	Synonyms
Terms	*A word or expression that has a precise meaning in some uses or is peculiar to a science, art, profession, or subject*. (Merriam-Webster 2013a)	Names, Words
Definition	*An exact statement or description of the nature, scope, or meaning of something* (Merriam-Webster 2013a)	Description, Explanation
Attribute	*A quality or feature regarded as a characteristic or inherent part of someone or something* (Oxford Dictionary 2013a)	Property, Characteristic
Classes	*A group, set, or kind sharing common attributes* (Merriam-Webster 2013b)	Types, Concepts
Class Hierarchy	*An arrangement or classification of things according to relative importance or inclusiveness* (Oxford Dictionary 2013b)	Structure, Organization

2.1.3.1 Standard Terms

An ontology includes a list of all terms that are relevant to the domain including names for the terms themselves, but also those terms that relate the terms (Noy and McGuinness 2001). The ontological definition of "term" is similar to that of the English definition, where term is defined as *a word or expression that has a precise meaning in some uses or is peculiar to a science, art, profession, or subject* (Merriam-Webster 2013a). More simply, a term is a *word or phrase used to describe a thing or to express a concept, especially in a particular kind of language or branch of study* (Oxford Dictionary 2013d).

2.1.3.2 Standard Definitions

Within an ontology, each term must have a concise definition and description. This exact statement or description of the nature, scope, or meaning of the term. The exact definition allows for the shared understanding of the meaning of the various terms.

2.1.3.3 Standard Attributes Types

Part of an ontology are standard attributes (or characteristics) for each and all the terms. The ontological definition of "attribute" is similar to that of the English definition where an attribute is defined as *a quality or feature regarded as a characteristic or inherent part of someone or something* (Oxford Dictionary 2013a). An attribute is a property or characteristic of the class which can be applied to describe it. However, attributes typically do not define the class itself because attributes are often variable. These attributes can be extrinsic rather than intrinsic, which if applied to developed classes would also the instances to move from one class to another (Noy and McGuinness 2001). For example, an attribute of a class could be based on its status such as weight, temperature, speed, time, and cost.

2.1.3.4 Standard Classes

A part of an ontology is a class. The ontological definition of "class" is similar to that of the English definition, where a class is defined as *a group, set, or kind sharing common attributes* (Merriam-Webster 2013b) More specifically in ontological research, *classes describe the concepts or groups within the domain* (Noy and McGuinness 2001). Classes are applied to group instances with similar attributes. In order for a class to be properly created, an instance should only be a part of one class. Additionally, it may be possible to create several different class sets based on different attributes (or characteristics) of the instances. In some cases, these may not follow the typical rules of classes, and there may be more methods to sort the instances than formal classes.

2.1.3.5 Standard Class Hierarchy

An ontology should contain a hierarchical structure for the classes. The ontological definition of "hierarchy" is similar to that of the English definition where an hierarchy is defined as a*n arrangement or classification of things according to relative importance or inclusiveness* (Oxford Dictionary 2013b). A hierarchy establishes and illustrates the relationship of the classes to one another.

2.1.4 Methodologies for Ontology Development

Many articles have been published about the different methods to create ontologies. Some of these methods to develop ontologies include the TOVE (Toronto Virtual Enterprise) approach, the Enterprise Model Approach, the METHONTOLOGY approach, and the IDEF5 approach. (Noy and McGuinness 2001; Uschold and King 1995). Jones et al. (1998) discusses at least thirteen different methodologies in their article *Methodologies for Ontology Development*. The number of different methodologies supports one of Noy and McGuiness's fundamental rules of ontology creation: "*There is no one correct way to model a domain— there are always viable alternatives. The best solution almost always depends on the application that you have in mind and the extensions that you anticipate."* (Noy and McGuinness 2001).

The methodology described in the majority of the literature follows as similar resulting pattern which can be summarized as follows:

1. Define domain and scope
    a. Define Purpose
    b. Define Scope
    c. Define Uses
    d. Define Users
    e. Create Competency Questions
    f. Establish completion Criteria
2. Knowledge Acquisition
    a. Research other ontologies
3. Document Domain Terms
4. Integration of Terms
    a. Group terms
    b. Define classes
    c. Define the class hierarchy
    d. Define the properties of classes
5. Evaluation
6. Documentation

Even before proceeding through the steps of ontology creation, the reason to create an ontology in the first place should be established (Jones et al. 1998). This "motivating scenario" is usually the story about why an ontology needs to be created.

2.1.4.1 Define Domain and Scope

The first step of creating an ontology is to define its domain and scope. This includes defining the purpose of an ontology (Jones et al. 1998), which includes how and who will apply the ontology. The scope of an ontology must also be determined, including the specific terms within the domain, their characteristics, and the required level of detail. The scope includes both parts of the domain that will be included and those parts that will be excluded (Jones et al. 1998). In addition to answering the questions of what will the ontology cover, and who will apply the ontology, the question of who will maintain the ontology should also be answered (Noy and McGuinness 2001). It is possible that scope may change slightly throughout the creation of an ontology, but a scope must be established in order to make the task accomplishable. Creating competency questions may help to determine the scope of an ontology. Competency questions are the items that should be answered by the knowledge contained within an ontology (Gruninger and Fox 1995). Also, a set of completion criteria for an ontology should be established that both contain objectives and requirements (Jones et al. 1998). At the conclusion of this phase, a statement should be created about what will be included within an ontology.

2.1.4.2 Knowledge Acquisition

During this step, knowledge or data about the domain should be collected. This process will occur in parallel with the first step (Jones et al. 1998). Knowledge acquisition may be started prior to the first, with the knowledge about the domain helping to establish the need for an ontology. This stage does not have a specific methodology for completion; however expert interviews and content analysis are major portions.

2.1.4.3 Document Domain Terms

After the data has been collected in the previous step, the data should be extracted in a manner it can be applied to create an ontology. During this step, a list of all terms that are relevant to the domain should be created (Jones et al. 1998; Noy and McGuinness 2001). This includes names for the tasks themselves and the terms that relate the tasks (Noy and McGuinness 2001). During this stage the lists should be as comprehensive as possible. The overlap, relations, properties, or classes should not be considered when creating lists of terms. Some methodologies state that a basic description of each term should be included in this step (Jones et al. 1998). The identification of domain terms can be accomplished using multiple methodologies. Inherently the terms should come from the knowledge acquisition phase; however, additional brainstorming should be conducted to ensure the list is comprehensive. The list of terms will also help to confirm that the scope of an ontology is appropriate for an ontology's domain.

2.1.4.4 Integration of Terms

The next step to develop an ontology is to integrate the various domain terms. Within ontology development literature, the process of integrating terms is referred to using multiple terms. In most methodologies, an initial ontology is first created during the term integration phase of an ontology's development. Term integration includes documenting an initial description of kinds, relations and properties (Jones et al. 1998). During this stage the terms defined in the previous stage should be grouped by logical means to form classes. Classes describe *the concepts or* *groups within the domain* (Noy and McGuinness 2001). The grouping of terms, which is based upon attributes of the terms, should be completed through brainstorming and focus group meetings. The classes should then be put into superclasses and a class hierarchy. When creating the class hierarchy, all subclasses should be part of the superclass and all of the superclasses should contain the attributes of the subclasses. Once the development of classes and a class hierarchy is complete the properties of the classes should be defined including names, properties and attributes. During this process other ontologies which exist within the domain can be applied, when possible, for the class names and definitions of terms.

There are multiple approaches to developing a class hierarchy including a top-down approach, a bottom-up, or a combination of the two approaches (Noy and McGuinness 2001). A top-down approach starts with the most general groups and concepts. A bottom-up approach begins with the lowest-level, most-specific classes defined and works towards the general classes. A combination approach employs both the bottom-up and the top-down approach by classifying the most defined terms and classes first.

2.1.4.5 EVALUATION

After an initial ontology is developed, the ontology should be refined, verified, and validated. During this evaluation, an ontology is checked for completeness, inconsistencies, comprehensiveness, and redundancies (Jones et al. 1998). Completeness can be checked, among other methods, by ensuring that all of the competency questions can be answered by an ontology. In this case evaluation means to carry out technical judgment of an ontology (Fernandez et al. 1997). Verification refers to the correctness of an ontology and validation guarantees an ontology corresponds to the system or domain that it is supposed to represent (Fernandez et al. 1997). . Some methodologies suggest that this take place during each phase of an ontology's development. The processes applied to evaluate an ontology should be part of the documentation justifying the validity of an ontology.

2.1.4.6 DOCUMENTATION

After an ontology has been evaluated, an ontology should be documented including combining and consolidating documents that resulted from other activities (Jones et al. 1998). The ontology development methodology, *Methontology*, states that the documentation of an ontology should include documentation on each of the steps of an ontology's development. These steps include the domain, purpose, scope, application, knowledge acquisition, domain terms, integration, and evaluation processes. This process can be done at the completion of an ontology's creation, however it is better to document at each phase of the creation of an ontology (Fernandez et al. 1997).

2.1.5 Challenges when Developing Ontologies

Many items can hinder the developing of ontologies. However, methods exist to overcome these challenges. Some of the challenges in ontology development include:

- **Competency Questions:** Difficulty creating a useful set of competency questions before creation of an initial ontology is a challenge. (Uschold and King 1995) Uschold and King state while competency questions are helpful, competency questions are not the only method to develop ontologies and an ontology can be created without competency questions.
- **Term Bias**: Pre-established terms have pre-conceived ideas about each term is a challenge. Each term has different meaning to different people. To overcome this challenge create new terms during the process of creating an ontology which focus on the core meaning. At this stage of ontological development the terms can be arbitrary as long as they have an agreed upon definition. After an ontology is created, it may be possible to employ more established terms (Uschold and King 1995).
- **Class Cycling:** Ensuring that the class hierarchy is correct is a challenge. Ensuring that all subclasses are part of the superclass without overlap is a challenge (Noy and McGuinness 2001). Class cycling, where a subclass is part of a superclass and the superclass is part of the subclass, is also possible. Diligence needs to be taken when creating and evaluating classes and class hierarchy to ensure that classes are properly structured.
- **Multiple Inheritance:** When a class is a subclass of multiple superclasses is a challenge. Classes should be developed in such a way to not allow this to happen or have multiple inheritance modeled into its structure (Noy and McGuinness 2001). The challenge of multiple inheritance is dependent upon the domain.
- **New Class Introduction:** Determining when to introduce a new class is a challenge (Noy and McGuinness 2001). An additional class should be created when instance within the class "has (1) additional properties that the superclass does not have, or (2) restrictions different from those of the superclass, or (3) participate in different relationships than the superclasses." (Noy and McGuinness 2001). For an ontology to be useful, a balance needs to be found between not having enough classes and having too many classes.
- **Subclass Numbers:** Determining the number of subclasses below a superclass is a challenge. There is no defined number of subclasses that should be part of a superclass. However, experts state if a class has only one subclass, the subclass maybe incomplete or modeled incorrectly; and if a class has more than a dozen subclasses, additional class in between the subclass and superclass may exist (Noy and McGuinness 2001).

- **Classes versus Instances:** Determining if a term is a new class, property value or instance is a challenge (Noy and McGuinness 2001). The challenge is whether an attribute or property with similar values should be created into a new class. While, on the other hand, it may be possible that an instance of the class is actually a whole class on its own.
- **Scope Creep:** Limiting the scope of an ontology is a challenge (Noy and McGuinness 2001). An ontology cannot contain all information, including attributes and properties, about the domain. The scope should be defined during the first stage to help prevent this challenge from occurring. It is not possible to document all information about a particular domain. However an ontology must allow for expansion to include the additional domain information as necessary.

Taking into account these challenges while creating an ontology helps to ensure the validity of the ontology created.

2.2 RELATED ONTOLOGIES WITHIN THE INDUSTRY

Many ontologies exist within the AECO Industry that are applied on a daily basis. Examples of these include ASTM UniFormat II, CSI MasterFormat, and OmniClass. Most of the ontologies implemented were not developed as comprehensive ontologies using strict ontology development standards. However, these ontologies have become the de facto standards which allow for communication of concepts within the AECO Industry. Most of the ontologies within the AECO Industry focus on facility elements and few focus on the processes of a facilities life. While no ontologies specific to the domain of BIM Uses exist, there are good examples of well-established and widely adopted ontologies within the industry.

2.2.1 ASTM UNIFORMAT II

An example of a widely accepted ontology is ASTM UniFormat II. ASTM UniFormat II is a classification system based on the elements of building and related systems. UniFormat was first develop through collaboration effort between GSA and AIA in 1972. UniFormat was then enhanced and released as UniFormat II in 1993. Figure 2-2 illustrates the elements within the UniFormat II structure.

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
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
C INTERIORS	C10 Interior Construction	C1010 Partitions C1020 Interior Doors C1030 Fittings
	C20 Stairs	C2010 Stair Construction C2020 Stair Finishes
	C30 Interior Finishes	C3010 Wall Finishes C3020 Floor Finishes C3030 Ceiling Finishes
D SERVICES	D10 Conveying	D1010 Elevators & Lifts D1020 Escalators & Moving Walks D1090 Other Conveying Systems
	D20 Plumbing	D2010 Plumbing Fixtures D2020 Domestic Water Distribution D2030 Sanitary Waste D2040 Rain Water Drainage D2090 Other Plumbing Systems
	D30 HVAC	D3010 Energy Supply D3020 Heat Generating Systems D3030 Cooling Generating Systems D3040 Distribution Systems D3050 Terminal & Package Units D3060 Controls & Instrumentation D3070 Systems Testing & Balancing D3090 Other HVAC Systems & Equipment
	D40 Fire Protection	D4010 Sprinklers D4020 Standpipes D4030 Fire Protection Specialties D4090 Other Fire Protection Systems
	D50 Electrical	D5010 Electrical Service & Distribution D5020 Lighting and Branch Wiring D5030 Communications & Security D5090 Other Electrical Systems
E EQUIPMENT & FURNISHINGS	E10 Equipment	E1010 Commercial Equipment E1020 Institutional Equipment E1030 Vehicular Equipment E1090 Other Equipment
	E20 Furnishings	E2010 Fixed Furnishings E2020 Movable Furnishings
F SPECIAL CONSTRUCTION & DEMOLITION	F10 Special Construction	F1010 Special Structures F1020 Integrated Construction F1030 Special Construction Systems F1040 Special Facilities F1050 Special Controls and Instrumentation
	F20 Selective Building Demolition	F2010 Building Elements Demolition F2020 Hazardous Components Abatement

Figure 2-2: ASTM UniFormat II Classification for Building Elements (E1557-97)
(Charette and Marshall 1999)

2.2.2 CSI MasterFormat 1995

CSI MasterFormat 1995 is another example of a widely accepted ontology with industry. CSI MasterFormat 1995 divides the work results of construction into 16 categories. In 2004, CSI determined that the 16 divisions were not enough and divided the work results into 50 divisions. However by that time, the industry had already standardized on the sixteen divisions, and many firms still employ the sixteen divisions today. Figure 2-3 illustrates the top level CSI MasterFormat 1995 divisions

Division	Contents
1	General Requirements
2	Site Construction
3	Concrete
4	Masonry
5	Metals
6	Woods and Plastics
7	Thermal and Moisture Protection
8	Doors and Windows
9	Finishes
10	Specialties
11	Equipment
12	Furnishings
13	Special Construction
14	Conveying Systems
15	Mechanical
16	Electrical

Figure 2-3: CSI MasterFormat 1995 Divisions
(Construction Specifications Institute 1995)

2.2.3 CSI MasterFormat 2004

With the advent of more complex facilities, the 16 divisions within CSI MasterFormat 1995 were no longer sufficient. Therefore, in 2004 CSI released a version of MasterFormat with 50 divisions. However at this point, fifteen of the divisions are reserved for future needs. Figure 2-4 shows the CSI Master Format 2004 Divisions.

Division	Contents	Division	Contents
00		**25**	Integrated Automation
01	General Requirements	**26**	Electrical
02	Existing Conditions	**27**	Communications
03	Concrete	**28**	Electronic Safety and Security
04	Masonry	**29**	Reserved
05	Metals	**30**	Reserved
06	Wood, Plastics, and Composites	**31**	Earthwork
07	Thermal and Moisture Protection	**32**	Exterior Improvements
08	Openings	**33**	Utilities
09	Finishes	**34**	Transportation
10	Specialties	**35**	Waterway and Marine Construction
11	Equipment	**36**	Reserved
12	Furnishings	**37**	Reserved
13	Special Construction	**38**	Reserved
14	Conveying Equipment	**39**	Reserved
15	Reserved	**40**	Process Integration
16	Reserved	**41**	Material Processing and Handling Equipment
17	Reserved	**42**	Process Heating, Cooling, and Drying Equipment
18	Reserved	**43**	Process Gas & Liquid Handling, Purification, & Storage Equipment
19	Reserved	**44**	Pollution Control Equipment
20	Reserved	**45**	Industry-Specific Manufacturing Equipment
21	Fire Suppression	**46**	Reserved
22	Plumbing	**47**	Reserved
23	Heating, Ventilating, and Air Conditioning	**48**	Electrical Power Generation
24	Reserved	**49**	Reserved

Figure 2-4: CSI MasterFormat 2004 Divisions
(Construction Specifications Institute 2004)

2.2.4 OmniClass Tables

OmniClass is a relatively new classification system and is a strategy for classifying the entire built environment (CSI 2006). OmniClass incorporates other standards such as UniFormat and MasterFormat within its tables. OmniClass is gaining a lot of traction within the industry because it's open and extensible. Figure 2-5 shows the tables within OmniClass.

11 Construction Entities by Function
12 Construction Entities by Function
13 Spaces by Function
14 Spaces by Form
21 Elements – UniFormat
22 Work Results – MasterFormat 04
23 Products

31 Phases
32 Services
33 Disciplines
34 Organizational Roles
35 Process Aids
41 Information
42 Materials
49 Properties

Figure 2-5: OmniClass Tables
(OCCS Development Committee Secretariat 2013)

Of the AECO Industry ontologies, OmniClass is the most comprehensive and is one of the few classification systems to address items other than facility elements. However, a challenge with OmniClass and the other classification systems are the methods employed to develop the systems. The development of the OmniClass tables is not a comprehensive process and as facility technology evolves so do the classification systems. While OmniClass is an ontology based on the fundamental definition of ontology, OmniClass has not met all the criteria for a well-developed ontology such as multiple inheritance. Once OmniClass gains more of a consensus adoption and been more vigorously validated, then OmniClass will align with all of the criteria of an ontology.

2.3 Overview of BIM

BIM is changing the AECO Industry. While BIM does not change the purpose of the industry and the fact that we are still designing, constructing, and operating facilities, BIM can alter the processes applied to accomplish these tasks. BIM can be applied to improve a number of processes in all phases of a facility's life. Unlike "traditional" 2D-based processes BIM allows for the focus to be on the product of the facility rather than another deliverable (such as constructions documents) which need to be interpreted to be built. The models that are properly developed using BIM processes actually represent the physical object that has yet to be realized.

This paradigm shift allows for the optimization of numerous processes including

- improving the ability to visualize and review by project stakeholders during design;
- improving construction documents because of the parametric nature of the models;
- improving the construction coordination process by reviewing the models in detail and coordinating the model prior to construction;
- improving the richness of the data turned over to the owner at the end of construction; and
- improving the ability of the facility operators to access data about the facility.

Two benefits consistently become apparent when implementing BIM including improved visualization through modeling and improved understanding of the facility through improved access to facility information.

2.3.1 Definitions of Building Information Modeling

There has been much debate over a definition of a Building Information Model and Building Information Modeling. Smith and Tariff (2009) argue that "far too much time is still devoted to defining exactly what terms "Building Information Model" and "Building Information Modeling" mean." The term BIM was created to distinguish between the next generation of digital design tools and the CAD tools of the past. The term itself was not designed to be analyzed and scrutinized to the degree it has received in recent years.

To attempt to overcome the confusion of the meaning of BIM, numerous organizations have attempted to develop a singular definition of a Building Information Model and Building Information Modeling. The buildingSMART alliance (bSa) in its National BIM Standard Charter puts forth the definition that "*A Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM can represent viewpoints – graphically and in text and table form, of a building from any practitioner perspective – Architect, Specifier, Engineers, Fabricators, Leasing Agents, General Contractors and so on. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward."* The buildingSMART alliance's definition of "*Building Information Modeling is the act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes."*(buildingSMART alliance 2007).

Meanwhile, the Associated General Contractors of America's (AGC) *Contractors' Guide to BIM* defines Building Information Modeling as "*the development and use of a computer software model to simulate the construction and operation of a facility"* and defines Building Information Model as *"a data-rich, object-oriented, intelligent and parametric digital representation of [a] facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivery the facility."* (The Associated General Contractors of America 2006)

Additionally, the U.S. General Services Administration (GSA) employs a very similar definition to that of the AGC were *"Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design"* (General Services Administration 2007).

While the definitions of GSA, AGC, and the buildingSMART alliance try to encompass the entire meaning of the term, the simplest description of BIM (model) could be stated as *a digital representation of a facility* and BIM (modeling) is *the act of creating a BIM*. Within this definition, BIM can be applied for whatever purpose a user deems applicable. If more understanding of the term is required, the term should then be broken down into its individual terms: building, information, model, and modeling.

2.3.1.1 *Building*

The term building typically refers to a type of facility construction. However, in the case of Building Information Model and Modeling, a better definition of building would be anything built or constructed. The term building causes confusion because the term building typically refers to an enclosed construction that has a roof and windows. Under that definition, a building does not include facilities such as roads, transportations systems, processing plants and other forms of construction. When using the definition of anything built or constructed, the definition is adequate to include all forms of capital facility construction. While this is not the typical definition of building discussed within the industry, it would reduce the need for additional information modeling such as Civil Information Modeling (CIM), Infrastructure Information Modeling (IIM), and the many other information modeling acronyms based on a sector of the facilities industry. Moreover, the term can then also include the act, business, or practice of constructing.

2.3.1.2 *Information*

Information is organized data communicated or received concerning a particular fact or circumstance. In the case of BIM, the circumstance is the building, facility, or construction. The information contained within Building Information Models is what separates BIM from previous design communication tools. While CAD contained only points, lines, areas, and volumes, Building Information Models include information about the building elements and systems within the facility (General Services Administration 2007).

2.3.1.3 *Model*

The term model has many meanings depending upon its application. These multiple meanings have led to confusion within the industry. The confusion lies within a model being a visual representation of something else and a model being a mathematical description of a state of affairs. While confusing, both definitions are accurate when considering BIM. The model is an accurate representation of a facility that can exist within the real world. This representation can also be applied to create simulation of the model's performance within that world.

2.3.1.4 *Modeling*

Modeling refers to the act of creating a model or, in this case, a Building Information Model. Often design professionals only associate modeling with the creation of 3D geometry. Additionally, it also refers to not only creating the geometry of a building, but also representing its processes or systems (Smith and Tardif 2009). The critical difference between modeling and "traditional" drafting is that the modeling creates the representation of the elements of the facility whereas drafting creates lines and shapes which are the symbolic representation of the facility elements.

2.3.1.5 Management

Yet another school of the thought is that BIM should really be Building Information Management rather than modeling. Some have even gone as far as suggesting Building Information Modeling and management. The management school of thought focuses primarily on the application of the data that is contained within the model. It is the managing of the data and using the data to accomplish the processes of the facility that lead to it being given the name management. However, management is one part of the Building Information Modeling process as a whole.

2.3.2 Benefits of Building Information Modeling

Currently the AECO Industry is improving because of the immense benefits of Building Information Modeling. While CAD was collections of points, lines, 2D shapes and 3D volumes, BIM includes geometric entities that also have symbolic or abstract "meaning", as well as quantitative or qualitative data (Yan and Damian 2008). While not the only benefit, the article adopting BIM for facilities management argues a benefit of BIM is the "accurate geometrical representation of the parts of a building in an integrated data environment that is the key benefit of BIM" (CRC Construction Innovation 2007). BIM enables an interactive design process that is supported by a 2D CAD environment.

Because of the accurate geometrical representation of the facility more benefits of BIM can be derived. These include:

- "Faster and more effective processes – information is more easily shared, can be value-added and reused" (S. Azhar et al. 2008)
- "Better design – building proposals can be rigorously analyzed, simulations can be performed quickly and performance benchmarked, enabling improved and innovative solutions" (S. Azhar et al. 2008)
- "Controlled whole-life costs and environmental data – environmental performance is more predictable, life-cycle costs are better understood" (S. Azhar et al. 2008)
- "Better production quality – documentation output is flexible and exploits automation" (S. Azhar et al. 2008)
- "Automated assembly – digital product data can be exploited in downstream processes and be used for manufacturing/assembling of structural systems" (S. Azhar et al. 2008)
- Better customer service – proposals are better understood through accurate visualization (S. Azhar et al. 2008)
- Life-cycle data – requirements, design, construction and operational information can be used in facilities management (S. Azhar et al. 2008)
- Up to 40% elimination of unbudgeted change. (Center for Integrated Facility Engineering 2007)
- Cost estimation accuracy within 3%. (Center for Integrated Facility Engineering 2007)
- Up to 80% reduction in time taken to generate a cost estimate. (Center for Integrated Facility Engineering 2007)

- A savings of up to 10% of the contract value through clash detections (Center for Integrated Facility Engineering 2007)
- Up to 7% reduction in project time. (Center for Integrated Facility Engineering 2007)
- The implementation of BIM lowers overall risk distributed with a similar contract structure (Gilligan and Kunz 2007)
- The application of BIM leads to increased productivity, better engagement of project staff and reduced contingencies (Gilligan and Kunz 2007)

2.3.3 Challenges with BIM Implementation

While there are numerous benefits to implementing BIM within an organization and on a facility, BIM implementation is not without its challenges. BIM is a relatively new technology that has not reached its full maturity for all of the processes and BIM Uses. A lack of maturity leads to a number of different organizations supplying software and services to varying degrees of success. While speculation, it is possible that smaller software developers will either be bought out or no longer exist in several years.

Another challenge with adopting BIM is that there is not a clear understanding of the scope of the BIM implementation. While not the case of every project that implements BIM, often when promoting the implementation of BIM there tends to be what is termed "BIM washing", or over promising the benefits of BIM and the ease of adaption. It has been noted that the transition to BIM is not easy for most individuals. "BIM washing" leads to increased confusion on what is already a confusing topic. The act of "BIM washing" adds more terms for the shear marketability factor and as the addition of BIM becomes more common "BIM washing" becomes less and less effective.

It is challenging to develop a concrete business case when determining whether or not to implement BIM. This is due to the nature of the industry and the fact that there are very few metrics that support the return on investment of building information. The current metrics are all over the scale and are very dependent on the processes and the personnel implementing BIM. When implementing BIM there are numerous factors besides just BIM that may be changed such as collaboration level, delivery method, and construction methodologies. All of these factors influence the cost of a facility. However, BIM typically improves processes and most organizations quickly see a qualitative benefit shortly after implementing.

Once an organization decides to implement BIM within their processes and on their facilities, there are other challenges that they must overcome. A primary challenge is the culture of the organization and its resistance to change. Depending on the culture, one organization may more quickly adopt BIM, while another organization may take longer to implement BIM. With the adoption of any new technology there is a learning curve to it. BIM is no different. In fact, depending upon the number of years an individual or organization have been using a technology, the prior methods influence how quickly the will implement the new technology. This is due to a dramatic shift and process change.

Additionally, when an organization begins to implement BIM they quickly become aware that there are few industry standards. This lack of standards is primarily due to the relative newness of the technology and its constant improvement. Also, the lack of standards could be due to the large amount of fragmentation that exists within the industry. To overcome the lack of standards, every organization has to develop their own processes and standards. In many cases, these processes are developed on-the-fly on the project without carefully analyzing and documenting the process. Developing processes on-the-fly leads to a lack of standards within the organization itself and a duplication of effort. Lack of standards adds cost and extra effort to the implementation and adoption of BIM. However, despite these challenges BIM is being rapidly adopted and implemented within the industry.

2.4 BIM PLANNING

As stated in the introduction, the need for this research was established during the creation of the BIM planning guides developed by the Computer Integrated Construction (CIC) Research Program. The CIC Research Program first released the *BIM Project Execution Planning Guide* in the fall of 2009. This guide focused primarily on the implementation of BIM during the design and construction of a facility project. A critical development to come out of the BIM Project Execution Plan was the BIM Project Execution Plan Template. This template, released early in 2010, was reviewed in detail by the U.S. Army Corps of Engineers (USACE) / Industry Advisory Committee and adopted into their BIM contract language. Case studies were then implemented to validate the guide. The BIM Project Execution Plan Template was then updated and rereleased in the summer of 2010. Since its release, the template has been downloaded over 15,000 times and has been adopted by a number of organizations as part of their BIM contract language. It was also adopted into the U.S. National BIM Standard in 2011 as best practice.

During the course of the development of *the BIM Project Execution Planning Guide*, it was determined that there was a need to provide owner organization with guidance on how plan for implementation of BIM. The need led to the development of the *BIM Planning Guide for Facility Owners*. This guide provides the reader with three separate procedures include 1) BIM Organizational Strategic Planning, 2) BIM Organization Implementation Planning, and 3) BIM Project Procurement.

This guide was developed through content analysis, case study analysis, and industry feedback. The owners' guide was first released in April of 2012. After which it was evaluated via implementation case studies, an updated version of the *BIM Planning Guide for Facility Owners* was then released in June of 2013. Both BIM planning guides are the leading resources for BIM planning within the industry.

2.4.1 BIM Planning Elements

The BIM planning guides include common items referred to as BIM Planning Elements. The BIM Planning Elements, shown in Figure 2-6, are classified into six categories including:

1. **Strategy:** The mission, vision, goals, and objectives, along with management support, BIM champions, and BIM planning committee
2. **Uses:** The specific strategies of implementing BIM, including those BIM Uses for generating, processing, communicating, executing, and managing facility information
3. **Process:** The means and methods by which the BIM Uses are accomplished, including understanding current processes, designing new BIM processes and developing transition processes
4. **Information:** The facility informational needs of the organization, including the model element breakdown, level of development, and facility data
5. **Infrastructure:** The resources needed to support BIM implementation, including software, hardware, and workspaces
6. **Personnel:** The effects of BIM on the personnel, including the roles and responsibilities, the structure or hierarchy, the education and training programs, and change readiness

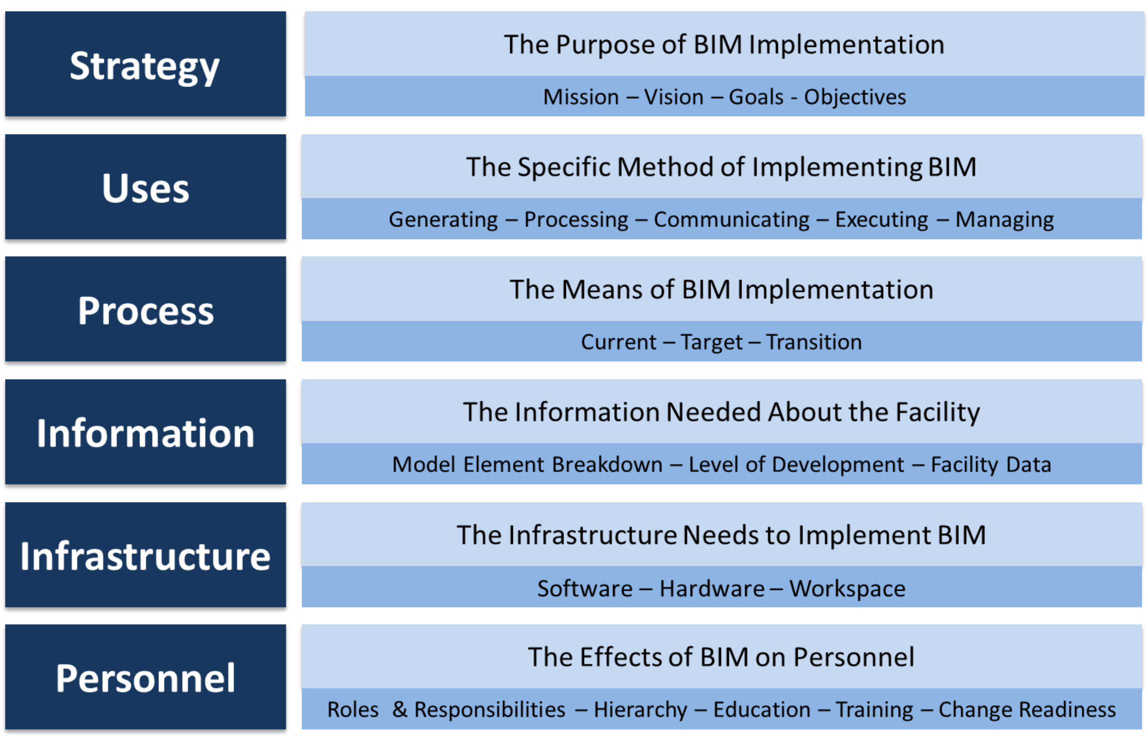


Figure 2-6: The BIM Planning Elements
(Computer Integrated Construction Research Program 2012)

The BIM Uses are the second category of these BIM elements. While they are a major part of the BIM planning process, the level of definition is not consistent throughout all the BIM Uses. The outcomes of this research could replace the BIM Uses section in all of the planning guides with a standardized BIM Use guide.

2.4.2 BIM PROJECT EXECUTION PLANNING (OR FACILITY-BASED BIM PLANNING)

The first procedure that was developed by the CIC Group was the BIM Project Execution Planning Procedure. The goal of a BIM Project Execution Plan is to ensure that all parties are clearly aware of the opportunities and responsibilities associated with the incorporation of BIM into the project workflow. A completed BIM Project Execution Plan should define the appropriate BIM Uses on a project e.g., design authoring, cost estimating, and design coordination, along with a detailed design and documentation of the process for executing BIM throughout a project's life-cycle. Once the plan is created, a project team can follow and monitor their progress against this plan to gain the maximum benefits from BIM implementation. The four steps within the procedure include:

1. Identifying project goals and high value BIM Uses during project planning, design, construction and operational phases
2. Design the BIM execution process by creating process maps
3. Define the BIM deliverables in the form of information exchanges
4. Develop the infrastructure in the form of contracts, communication procedures, technology and quality control to support the implementation

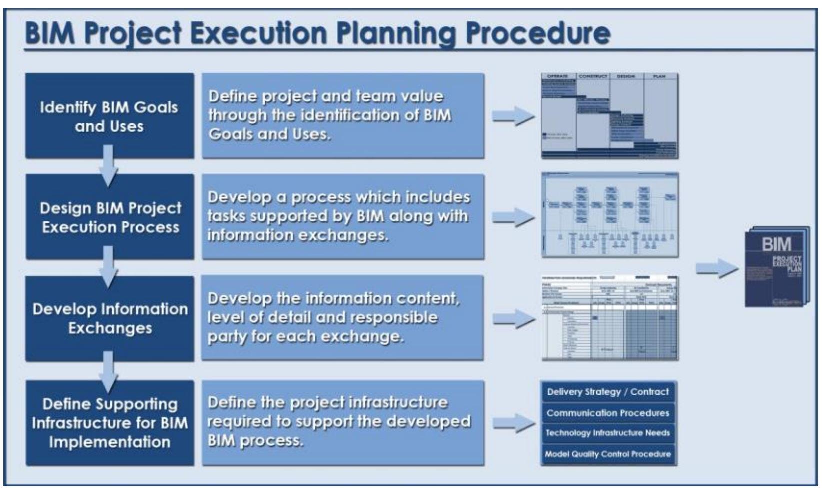


Figure 2-7: BIM Project Execution Planning Procedure
(Computer Integrated Construction Research Program 2010a)

While *the BIM Project Execution Planning Guide* was developed to further the BIM implementation on a project, the procedure could be considered a facility-based BIM execution planning guide. This is because the facility and its entire life should be at the center of this execution plan. The driving question should be how BIM could best be applied to enhance the facility operations over its life. It is possible that the planning, design, construction, and operation the facility is actually numerous projects. Therefore, the planning of BIM should be applied to the facility, rather than a specific project. A planning team must ask itself the question, "what is the product that is being developed or enhanced through BIM?"

2.4.3 Organizational BIM Planning

Organizational BIM planning focuses on integrated BIM into the organizational processes. Organizational processes are continuously repeated within the facility. Much like project or facility planning, organizational planning has the same core planning elements. There are three different areas of planning that should be addressed within an organization. The areas of planning include strategic planning, implementation (or tactical) planning, and procurement planning. The challenge with these three are is that there is overlap between them and each is dependent upon each other. While the *BIM Planning Guide for Facility Owners* suggests an organization develop a strategic plan, then an implementation plan, and then procurement language, typically organizations revise that development and start with a facility/project plan and work their way to a strategic plan.

2.4.3.1 BIM Organizational Strategic Planning

The strategic planning section discusses the need to look at BIM from a strategic level or major objectives level. In order to assist in this process the Guide presents a procedure with the goal to allow an organization to determine its purpose and vision for the integration of BIM. BIM Organizational Strategic Planning Procedure, as shown in Figure 2-8, for BIM includes:

1. Assessing the organization's internal and external BIM status;
2. Aligning the organization's BIM objectives by identifying its desired level of maturity; and
3. Advancing the BIM maturity level through developing a defined advancement strategy.

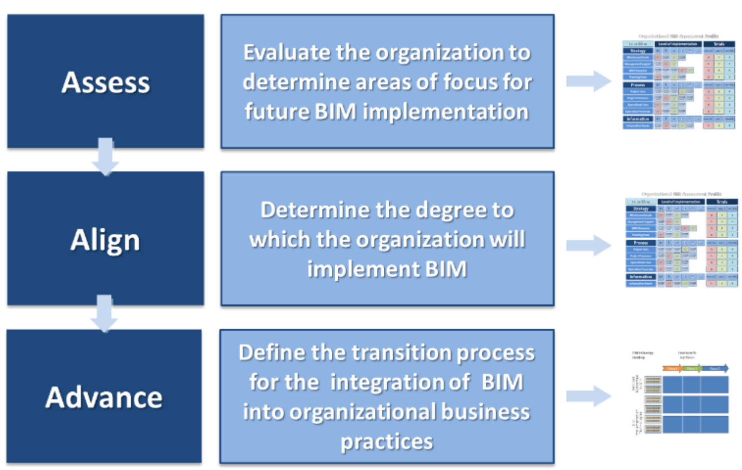


Figure 2-8: Strategic Planning Procedure for BIM
(Computer Integrated Construction Research Program 2012)

The challenge with the organization strategic planning procedure is that is very high level and some of the goals and objectives seem unobtainable. This requires the development of a detailed transition plan. Typically if an organization fails to develop a detailed transition plan, they will never achieve the objectives of the strategic plan.

2.4.3.2 BIM ORGANIZATIONAL IMPLEMENTATION PLANNING

Within the *BIM Planning Guide for Facility Owners*, the CIC Research Program outlines the BIM Organizational Implementation Planning Procedure. The BIM Organizational Implementation Plan is to be created after an organization completes a strategic planning effort. The purpose of this plan is to determine and document the detailed process for implementation to achieve the next stage in the organization's BIM development. The steps of the BIM Organizational Implementation Planning Procedure, shown in Figure 2-9, include:

1. Evaluating strategy;
2. Determining BIM Uses;
3. Mapping processes;
4. Documenting information requirements;
5. Determining infrastructure needs; and
6. Defining personnel requirements.

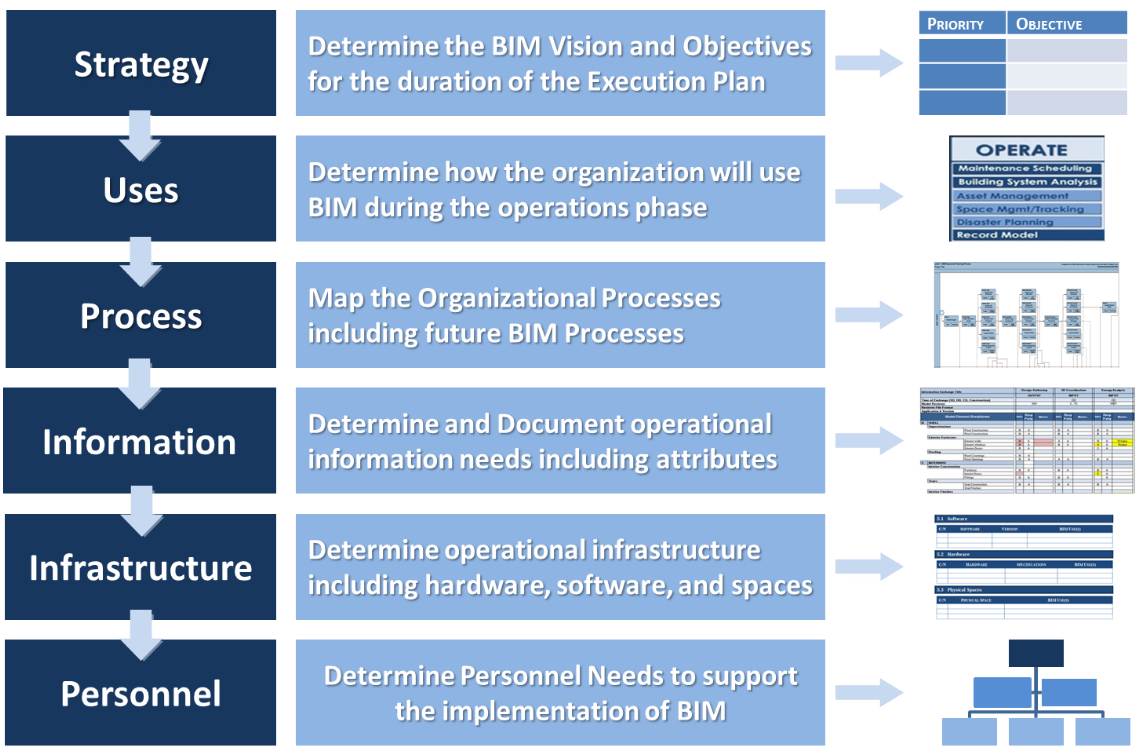


Figure 2-9: The BIM Organizational Implementation Planning Procedure
(Computer Integrated Construction Research Program 2012)

A major portion of the implementation planning procedure is to analyze the BIM Uses and the purpose for which an organization will be implementing BIM. This is challenging to accomplish when certain BIM Uses are aligned to certain disciplines, as is the case with the current BIM Uses within the *BIM Project Execution Planning Guide*. Rather, an organization needs to consider all the possibilities for which they will be implementing BIM.

2.4.3.3 BIM Project Procurement Planning

The *BIM Planning Guide for Facility Owners* also talks about procuring BIM services. The guide talks about the importance for an organization to develop contractual language that will ensure all of the owner's BIM needs are met, and all project members understand the requirements to which they are agreeing. With the proper documentation in place at the beginning of the project, the team can begin the BIM process much earlier and effectively. As Figure 2-10 shows, the two primary procurement documents include a standard BIM Project Execution Plan and the contract language itself.

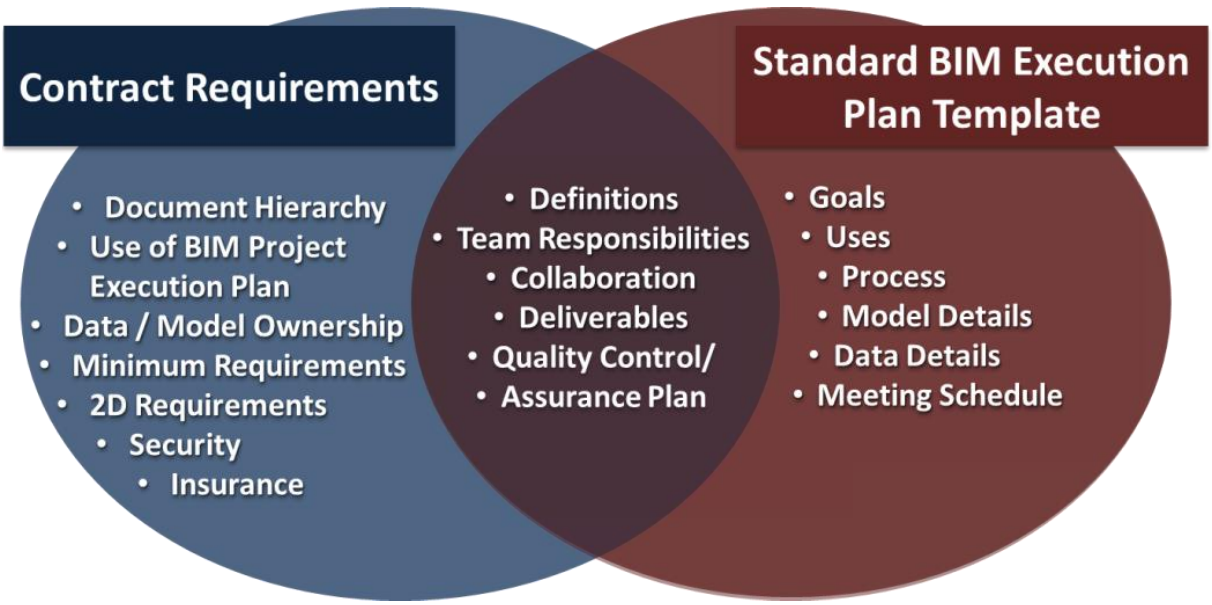


Figure 2-10: BIM Contract Requirements and Standard BIM PxP Template Features
(Computer Integrated Construction Research Program 2012)

With BIM contract language, just like any contract language, the challenge is to balance being too prescriptive vs. not prescriptive enough. If too prescriptive when planning, items may be missed and being too prescriptive can lead to just doing the minimum. On the other hand, if not prescriptive enough, it could lead to higher costs due to uncertainty and varied levels of BIM implementation between organizations. However, a better way to develop the contract language is to include the end applications of the information for which the organization needs. Basically, what does the organization want at the end of the implementation?

2.5 **BIM USES**

The BIM planning guides identify a concept of BIM Uses. The BIM Uses are the specific methods of implementing BIM. These BIM Uses (or methods) are simply replacing methods for activities that take place or should be taking place when developing a facility. The confusion with the meaning of a BIM Use is when the BIM Uses vary from publication to publication, from guide to guide, and from BIM plan to plan.

2.5.1 DEFINITION OF BIM USE

There are two common BIM Uses that organizations typically implement and then consider themselves "fully BIM capable". When most designers consider BIM, they think of the employment of tools like *Revit* to create a 3D Model of a proposed facility. Contractors, on the other hand, consider BIM to be using software like *Navisworks* to determine if there are any physical interferences in the design before the facility is built in the real world. While this is a generalization, it holds true especially when contractors and designers are first implementing BIM. The examples of design authoring and 3D coordination are only a few examples of the ways in which BIM can be applied.

The first version of the *BIM Project Execution Planning Guide* defined BIM Use as *A unique task or procedure on a project which can benefit from the application and integration of BIM into that process.* (Computer Integrated Construction Research Program 2010a) A BIM Use could also be called a BIM application, BIM strategy, BIM tool, BIM use case, or BIM solution. This definition was later refined in the *BIM Planning Guide for Facility Owners* as *a method of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives* (Computer Integrated Construction Research Program 2013b).

2.5.2 CURRENT TERMS AND DEFINITIONS OF BIM USES

There have been many lists of BIM Uses created and presented in BIM literature. While most of the lists are not comprehensive, nor organized into a structure or ontology, they provided a starting point for the creation of a comprehensive ontology. Most of the BIM Uses are developed for another purpose beyond the BIM Uses themselves. In most cases these BIM Uses are documented with the traditional biases of the AECO Industry. Most lists of BIM Uses are very discipline-dependent, and are not extensible. For the lists of BIM Uses that have been extended, most of the additional BIM Uses vary greatly from the original BIM Uses within the list. The following is a brief overview of all the current lists of BIM Uses.

2.5.2.1 BIM PROJECT EXECUTION PLANNING GUIDE WEBSITE

The most widely adopted BIM Uses are the BIM Uses defined on the BIM Execution Planning website (Computer Integrated Construction Research Program 2013a). Despite the wide adoption of the BIM Uses on the website, there are still a number of issues with those BIOM Uses. One issue is that the Uses change slighting between publications. The changing between versions makes it necessary for an organization to move from to version to version of the slightly updated BIM Uses.

Another challenge is the terms BIM Planning website overlap. An example of overlapping terms is the BIM Uses of phase planning and site utilization planning. Both of these BIM Uses are about how the facility will be constructed and the only difference is that phase planning focuses on permanent elements while site utilization planning focuses on temporary elements and construction logistics. Another example of overlapping terms is design authoring and record modeling. The only deference between these BIM Uses is the phase at which the BIM Use is performed. For example, record modeling is performed at the end of the construction process, while design authoring can be performed at any point during the construction process.

Additionally, there are number of cases where BIM Uses are simply missing. An example of this is the lack of drawing production, which is one of the major BIM Uses in which a designer may apply BIM. The challenge with BIM Uses missing is that when a Use is added, where will it be located within a phase of a facility? The BIM Use of drawing production could be placed at any phase of a facility's life-cycle and the subject of the BIM Use would then determine phase. For example, construction drawings, shop drawings, as-built drawings, or as-maintained drawings are the same except for the phase. Additionally, the subject often assumes a discipline which also should be conveyed. Based on this fundamental failure, the list of BIM Uses contained within the BIM PxP Guide is not easily extensible.

The division or level of specificity varies greatly between the BIM Uses defined in the *BIM Project Execution Planning Guide*. For example, a primary BIM Use such as design authoring is very basic and high level. The level of specificity does not tell the user, the element or discipline of the BIM Use. While a BIM Use like mechanical analysis is more specific by defining the purpose (analysis), element (HVAC), phase (design), and discipline (Mechanical). The level of specificity was the major challenge with all BIM Uses.

The BIM Uses are organized by proposed project phase because, currently, no suitable ontology exists to organize them. This organization is also due to the methodology applied to develop the list of BIM Uses. Each researcher developing the *BIM Project Execution Planning Guide* was assigned a facility phase and then tasked with the responsibility to document the BIM Uses within that phase. After the BIM Uses were documented, they were consolidated and the BIM Uses that were in multiple phases were simply shown with a line across multiple phases. If this were an ontology, the BIM Uses could not be in multiple phases. These BIM Uses, shown in Table 2-2, have now become to a certain degree an industry standard for the BIM Uses through various organizations' adoption of the concepts within the BIM project execution planning procedure.

The following, Table 2-2, is list of the BIM Uses defined in the *BIM Project Execution Planning Guide*.

Table 2-2: BIM Project Execution Planning Guide's BIM Uses
(Computer Integrated Construction Research Program 2011)

Use	Description
Existing Conditions Modeling	a process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility.
Cost Estimation	cost estimation / quantity take-off is "a process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the life-cycle of a project
Phase Planning (4D Modeling)	a process in which a 4D model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site
Programming	a process in which a spatial program is used to efficiently and accurately assess design performance in regard to spatial requirements
Site Analysis	a process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project
Design Review	a process in which stakeholders view a 3D model and provide their feedbacks to validate multiple design aspects
Design Authoring	a process in which 3D software is used to develop a Building Information Model based on criteria that is important to the translation of the building's design
Structural Analysis	a process in which analytical modeling software utilizes the BIM design authoring model so to determine the behavior of a given structural system
Lighting Analysis	lighting analysis is a process in which intelligent modeling software uses a Building Information Model to determine the most effective lighting method based on lighting design specifications.
Energy Analysis	a process in the facility design phase which one or more building energy simulation programs use a properly adjusted BIM model to conduct energy assessments for the current building design
Mechanical Analysis	a process in which intelligent modeling software uses a Building Information Model to determine the most effective mechanical engineering method based on mechanical design specifications
Engineering Analysis	a process in which intelligent modeling software uses [a Building Information Model] to determine the most effective engineering method based on design specifications
Sustainability / LEED Evaluation	a process in which a BIM project is evaluated based on LEED or other sustainable criteria
Code Validation	a process in which code validation software is utilized to check the model parameters against project specific codes
3D Coordination	a process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems
Site Utilization Planning	a process in which BIM is used to graphically represent both permanent and temporary facilities on site during multiple phases of the construction process
Construction System Design	a process in which 3D System Design Software is used to design and analyze the construction of a complex building system (e.g. form work, glazing, tie-backs, etc.) in order to increase planning
Digital Fabrication	a process that uses digitized information to facilitate the fabrication of construction materials or assemblies
3D Control and Planning	a process that utilizes an information model to layout facility assemblies or automate control of equipment's movement and location
Record Modeling	a process used to depict an accurate representation of the physical conditions, environment, and assets of a facility
Building Maintenance Scheduling	a process in which the functionality of the building structure (walls, floors, roof, etc.) and equipment serving the building (mechanical, electrical, plumbing, etc.) are maintained over the operational life of a facility
Building System Analysis	a process that measures how a building's performance compares to the specified design
Asset Management	a process in which an organized management system is bi-directionally linked to a record model to efficiently aid in the maintenance and operation of a facility and its assets
Space Management / Tracking	a process in which BIM is utilized to effectively distribute, manage, and track appropriate spaces and related resources within a facility
Disaster Planning	a process in which emergency responders would have access to critical building information in the form of a model and information system

2.5.2.2 THE BIM HANDBOOK

The BIM Handbook, first released in 2008, is one of the leading references for Building Information Modeling. The handbook contains a number of ways in which BIM tools can be used by various disciplines of the building industry. The handbook organizes the BIM tools by BIM for owners and facility managers, BIM for architects and engineers, BIM for the construction industry, and BIM for subcontractors and fabricators. There are advantages and drawbacks to this organization. The primary advantage is that this organization allow for a personalized application of BIM. Typically, based on the stratification of the industry, each discipline is primarily concerned with their own discipline. This could also be a drawback because it limits other disciplines from considering the needs of other trades. Additionally there is much overlap between disciplines with little alignment of terminology. For example, BIM estimating tools, cost estimation, and quantity take-off and cost estimating. This may be a result of how the handbook was written. However when the duplication in the list is removed, the list of BIM tools is reduced from about 23 to 13 separate items. Overlapping using different terms adds to the confusion of the terms.

The following tables, Table 2-3 and Table 2-4, are the lists of Uses that are contained within each version of the BIM Handbook.

Table 2-3: BIM Uses in BIM Handbook (1st Edition)
(Eastman et al. 2008)

BIM for Owners and Facility Managers	BIM for Architects and Engineers / BIM Use in Design Processes

• BIM Estimating Tools
• Model Validation, Program, and Code Compliance
• Project Communication and Model Review Tools
• Model Viewing and Review
• Model Servers
• Facility and Asset Management Tools
• Operation Simulation Tools
	• Concept Design and Preliminary Analyses
	  ○ Space Planning
	• Building System Design and Analysis/Simulation
	  ○ Analysis/Simulation Software
	  ○ Cost Estimation
	  ○ Collaboration
	  ○ Experimental Design Using a Design 'Workbench'
	• Construction - Level Building Models
	  ○ Building System Layouts
	  ○ Drawing and Document Production
	  ○ Specifications
	• Design - Construction Integration
	• Design Review

BIM for the Construction Industry	**BIM for Subcontractors and Fabricators**
• Clash Detection • Quantity Takeoff and Cost Estimating • Construction Analysis and Cost Estimating • Cost and Schedule Control • Offsite Fabrication • Verification, Guidance, and Tracking of Construction Activities	(None Listed)

Table 2-4: BIM Uses in BIM Handbook (2nd Edition)
(Eastman et al. 2011)

BIM for Owners and Facility Managers	BIM for Architects and Engineers / BIM Use in Design Processes

• Pro forma analysis
• Operation simulation
• Commissioning and asset management
• Prefabrication
• Project Controls
• Schedule simulation/4D
• Design Coordination (clash detection
• Quantity takeoff and cost estimation
• Building system analysis / simulation
• Design Configuration / scenario planning
• Energy (environmental) Analysis
• Space planning and program compliance
	• BIM-Based Concept Design
	  o 3D Sketching Tools
	  o Sketching with BIM applications
	  o Preliminary circulation and security assessment
	  o Preliminary energy analysis
	  o Preliminary cost estimate
	• Building System Design, Analysis, Simulation, and checking
	  o Analysis/Simulation Software
	  o Analysis of Conformance to Building Code Requirements and Regulations
	  o Cost Estimation
	  o Simulating Organization Performance within Facilities.
	• Construction - Level Building Models
	  o Building System Layout
	  o Drawing and Document Production
	  o Specifications
	• Design - Construction Integration
	• Design Review

BIM for the Construction Industry	**BIM for Subcontractors and Fabricators**
• Clash Detection • Quantity Takeoff and Cost Estimating • Construction Analysis and Planning • Cost and Schedule Control • Offsite Fabrication • Verification, Guidance, and Tracking of Construction Activities	(None Listed)

2.5.2.3 GSA BIM Guide Series

The U.S. General Services Administration has taken a different approach than other guides and BIM efforts. Rather than trying to create and exhaustive list of the BIM Uses, they have created, or are creating, a guide on each of the major BIM Uses important to their organization. There are several advantages and drawbacks to this organization. An advantage is that this improves the ease of which each by the guides are developed because they do not have to be dependent on one another. However this leads to duplication and inconsistences in terminology between the guides. It also leads to the guide being at varying levels of specificity. For example, 3D laser scanning refers to a very specific method of capturing a facility's condition while facility's management refers to entire phase of the facilities life.

The following are GSA guides, shown in Table 2-5, that correlate directly to a BIM Use:

Table 2-5: GSA BIM Guides
(U.S. General Services Administration 2011)

	Guide
01	3D-4D BIM Overview
02	Spatial Program Validation
03	3D Laser Scanning
04	4D Phasing
05	Energy Performance and Operations
06	Circulation and Security Validation
07	Building Elements
08	Facility Management

2.5.2.4 The VA BIM Guide

The U.S. Department of Veteran Affairs (VA) released BIM Guidelines in 2010. These guidelines, unlike most others, are not organized by phase or discipline. The BIM Uses are organized into ten primary BIM Uses, which are listed on the same level with nine additional BIM Uses. This method of organization keeps the requirements simple, but the method of organization leads to the challenge of the BIM Uses varying in level of detail. For some of the BIM Uses, the VA guide separates the BIM Uses by systems, making the system the only difference between the BIM Uses. For example *Architecture – Spatial and Material Design Models* and *Building Systems Models* are only different because of the system being modeled. Moreover, the level of detail, or scale, is only the difference between *Master Plan Space Scheduling and Sequencing*; and *Communication of Construction Scheduling and Sequencing*. Moreover, there is no consistency in the naming of the use cases. Some of the use cases are two words while others are seven or eight words. The inconsistency in naming leads to some use cases having a specific meaning while other use cases are very general. Additionally, the list of BIM use cases is placed at the end of the document rather than appearing earlier as part of the core BIM requirements.

The following is a list of BIM Uses in the VA BIM Guide (Department of Veterans Affairs 2010):

- Space and Medical Equipment Validation
- Architecture – Spatial and Material Design Models
- Energy Analysis
- Design Visualization for Communication, Functional Analysis, & Constructability
- Building System Models – Structural, MEPF, and Interiors
- Master Plan Space Scheduling and Sequencing – 4D
- Communication of Construction Scheduling and Sequencing – 4D
- COBIE/Commissioning
- Clash Detection/Coordination
- Virtual Testing and Balancing
- Additional BIM Uses
    - Evaluating physical security & survivability
    - Early MEP design
    - 3D – Virtual functionality viewing and testing of the design
    - 5D – Material take-offs & cost estimating
    - Creating a interactive virtual workspace for the Design Team to achieve integrated design goals
    - Integrating information, e.g., electronic specifications that are tied to the BIM
    - Achieving automated code checking
    - Repeatable modular construction components to speed construction erection time
    - Modular construction & off-site fabrication

2.5.2.5 BIM Applications From Building Information Modeling (BIM): Benefits, Risks and Challenges

The article *BIM Benefits, Risks, and Challenges* (Salman Azhar et al. 2008) presents one of the first lists of BIM Uses within an academic peer reviewed journal. While the list seems incomplete, it does give some basic categories of BIM and basic definitions of each BIM Use. The Uses described in the article are still some of the most commonly implemented BIM Uses. Some of these items are very specific while others are general. For example, visualization is general while code review and forensic analysis are more specific. Some items are phases of facility life-cycle while others are products of the design and construction process. For example, facilities management is a phase in the life of a facility and fabrication/shop drawings are a deliverables during the construction process. Below is a list of the applications of BIM from Salman et al. (2008).

Table 2-6: Applications from Building Information Modeling: Benefits, Risks, and Challenges
(Salman Azhar et al. 2008)

BIM Application	Description
Visualization	"3D renderings can be easily generated in-house with little additional effort."
Fabrication/shop drawings	"It is easy to generate shop drawings for various building systems, for example, the sheet metal ductwork shop drawing can be quickly produced once the model is complete."
Code reviews	"Fire departments and other officials may use these models for their review of building projects."
Forensic analysis	"A Building Information Model can easily be adapted to graphically illustrate potential failures, leaks, evacuation plans, etc."
Facilities management	"Facilities management departments can use BIM for renovations, space planning, and maintenance operations."
Cost estimating	"BIM software(s) have built-in cost estimating features. Material quantities are automatically extracted and changed when any changes are made in the model."
Construction sequencing	"Building Information Model can be effectively used to create material ordering, fabrication, and delivery schedules for all building components"
Conflict, interference and collision detection	"… Because BIM models are created, to scale, in 3D space, all major systems can be visually checked for interferences. This process can verify that piping does not intersect with steel beams, ducts or walls."

2.5.2.6 Value From VDC / BIM Use: Survey Results

Another early list of BIM Uses comes for the Center for Integrated Facility Engineering at Stanford (CIFE) reporting the results of a survey developed to determine the application of BIM within design and construction (Gilligan and Kunz 2007). The list of the BIM Uses within that survey included:

- Present architectural design
- Space utilization
- 3D clash detection and interference management
- 4D clash detection and interference management
- Cost estimation or management
- Safety analysis of management
- Present scheduling as 4D animation
- Energy analysis or management
- Structural analysis
- Engage neighbors or users in understanding construction process
- Enhance submittal / shop drawing review
- Enhance shop fabrication process
- Drive shop fabrication process

The primary challenge with this list is that it is not comprehensive and focuses only on design and construction. The list of BIM Uses details a specific element of the facility, such as structural analysis, but does not detail other elements of the facility, such as electrical analysis. The shortcoming is there is little difference between some of the terms such as *enhance the shop fabrication process* and *drive the shop fabrication process*. Due to these issues, the list of BIM Uses employed within the CIFE survey is incomplete.

2.5.2.7 The Contractors' Guide to BIM

The AGC's *Contractors' Guide to BIM* is one of the first industry publications to refer to BIM Uses. The AGC guide has a partial list of BIM Uses, in which BIM Uses are referred to as a tool, and each BIM Use would be an application of a BIM tool. The challenge with the list of BIM tool is the focus on the BIM Uses that are applicable to contractors. While important to the contractor, the AGC guide does not contain a comprehensive picture of the application of BIM through the life-cycle of a facility. Moreover, probably due to the way it was developed, there are separate lists of BIM Uses, shown in Table 2-7, within the main content of the guide and in the appendix of the guide. The issue of two separate lists creates an additional layer of overlap.

Table 2-7: AGC Contractors' Guide to BIM - BIM Uses
(The Associated General Contractors of America 2006)

Uses within Body of Guide	Uses within Appendix of Guide
• Visualization • Scope Clarification • Partial Trade Coordination • Collision Detection/Avoidance • Design Validation • Construction Sequencing Planning/ Phasing Plans/ • Logistics • Marketing Presentations • Options Analysis • Value Engineering Analysis • Walk-throughs and Fly-through • Virtual Mock-Ups • Sight Line Studies • 2D conversions • 3D designs • 4D Model • 5D Model	• Creating and Reviewing 3D Models • 3D Modeling • Virtual Building • Architecture Design • 2D and 3D Production Management • Combining and Reviewing 3D Modeling • Combine Designs into one model • Report indifferences in 3D project models and tract project status • Identify communicate and manage changes • Digital Technology Integration

2.5.2.8 *Smart Market Reports*

Over the past years, McGraw-Hill Construction has surveyed industry members to determine the usage of BIM. The results of this survey are freely available and demonstrates the overall growth of BIM within the industry. The initial McGraw-Hill survey asked about BIM in general terms, however the last several surveys became increasingly more detailed about the specific BIM Uses each organization is implementing. The SmartMarket report refers to their BIM Uses as BIM processes or activities. The following is a list on BIM Uses found within those reports:

Table 2-8: BIM Activities with SmartMarket Reports
(Bernstein 2012)

Base Building Design Activities	**Interior Planning and Construction Activities**
• Modeling the Building Envelope • Position a Project on Its Site • Sustainability Rating • Life Safety and Code Analysis / Validation	• Interior space calculation and analysis • Layouts and space plans • Model interior construction • Validate Space Program
Technical Analysis Activities	**Preconstruction Activities**
• Energy Use/Performance • Thermal Comfort Analysis • Lighting/Day lighting analysis • Airflow Analysis • Structural Analysis • Mechanical System Performance Analysis	• Spatial Coordination • Quantity Take-Off • Preliminary Design Phase Budgeting • 4D Models for Relocations/ Moves • 5D Models with Cost
Contractor Activities	**Digital Construction at the Job Site**
• Constructability Analysis • Jobsite Planning and Logistics • Labor and cost estimating for Bidding • Construction phasing and scheduling • Integration with cost, project management, and accounting software.	• Layout • Validation of As-Built Construction to the Model • Site Logistics • Generation of Daily Work Packages • Materials Delivery and Management
Uncategorized	
• Model Driven Fabrication • Authoring Models • BIM-Generated Visualizations • Project Close-Out Processes • Operations and Maintenance/Facility • Project Controls	

The SmartMarket report categorizes the BIM activities into the six separate categories including base building design activities, interior planning and construction activities, technical analysis activities, preconstruction activities, contractor activities, and digital construction at the job site. Additionally there are several BIM activities that do not fall into a specific category. The element or attribute on which the category is organized varies. For example, some categories are discipline based (contractor activities), some categories are phase-based (such as preconstruction activities), some categories are system-based (such as technical analysis), and some categories are location-based (such as digital construction at the job site). Also, the activities within the categories repeat themselves. For example, the activities of 5D models with cost, quantity take-off and labor and cost estimation are essentially the same BIM activities. Another example of categories repeating themselves are the activities of *logistics*, *scheduling*, and *systems analysis,* which are each repeated at least twice. Overall while the SmartMarket report contains numerous BIM activities or BIM Uses, it organizes them inconsistently, and has number of overlaps between categories.

2.5.2.9 Summary of BIM Use Lists

Overall, while each of these lists helps the industry advance, none of them are completely comprehensive. Most lists are just a product of brainstorming by a few individuals. Additionally, the BIM Uses are mostly organized by project phase, discipline, or the combination of multiple items. The methodology implemented to create these has led to duplications and inconsistencies between terms. This, in turn, has led to inconsistencies in the meaning and understanding of the terms as well.

2.5.3 Current Hierarchies of BIM Uses

There are several basic hierarchical structures of BIM Uses developed to organize the BIM Uses. This section primarily focuses on the hierarchical structures created as part of the BIM Project Execution Planning Project including the hierarchical structures in the guide itself, the ontology used in the BIM Project Execution Plan Template, and a taxonomy of BIM Uses in design. Additionally other ontologies have been created including those created by the U.S. Army Corps of Engineers and the buildingSMART alliance. However, most hierarchical structures have been based on the BIM Uses within the *BIM Project Execution Planning Guide*.

2.5.3.1 BIM Use Ontologies From BIM Project Execution Planning Project

In order to better plan for the execution of BIM, the project research team thought it important to document the various ways BIM could be implemented on a project. In order to accomplish this, the team divided the project into four primary phases and attempted to determine the BIM Uses for each phase. From there they developed a list of BIM Uses and published it in the *BIM Project Execution Planning Guide*. This list and organization has become the de facto standard for the industry.

2.5.3.1.1 Ontologies Used in BIM Project Execution Plan Guide

Within the *BIM Project Execution Planning Guide* itself are two organizational structures for the BIM Uses. Each structure is based on project phase with multiple BIM Uses spanning multiple phases. The first, Figure 2-11, is organized from plan through operate – the more traditional way of looking at a facility's life. The second, Figure 2-12, is organized from operate to plan. This organization is to promote the philosophy of "Begin with the end in mind," which illustrates the need to consider the owner's end needs of Building Information Modeling from the very beginning of the facility's life and pull the information needed through the other phases of constructing, designing, and planning the facility. This organization makes it challenging to understand those BIM Uses that span multiple phases, which illustrates that phase may be an attribute of each BIM Use rather than the dividing element of the BIM Uses.

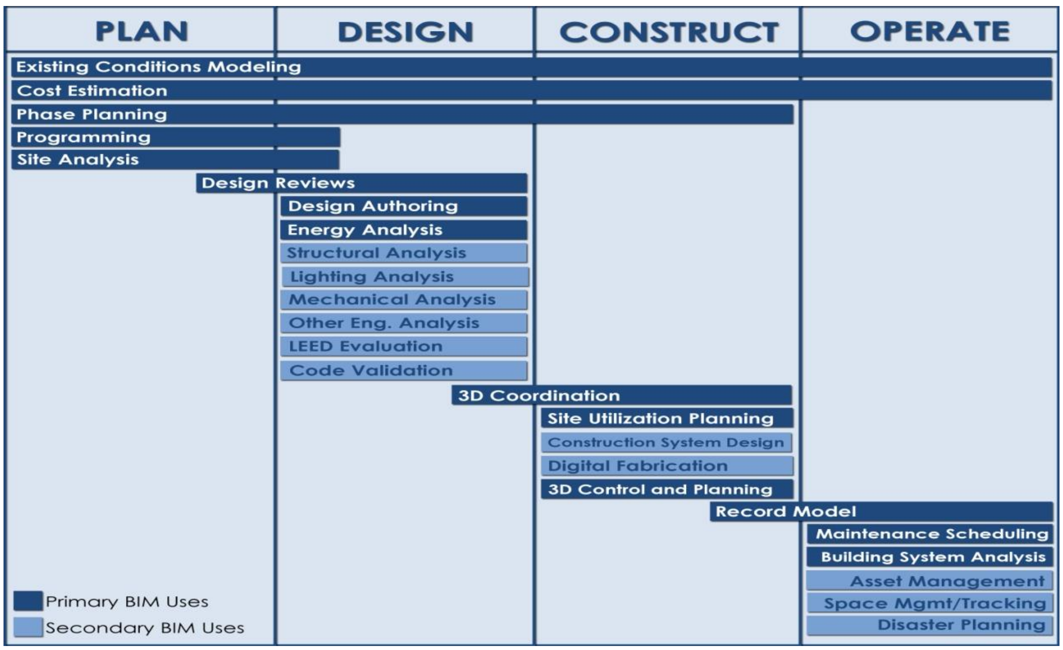


Figure 2-11: BIM Uses Organized by Project Phase (Plan through Operate)
(Computer Integrated Construction Research Program 2010a)

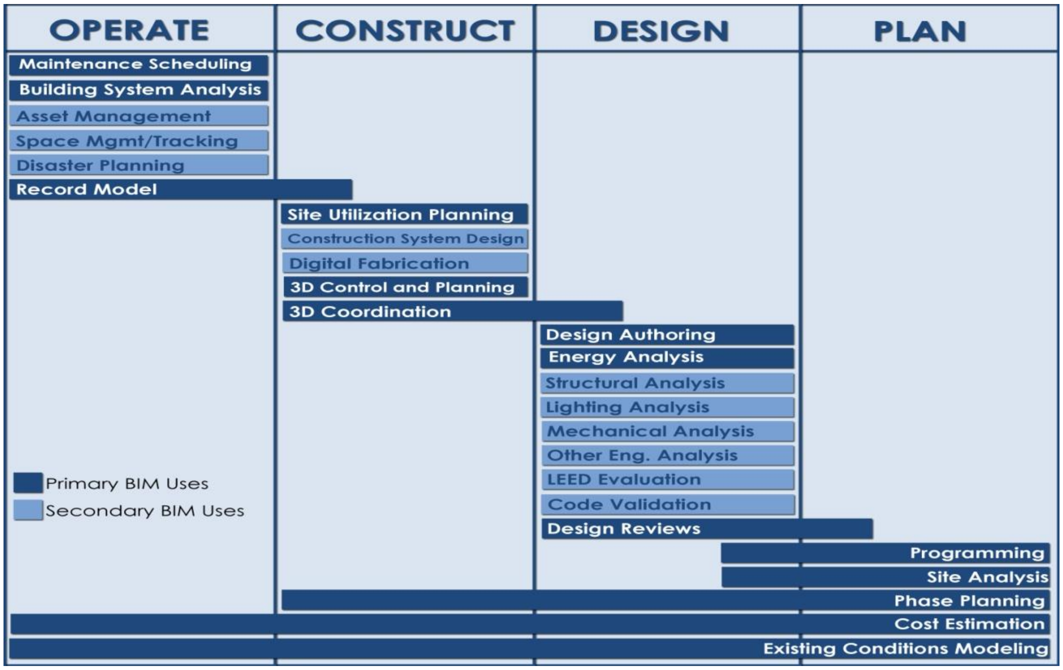


Figure 2-12: BIM Uses Organized by Project Phase (Operate through Plan)
(Computer Integrated Construction Research Program 2010a)

2.5.3.1.2 Ontologies Used in BIM Project Execution Plan Template

Within the BIM Project Execution Plan Template an ontology of BIM Uses is presented. This ontology, shown in Table 2-9 is organized again by project phases (plan through operate) and is designed to allow for organizations to easily select and display the BIM Uses on the Project. The challenge again is that several BIM Uses are in multiple phases of the facility's life creating the challenge of duplication.

Table 2-9: BIM Uses within the BIM Project Execution Plan Template
(Computer Integrated Construction Research Program 2010b)

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

2.5.3.1.3 Hierarchical Structures Used Within Each Project Specific BIM PxPs

Often an organization will adapt the BIM Project Execution Planning Template to suit their needs. Some organizations remove entire phases of the facility's life. This is most often the case when those phases are not part of the scope of the project. Additionally, organization modify the language to match their standards, rather than shifting their language to the standard. In all honesty, if the project team goes to the level of creating high-level process maps, these are typically the best ontologies within each project execution plan.

2.5.3.1.4 Taxonomy of BIM Uses in Design

In her master's thesis, Zikic (2009) documented the BIM Uses that are critical during design. These BIM Uses were then applied to develop the *BIM Project Execution Planning Guide*'s BIM Uses. She classified the BIM Uses in Design into four major categories or classes including design communication, system analysis, estimating, and scheduling, illustrated in Figure 2-13 (Zikic 2009). This categorization and the BIM Uses within were developed through industry expert interviews and literature review.

Figure 2-13: Taxonomy of the BIM Uses in Design
(Zikic 2009)

There are a few challenges with this taxonomy. First, while it limits the scope of the research, only documenting the design BIM Uses limits the level of completeness the document can have. Another challenge is some of the classes only have one sub-BIM Use. It may be possible that these BIM Uses should have been part of another class. Moreover, the pool from which these BIM Uses were identified is rather limited and consisted of approximately 10 to 12 industry interviews primarily based in the DC area.

2.5.3.2 Hierarchical Structure in USACE Project Execution Plan Template

The United States Army Corps of Engineers (USACE) generated an ontology of BIM Uses for the creation of their BIM Project Execution Plan Template (USACE/Industry BIM Advisory Committee 2013). This hierarchical structure is very similar to the hierarchical structure in the BIM Project Execution Plan Template, on which it was based. It is also based on project phase with its differences lying within the title of the BIM Uses and that the USACE has highlighted several BIM Uses that USACE requires to be applied on projects. The guide and the requirement have been adopted by a number of different standards. Table 2-10 illustrates the structure of the USACE BIM Use Requirements.

Table 2-10: BIM Use Requirements in USACE Project Execution Plan Template
(USACE/Industry BIM Advisory Committee 2010)

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

This hierarchical structure has most of the same limitations as the BIM hierarchical structure found in the BIM Project Execution Plan. Another limitation is the fact USACE modified some of the specific terminology therefore requiring a separate update. They also do not provide detailed explanations for each of the terms in the hierarchical structure.

2.5.3.3 BUILDINGSMART DATA DICTIONARY AND TETRALOGY OF BIM

An effort that exists in the domain of BIM Uses is that of the *buildingSMART Data Dictionary*. The Data Dictionary is established to create "*a catalogue of what objects are called (the 'vocabulary') and brings together disparate sets of data into a common view of the construction project or asset, whether information from a product manufacturer, typical room requirements, cost data or environmental data.*" (BuildingSMART 2012). The dictionary divides BIM into two categories or "rooms" including the product room and the process room. The product room focuses on defining the elements of the facility and the process room focuses on the various processes that are implemented within BIM. These processes align fairly well with BIM Uses. Other work in this area primarily focuses on defining the terms themselves with little regard of whether they are processes or products and with little regard to the structure or organization of those terms. Very little work focuses on the specific purpose of implementing BIM.

Part of *buildingSMART Data Dictionary* effort, shown in Figure 2-14, is the development of what is termed the "tetralogy" of BIM. The name tetralogy refers to a work that is made up of four separate phases / parts. In this case the four "works" or groups are roughly the phases of a facility's life: Design, Procure, Assemble, and Operate. The more common phases of a facility's life are Plan, Design, Construct, and Operate. This breakdown of BIM Uses is flawed because it limits a BIM Use to being performed in a single phase. For example coordination can no longer be performed during construction. Nor can way-finding be accomplished during assembly. Moreover, the name itself tetralogy precludes that all of these are completely independent and separate. This is not the case, and as demonstrated, an argument can be made for a number of these to go into another category.

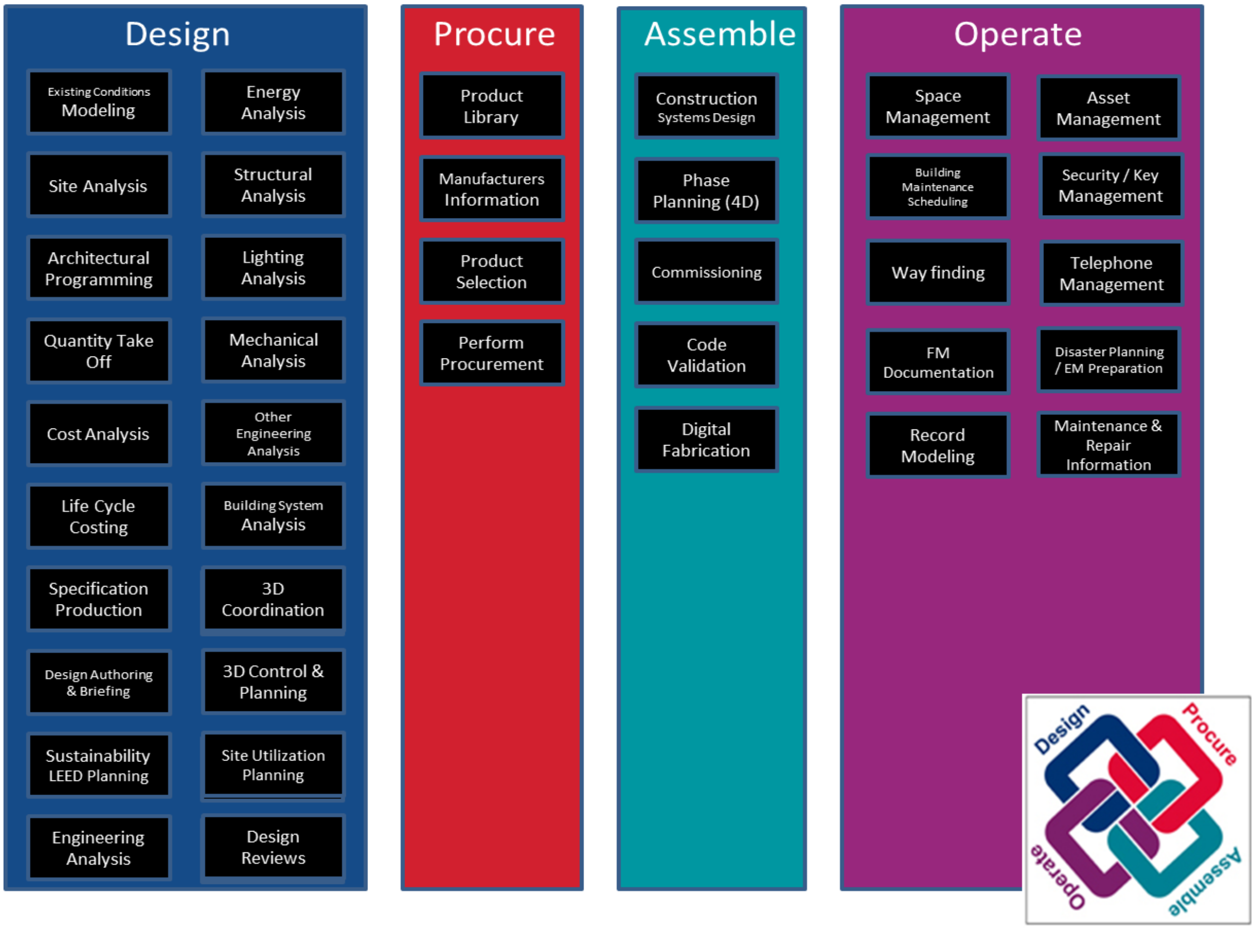


Figure 2-14: Tetralogy of BIM
(buildingSMART alliance 2013)

The BIM Uses are based on the BIM Uses within the CIC Research Program's *BIM Project Execution Planning Guide*. However, commissioning, security & key management, telephone move/add/change management, way finding, FM documentation, maintenance & repair information, product library, life-cycle cost analysis, specification production, consistency control, product selection, and perform procurement have been arbitrarily added. These additional BIM Uses were not sufficiently validated using a comprehensive methodology. Adding new BIM Uses to an already flawed *BIM Project Execution Planning Guide* list of BIM Uses, adds to the confusion. While some are legitimately added BIM Uses, others are very specific to a single facility element. For example, telephone move management is too specific an element. Not to mention that as the mobile phone industry takes over, why is this not just move management? While telephones are important, so is the rest of the equipment in the facility. Overall, the industry needs to move away from "silo-ing" items by facility phase, and move towards purpose.

2.5.3.4 Summary of BIM Use Hierarchal Structures/Taxonomies:

Overall there are very few hierarchal structures or taxonomies of BIM Uses that are available for public consumption. Most of those that are available are based on the structure developed by the Penn State Computer Integrated Research Program. Each one, however, slightly modifies it or adds to it to suit their needs. Moreover, each of these structures employs project phase to organize it. This organization leads to duplication of BIM Uses, which leads to inconsistencies from phase to phase. Overall, another method of organizing outside of phase, element, and discipline needs to be determined.

2.6 **U.S. National BIM Standard**

The *U.S. National BIM Standard* is the defining document for how BIM is implemented within industry. The standard is developed as buildingSMART alliance project and is developed by industry experts and volunteers. The first version of the National BIM Standard was released in 2007. It was really a framework document that discussed how the *U.S. National BIM Standard* would be developed. The first practical National BIM Standard was release in the spring of 2012. It contains items such as the construction operation building information exchange, the *BIM Project Execution Planning Guide*, and standard references of OmniClass – to name a few.

The BIM Use Ontology can set the stage for how each of the separate parts of the National BIM Standard should be developed. Each BIM Use would have model view definitions and information delivery manuals. Additionally, standard information exchanges can then be established between BIM Uses. If a ballot for the BIM Use Ontology were adopted, it would allow for better communication throughout the industry.

2.6.1 Structure of the U.S. National BIM Standard

The current version of *U.S. National BIM Standard* released in 2012 contains five primary sections. These sections include: 1) scope, 2) reference standards, 3) terms and definitions, 4) information exchange standards, and 5) practice documents. In addition to the five primary sections there is an annex attached to the standard. Under each of the primary sections are the individual items that were balloted.

When balloting an item, each person balloting needed to select one of three categories for their ballot: reference standards, information exchange standards, and practice documents. The terms and definitions were developed as a glossary of sorts for all of the ballots. Meanwhile, the scope was developed to identify the purpose of the *U.S. National BIM Standard*.

2.6.2 Model View Definitions

A critical part of the National BIM Standard - U.S. is that of model view definitions. Model View Definition (MVD), also called an Industry Foundation Class (IFC) View Definition, "defines a subset of the IFC schema that is needed to satisfy one or many exchange requirements of the AECO Industry. The method applied, and propagated by buildingSMART international, to define such exchange requirements is the information delivery manual, IDM (also ISO/DIS 29481). An IFC model view definition defines a legal subset of the IFC Schema [being completed] and provides implementation guidance (or implementation agreements) for all IFC concepts (classes, attributes, relationships, property sets, quantity definitions, etc.) applied within this subset. It thereby represents the software requirement specification for the implementation of an IFC interface to satisfy the exchange requirements."

Currently, no MVDs have been accepted into the National BIM Standard and only three are available on the buildingSMART international website. These three include: *IFC2x3 Coordination View, IFC2x3 Structural Analysis View*, and *IFC2x3 Basic FM Handover View*. The BIM Use Ontology can be applied as a structure for the development of the required model view definitions.

2.6.3 Information Delivery Manuals

Another concept within the *U.S. National BIM Standard*, is an information delivery manual (or IDM). An IDM is *"a standard for processes specified when certain types of information are required during the construction of a project or the operation of a built asset. It also provides detailed specification of the information that a particular user (such as, architect or building services engineer) needs to provide at a point in time and groups together information that is needed in associated activities: cost estimating, volume of materials, and job scheduling [which] are natural partners."*

The term originally developed by the Norwegian buildingSMART organization and adopted by buildingSMART international. However, currently only two IDMs exist on the buildingSMART international website. These include the *IDM for Geographical Referencing* and the *IDM for Building Programming*. Just like MVD's many more IDMs are yet to be developed. The BIM Use Ontology can be applied as a structure to understand what information delivery manuals are necessary.

2.6.4 Information Exchanges Standards

Yet another critical concept within the *U.S. National BIM Standard* is that of information exchange standards. Information Exchanges or (IEs) are "packages of information passed from one party to another in a BIM process, or the act of passing such information." An information exchange can be a BIM deliverable where the parties involved have agreed upon the format and content to exchange. Information exchanges outline how information is to be passed between various MVDs and IDMs. Currently there are four information exchanges documented within the National BIM Standard and many more being balloted for version 3.0 of the National BIM Standard. The exchanges currently include:

- Construction Operations Building Information Exchange (COBie)
- Design to Spatial Program Validation (SPV)
- Design to Building Energy Analysis (BEA)
- Design to Quantity Take-off for Cost Estimating (QTO)

The BIM Use Ontology can be applied as a structure for the development of the required information exchanges and defining exactly which information exchanges are necessary.

2.7 SUMMARY OF AVAILABLE LITERATURE

There are many available sources with lists of how project teams or organizations are implementing and using BIM. But there is a lack of standard terminology within the AECO Industry when referencing these BIM Uses along with the purpose for implementing BIM. While the community has enough of a challenge defining what is and is not BIM, even more difficulty can be observed when attempting to consistently describe why BIM is implemented. When communicating a particular BIM Use, or is it BIM activity, or BIM tool, there is no consensus understanding of the specific BIM Uses. Currently, the industry is using various approaches to address this issue from the various model dimensions, or “Ds” of BIM to the tetralogy of BIM to communicate the intent of the BIM Use implementation. All of these methods lack consistency, include duplicate terms, or omit significant potential Uses. The terms vary in level of detail and complexity. The organizational structures are not classes but rather attributes of the BIM Uses, therefore creating overlap between the “classes”. Finally, they are often biased and arbitrary because of the source of the lists and a lack of rigor in the development process, which adds to the confusion. This research aims to remove this confusion and allow the industry to communicate their purpose for implementing BIM by developing the BIM Uses Ontology through a rigorous research methodology which is defined within the next chapter.

CHAPTER 3: RESEARCH METHODOLOGY

The methodology applied to develop the BIM Use Ontology combines ontology development methods documented in ontology creation literature. The methods include Toronto Virtual Enterprise (TOVE) approach, the Enterprise Model Approach, the METHONTOLOGY approach, and the Integrated Definition for Ontology Description Capture Method (IDEF5) approach (Noy and McGuinness 2001; Uschold and King 1995). The steps develop the BIM Use Ontology include:

1. Defining domain and scope of what is a BIM Use
2. Acquiring knowledge through collection of BIM Uses
3. Documenting domain terms by creating a list of BIM Uses and terms
4. Integrating domain terms by creating initial BIM Use Ontology
5. Evaluating (refining and validating) the BIM Use Ontology
6. Documenting the BIM Use Ontology so that it is understandable

To accomplish the goals of this research content analysis, focus group meetings, industry expert interviews, and surveys were applied. Figure 3-1 displays an overview of the research steps.

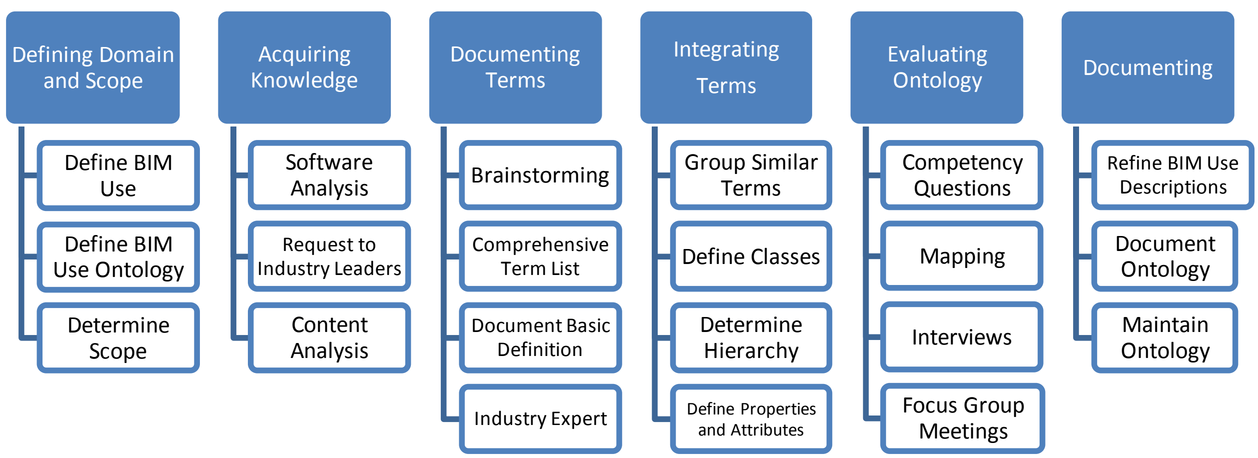


Figure 3-1: Methodology to Develop BIM Use Ontology

3.1 DEFINING DOMAIN AND SCOPE

Establishing a firm understanding of the domain and scope was an essential step in the development of the BIM Use Ontology. Domain is the subject matter of the scope, and scope is the scale or reach of an ontology. The domain refers to the BIM Uses that directly interact with the data within a model. The scope of the BIM Use Ontology includes all of the methods of applying BIM which alter the traditional facilities design, construction, or operation processes, and are currently being implemented within organizations and/or projects.

3.1.1 DEFINING DOMAIN

The domain of the BIM Use Ontology is those BIM Uses that interact with the model. To define the domain, it is important to understand the definition of a BIM Use. In literature there are a number of different terms and definitions for those terms that are similar to BIM Use. The domain was defined for the BIM Use Ontology based on the review of literature and the experience of the researcher.

3.1.2 DEFINING SCOPE

Establishing the scope of this Ontology is as important as establishing the purpose and domain; and equally challenging. The scope of an ontology defines what is included or excluded from the BIM Use Ontology. In other words, the scope defines which terms, or in this case which BIM Uses, are included in the BIM Use Ontology. To determine this, it must be understood what exactly qualifies as a BIM Use. The answer will vary from person to person, from expert to expert. Very few will state the same meaning. The scope of the BIM Use Ontology was determined by reviewing available literature and experience of the researcher.

3.2 ACQUIRING KNOWLEDGE

The primary goal of the knowledge acquisition phase of the research was to collect information on the BIM Uses. Research into this area was already conducted as part other industry efforts such as the *BIM Project Execution Planning Guide* (Computer Integrated Construction Research Program 2010b), BIM Handbook (Eastman et al. 2011) and various BIM guidelines(Department of Veterans Affairs 2010; U.S. General Services Administration 2011; USACE/Industry BIM Advisory Committee 2011). Those efforts were neither comprehensive nor have applied a consistent methodology to generate the BIM Uses. However, based on those efforts, a comprehensive list of BIM Uses, shown in Appendix B, was documented. The Use list was created using a number of methods including software analysis, by request to industry leaders, and additional content analysis.

3.2.1 Software Analysis

An analysis of the different types of software was conducted by developing a list of software which included the core functions of each software. The software in this list, shown in Table 3-1, includes:

Table 3-1: BIM Software

• 4MSA FineHVAC + FineLIFT + FineELEC + FineSANI • 4MSA IDEA Architectural Design (IntelliCAD) • 4MSA Strad and Steel • ActiveFacility • AECOSim • Archibus • ArchiCAD • ArchiFM • Autodesk 360 • Autodesk 360 Glue • Autodesk 360 Field • Autodesk Ecotect Analysis • Autodesk Green Building Studio • Autodesk Navisworks • Autodesk Revit Architecture • Autodesk Revit MEP • Autodesk Revit Structure • Autodesk Robot Structural Analysis • Autodesk's QTO • Bentley Architecture • Bentley ConstructSim • Bentley Facilities • Bentley Hevacomp Mechanical Designer • Bentley RAM, STAAD and ProSteel	• Bentley Structural Modeler • Bentley Tas Simulator • Bonzai3d • building Exodus • CADMEP (CADduct / CADmech) • Construction (Simulation, Estimating and Const. Analysis) • Crowd Behavior • CypeCAD • DesignBuilder • Dprofiler • EcoDomus • Ecotect Analysis • Facility Management • FM:Systems FM:Interact • Gehry Technologies - Digital Project Designer • Gehry Technologies - Digital Project MEP Systems Routing • Graphisoft ArchiCAD • Graphisoft EcoDesigner • Graytec Advance Design • Green Building Studio • IES Simulex • IES Solutions Virtual Environment VE-Pro	• Innovaya • Legion Studio • MAXIMO • Nemetschek Allplan Architecture • Nemetschek Scia • Nemetschek Vectorworks Architect • Onuma System • Rhinoceros • SketchUp • Solibri Model Checker • StructureSoft Metal Wood Framer • Sustainability • Synchro Professional • Tekla BIMSight • Tekla Construction Management, • Tekla Structures • TOCMO • Vela Field BIM • Vico Office Suite • "Vico • Takeoff Manager" • ViCrowd eRena • Vintocon ArchiFM (For ArchiCAD) • Vizelia suite of FACILITY management products

This list originally was from the website CAD Addict (Broquetas 2010). It has been expanded and updated through additional research. While not a comprehensive list of BIM software, the software list represents many of the current BIM Uses implemented. This software list was then analyzed to determine the core functions of each piece of software. The core function of the software, shown in Table 3-2, core BIM Uses include:

Table 3-2: Core Functions of BIM Software

• Conceptual Energy Analysis Tools • Point Cloud Tools • Construction Modeling Tools • Parametric Components • Conceptual Design Tools • Interference Check • Material Take-off • Detailing • Design Visualization • Design Options	• Bidirectional Associativity • Building Maker • Duct & Pipe System Modeling • HVAC/Electrical Design • Sun Path Simulation • Automatic Generation of Construction Document Views • Tag on Placement/by Category • Photorealistic Rendering • Construction Modeling • Reinforcement Enhancements	• Structural Details • Rapid early planning • Project Program Development • Charrettes (BIMStorms) • Schematic Design • Cost estimating • Energy Analysis • Life-cycle Costing • Facility Management • Portfolio and Program Management • Schedules

The analysis of each type of software took place by reviewing available literature on each product. This was done primarily by looking at each product's website. The more commonly implemented software was reviewed in detail, however to do so for all was prohibitively time consuming. Additionally, to develop the list of functions, it was not necessary to validate the functionality of the features of the software but only know the claims of the software provided. These functions and features were then added to the larger list, contained in Appendix B, of BIM Use Terms.

3.2.2 Industry Analysis

In order to document the BIM Uses that were currently being implemented, members of industry were contacted via email and asked for a list of their BIM Services. Thirty individuals were contacted, from eight of whom responses were received or about a 26% response rate. The individuals were asked how they implemented BIM and asked to briefly describe each term they provided. In general, the industry members responded with BIM Uses and services that were already part of the *BIM Project Execution Planning Guide*. However, some of these BIM Uses were organized differently. Most of the BIM Uses and services that were reported included several of the BIM Uses from *BIM Project Execution Planning Guide*. The BIM Uses from industry members were added to the list in Appendix B of BIM Uses.

3.2.3 Content Analysis

The primary method applied to develop a list of BIM Uses was content analysis. During this process, a number of industry and academic publications were reviewed for the various BIM Use terms within them. The sources include books, guides, and publications. Some of the major sources include items such as *the BIM Handbook* (Eastman et al. 2011), *the VA BIM Guide* (Department of Veterans Affairs 2010), *the BIM Project Execution Planning Guide* (Computer Integrated Construction Research Program 2010b), and research from Stanford's Center for Integrated Facility Engineering (CIFE). These BIM Uses were then added to the list of BIM Uses in Appendix B.

3.2.4 Brainstorm List of Core Functions

An additional list of BIM Uses, terms, and core functions were developed independently of content analysis, software analysis, and requests from industry members. This process was necessary to add an extra input into the overall BIM Uses. The brainstorming helped to ensure that the knowledge and terms acquired were comprehensive of the BIM Use. The process of brainstorming can be summarized in three steps: 1) Read the problem, 2) Generate ideas by free association, and 3) Continue to generate ideas by free association (Hender et al. 2001). The purpose of brainstorming was to create a list of the core functions of BIM. Brainstorming took place as part of a workshop for the creation of *the BIM Planning Guide for Facility Owners*. As part of the workshop participants were asked to brainstorm a list of BIM Uses. However, they were asked to focus on BIM Uses that we have not yet documented in the *BIM Project Execution Planning Guide*. Some of the BIM Uses brainstormed included:

Table 3-3: List of BIM Uses from Brainstorming Process

- "In the event" what happens
- Disaster planning
- Egress from facilities
- Employee flow
- Facility financial forecasting
- Operational training
- Real time operations overlay on the model
- Way finding
- Building system analysis
- Does what was built equal what was model?
- Ensure model integrity
- Quality control (how do you check models that you receive, ensure data integrity)
- Understanding equipment accessibility
- Backgrounds / equipment data for BAS
- Commissioning sign-offs.
- Extract logic diagrams
- Facility management handover
- Import / export "as maintained" data and model (ability to do as you want/need)
- O&M data embedded within the model.
- Reduced entry time for data
- Automated systems and controls
- Energy demand control and energy management
- Telecommunications integration, security and general administrative services
- Asset management
- Real estate acquisition and/or disposal
- Performance reviews
- Space management and tracking
- Occupancy ergonomics and sensing
- Security sensors (sensors placed in real time, generate reporting of facility security breaches.)
- Sensor tracking and monitoring
- After action review
- Compare as design to as operated energy analysis
- Diagnosis
- GIS data integration
- Have a dashboard to monitor buildings performance
- Increase occupancy efficiency
- Laser scanning in-process
- Materials recycling
- Photographic 3D as-built in-process
- Schedule progress tracking using the model
- Smart (intelligent) tagging FF&E
- Trending your data into useable information
- Capturing lessons learned
- Equipment requirement
- Feed forward program
- Performance for the user, understanding the space
- Training requirements
- Work specifications, installation and space management
- O&M as-maintained modeling
- New construction and/or renovation
- Record modeling
- Marketing purposes
- Virtual tours
- Architectural and engineering planning and design
- Maximize the efficiency of the space
- Long-range and annual facility planning
- Dispatching of work order
- Building maintenance scheduling
- Call systems
- Capital improvement scheduling
- Corrective action
- Decommissioning of facilities
- Disaster recovery
- Generate statements of work (assess condition of equipment after event)
- Personnel allocation
- PM maintenance scheduling
- Repair needs
- Scenario planning (failure, disaster) and sequence of operations
- Temporal and weather based event planning / maintenance
- Temporal events
- Threat response planning (scenario planning)
- Tool requirements
- Workflow scheduling
- Detailed framing

During that process, it was important to follow the rules of classical brainstorming methods developed in the 1930's. These include the two core principles of deferred judgment, and quantity breeds quality (Hender et al. 2001). Deferring judgment helped ensure that the creativity is not stifled by others. There was much overlap of terms especially as the terms "piggybacked" off of others. That practice was encouraged and allowed for creating a larger list. Piggybacking, also called hitchhiking, is "*the practice of generating additional ideas by building on other ideas"* (Hender et al. 2001). Moreover, the group must strive to continually develop terms. This was done by each group member writing a term onto a "sticky note" and placing it onto the wall. As they placed the word on the wall, they read it aloud and other people then repeated this cycle for their terms. It was important that the placing on the wall be almost at random. If not, it may inadvertently start to classify the Uses and terms. This process should wait until the next phase. It is important that the overlap, relations, properties, or classes of terms are not considered when brainstorming a list (Noy and McGuinness 2001). The brainstorming process was ended after the allotted time of one hour and fifteen minutes which coincided fairly closely to when the creativity of the group had been exhausted. In addition to this primary session, several smaller brainstorming session were conducted at a much smaller scale within the CIC research program. All of these terms were then added to the list of BIM terms.

3.3 **DOCUMENTING DOMAIN TERMS**

A primary goal of this research was to develop a comprehensive list of BIM Uses. During the knowledge acquisition stage of this research, the terms collected were not analyzed. The terms were simply added to list of BIM Uses. In addition to the BIM Use terms, attribute terms were also documented. These are terms that are employed to describe the BIM Uses. After all these terms were identified, if necessary a brief definition was developed.

3.3.1 COMPILING COMPREHENSIVE LIST

Once the brainstorming session was completed, as well as software analyses, and appeal to industry members, the terms from all the lists were compiled into a single, comprehensive list. This list included terms which identified core BIM functions, BIM Uses, applications of BIM, BIM services and many others. Each term on the list was entered into an Excel spreadsheet. Then the Excel spreadsheet was sorted alphabetically and exact duplicates were deleted. The list initially consisted of approximately 650 terms and was reduced to 575 by removing exact duplicates. This sorting also helped to prevent bias in the grouping of terms. The extent of BIM Use terms within the list, shown in Appendix B, confirmed the validity of the scope of the BIM Use Ontology. The list still included overlapping terms. This overlap would later be removed during the integration stage of the research to ensure the BIM Use Ontology's validity.

In addition to the standard list of BIM Uses, other relevant terms within the domain were documented. The other relevant terms included terms related to attributes, classes, hierarchy, and terms that were used to relate the BIM Uses to one another. The list of common terms is the first part of development of the BIM Use Ontology.

3.3.2 Defining Basic Terms

After the list was compiled, a basic definition was documented for some of the terms that were not understood. This basic definition was documented based on the original source of the term. It is important that the definition or description was one sentence or less, and it was designed to give a quick understanding of the term. A more formal definition and description of the term was developed later in the research process. In order to develop a brief definition, the source of the term was consulted and a definition was documented. It is important to note that all terms were not defined. Rather, terms that the researcher did not understand the meaning were defined. The 41 terms that were described are contained in Appendix C.

3.4 **Integrating Terms**

After a list of terms was compiled, the terms were then organized into an initial ontology. This process was completed with the following four steps: 1) Grouping Similar Terms / Uses; 2) Defining BIM Use Classes; 3) Determining a Class Hierarchy; and 4) Defining Properties and Attributes. While integrating the various terms, the initial BIM Use Ontology was developed.

3.4.1 Group Similar Terms / BIM Uses

The first pass of this process took place after all the terms were placed in the Excel workbook. This was accomplished by stepping through each term and determining the high-level purpose for which each term would be implemented. This was done for each item in the list individually by focusing on keywords of the processes within the terms. After that first pass, the terms were grouped into 29 subgroups. In no particular order, the initial 29 term groups include:

a. Activity Simulation
b. System Analysis
c. Validation
d. 3D Control and Planning
e. Digital Fabrication
f. 3D Coordination
g. Scheduling and Sequencing
h. Data Commissioning
i. System Control
j. Tracking
k. Augmented/Reality
l. Design Communication
m. Design Review
n. Document Production
o. Drawing Production
p. Generative Design
q. Model Production
r. Rendering
s. Systems Layout
t. Virtual Mockup
u. Visualization
v. Conditions Documentation
w. Cost Estimation/QTO
x. Scheduling and Sequencing
y. Construction Tracking
z. Material Tracking
aa. Space Tracking
bb. Performance Tracking
cc. Program Production

During this process, only the purpose for which the BIM Use would be implemented was considered and did not consider the attributes of the BIM Uses. Therefore, items such a project phase, facility element, discipline, and level of development were not considered when developing the classes. The BIM Use Ontology selected the purpose. This is different than most way the BIM Uses are organized. After the initial pass, the smaller groups were then grouped into larger groups. The initial 10 larger groups include:

1. Analysis / Simulation
2. Automated Implementation
3. Coordination
4. Coordination / Scheduling
5. Data Management
6. Design Communication
7. Layout
8. Quantifying
9. Scheduling
10. Validating

When initially grouping the BIM Uses, the characteristics such as project phase, facility element, and discipline were not used to develop the groups to ensure no bias toward a specific element, phase, and discipline. After these characteristics, the remaining attribute of the BIM Uses that remains in the purpose or objective of the BIM Use. The purpose is the reason for which the BIM is implemented. As noted earlier, BIM does not change the purpose, rather only the means by which the purpose is achieved. This focus on purpose of implementation of BIM is because the purpose is a common attribute across all phases, elements, and disciplines. Often other systems employ the attributes of phase, element, and discipline to classify BIM Uses rather than the primary objective of the BIM Use.

3.4.2 Define BIM Use Classes

The groups created were then formed into classes of BIM Uses. For example, those BIM Uses that had to do with analysis or simulation were grouped together, such as activity simulation and systems analysis. Each initial class was given a title. At this point, this title was simply adopted to support the classification effort. It did not necessarily represent the terms within the group.

Each class was then given a basic description that determined why the Uses were a part of the class. After the initial classes were determined they were evaluated based on whether or not they were too large or too small. If a class only has one subclass or instance (in this case one BIM Use) it is likely that class is incomplete or should be part of another class (Noy and McGuinness 2001). If a class has twelve or more subclass instances (or BIM Uses), it is most likely that there are subclasses in between the current superclass and subclasses. During these classifications it was determined that some of the classes did not have a sufficient number of subclasses and therefore were too small. The descriptions of other larger classes were modified to include these smaller one or two-instance classes. Some examples of this include coordination, scheduling, and quantifying, which were all re-organized into larger classes and then described further. After this effort, the first substantial list of BIM Uses was developed.

3.4.3 Determine Class Hierarchy

After developing the classes, the Uses were then organized into a structured, logical hierarchy. To accomplish this, a bottom-up approach was employed. In a bottom-up approach, each instance of a BIM Use Purpose was organized into a class. The class was then grouped into a superclass and then grouped into higher level classes yet. After this effort, three distinct layers of BIM Uses existed. Table 3-4 shows the initial BIM Use Ontology that was developed in this effort.

Table 3-4: Initial BIM Use Ontology

01 Generating	**the generating class of BIM Uses is those Uses in which the facility information is created.**
01 Self-Generating	to create facility information without human interact exception establishing parameters.
02 Authoring	to create information about the facility design
03 Programming	to determine need for facility spaces
04 Scheduling	to determine the need for and prescribe specific facility elements
05 Laying out	to determine location and arrangement of facility elements
02 Processing	**to change facility information from one state to another**
01 Coordinating	to bring different facility elements into a relationship that will ensure efficiency or harmony
02 Forecasting	to predict the future performance of the facility
01 Schedule	to plan an event to take place at a particular time
02 Temporal	to predict the performance of the facility or facility elements over time
03 Flow	to predict the circulation of the facility systems
04 Scenario	to predict possible situations within the facility such as crowd flow, evacuation procedures and other disasters
05 Financial	to predict the future monetary elements of the facility
06 Energy	to predict future energy use of the facility or facility elements
03 Analyzing	to methodically examine elements of the facility to gain a better understanding of it
04 Validation	to check or prove accuracy of facility information and that is logical and reasonable
01 Program (Space)	to ensure facility contains the necessary space to meet its desired function
02 Element	to ensure the facility contains the necessary facility elements to support the facility such as MEP equipment
03 Sustainability	to ensure the facility is designed, constructed, and operated sustainability
04 Constructability / Operability	to ensure facility is able to constructed and operated effectively
05 Usability	to an ensure the facility can perform its established purpose effectively
06 Code	to ensure facility meets established codes
03 Communicating	**to share or exchange facility information**
01 Visualizing	to form an image of a facility or facility elements
02 Modeling	to generate objects with intelligence to allow the model objects to emulate the actual facility element
03 Drawing	to make a symbolic representation of the facility and facility elements
01 Annotating	to add to notes to give further explanation of facility information
04 Documenting	to create a record of facility information
01 Condition	to communicate the current status of the facility and facility elements
02 Specifying	to describe or identify facility elements precisely or state the precise requirements for a facility element
04 Executing	**to put into effect facility information**
01 Controlling	to use facility information to regulate executing equipment
02 Assembling	to use facility information to fit together the separate components of a facility
03 Fabricating	to manufacture the elements of a facility using facility information
05 Managing	**to handle or direct the use of facility information**
01 Tracking	to follow and note the facility elements including spaces
02 Monitoring	to observe the performance of facility systems
03 Regulating	to control the operation of facility elements
04 Gathering	to collect, to bring together facility information
01 Quantifying	to express or measure the amount of a facility element
02 Condition documenting	to record the state of the facility or facility elements
05 Commissioning	to bring facility information into working condition and prepare for future use

While this list of BIM Uses was more comprehensive than most list of BIM Uses, the list had not yet been fully vetted and verified. This initial ontology was modified numerous times after the initial ontology development (discussed in Refinement Stage).

3.4.4 Define Characteristics (Properties and Attributes)

After the initial class hierarchy was developed, the properties and attributes types of the BIM Uses (instances) were determined. These attributes were critical to the later validation of the BIM Use classification. Some of the initial attributes included: Description, Other Names, Project Phase(s), Actors (from OmniClass), Process Maps (BIM Process), Level of Detail, Facility Systems, Benefits to Project, Super-Implementation-Strategy (i.e. the Use category above), Sub-Implementation-Strategy (any BIM Uses that could be a part of it), related BIM Uses (BIM Uses that either feed or pull information), and Technology Needs. In general, these attribute types were based on the elements of the BIM planning procedure and were originally classified into one large group. The attributes were later refined into three groups including of defining, elaborating, and implementing. The attributes were then updated and it was determined that these attributes should be called characteristics of the BIM Use because the characteristics can be used to further define or specify a specific BIM Use.

3.5 Refining: Evaluating and Validating

After the development of the initial ontology it was refined and validated using: competency questions, mapping, comparison, expert interviews, and a focus group meeting. As suggested in ontology validation literature, these evaluation methods were grouped into two stages: first, technical developer self-evaluation (including competency questions, mapping, and comparison) and second, external user/expert evaluation (including expert interviews and focus group meetings). A description of each method is discussed in Table 3-5.

Table 3-5: Methods of Evaluation and Validation

Method		Description
Internal	**Competency Questions**	Competency questions are a list of questions that knowledge based upon that ontology should answer (Gruninger and Fox 1995)
	Mapping	Associating original BIM terms with classes within ontology
	Comparison	Comparing the BIM Use Ontology with other formal ontology standards and structures
External	**Industry Interviews**	Meeting one-on-one with industry members to review terms and term mapping
	Focus Group Meeting	Meeting with a large group of industry members to evaluate the overall structure of the BIM Use Ontology as well as the definitions.

The internal evaluation ensured that the BIM Use Ontology functions in the real world and follows formal ontological model. Based on the internal review, the BIM Use Ontology was refined prior to the external user/expert review. The external user/industry review judges the BIM Use Ontology on a user/implementation level. Based on the external evaluation, the BIM Use Ontology was updated yet again to reflect its current form. Additionally, at the time this dissertation is being submitted, the BIM Use Ontology is being balloted for the U.S. National BIM Standards and being implemented on projects and within organizations.

The overall goal of the evaluation and validation was to ensure that the BIM Use Ontology is comprehensive, consistent, extensible, and easy to use. In the following table, Table 3-6, is a brief description of each goal:

Table 3-6: The Goals of the Validation of the BIM Use Ontology

Goal	Description
Comprehensive	The BIM Use Ontology's ability to cover the main concepts the main concepts within the domain.
Consistent	The BIM Use Ontology's ability to be free from variation in the style of the representation of objects within the BIM Use Ontology.
Extensible	The BIM Use Ontology's ability to be added to in a systematic manner.
Ease-of-Use	The BIM Use Ontology's ability to be understood, navigated, and implemented.

The validation evaluated the five primary elements of the BIM Use Ontology. These elements are shown in Table 3-7.

Table 3-7: Elements of the BIM Use Ontology Evaluated

Element	Description
Terms	All terms that are relevant to the domain were documented including names for the tasks themselves, but also those terms that relate the tasks (Noy and McGuinness 2001). Ensure no overlap in the terms.
Definitions	This exact statement or description of the nature, scope, or meaning of the term. In this case, the definitions, which were validated, are the objectives of the BIM Uses.
Attributes	An attribute is a quality or feature regarded as a property or inherent part of someone or something. In this case the attributes are the various components of BIM
Classes	The classes of the BIM Uses in this case are the groups of BIM Use Purposes. These are validated to ensure that there is not overlap amongst the classes.
Class Hierarchy	This is the overall structure of the BIM Use Ontology. It includes the BIM Uses Purposes, elaborating, implementing, and defining characteristics.

The different methods to evaluate and validate the BIM Use Ontology were employed to ensure that the goals of the evaluation were accomplished and that all elements of the BIM Use Ontology were evaluated. Table 3-8 illustrates which validation methods accomplish which goals and covered which elements of the BIM Use Ontology. Based on the table, it is easy to understand the degree to which the various methods evaluate the BIM Use Ontology.

Table 3-8: Methods of Validation vs. Goals and Elements

		Goals				Elements				
		Comprehensive	**Consistent**	**Extensible**	**Ease-of-Use**	**Terms**	**Definitions**	**Attributes**	**Classes**	**Class Hierarchy**
Internal	**Competency Questions**	1	1			1	1	1	1	1
	Mapping	1	1	1	1	1			1	1
	Comparison			1	1			1	1	1
External	**Expert Interviews**	1	1	1	1	1	1	1		
	Focus Group Meeting	1	1	1			1		1	1
Total		4	4	4	3	3	3	3	4	4

3.5.1 Self-Evaluation and Validation

After the initial development, the BIM Use Ontology was internally evaluated using three separate methods. These methods included competency questions, mapping, and comparison. A description of each method can be found below in Table 3-9.

Table 3-9: Internal Ontology Validation Methods

Method		Description
Internal	**Competency Questions**	Competency questions are a list of questions that knowledge based upon that ontology should answer (Gruninger and Fox 1995)
	Mapping	Associating original BIM terms with classes within ontology
	Comparison	Comparing the BIM Use Ontology with other formal ontology standards and structures

3.5.1.1 Competency Questions

The validation method of competency questions is designed to ensure that the BIM Use Ontology satisfies its original intent or its mission and goals. The intent of the BIM Use Ontology is to *provide a shared vocabulary which is utilized to model (or express) the BIM Uses, including the type of objects (or terms), and concepts, properties, and relationships that exist.* The competency questions are part to the goals or objectives of the BIM Use Ontology. The competency questions for the BIM Use Ontology include:

- What are the specific BIM Uses?
- What are the definitions of the BIM Uses?
- What are the important attributes of each BIM Use?
- What are the classes of BIM Uses?
- What is the class hierarchy of the BIM Uses?
- What is the relationship(s) of one BIM Use to Another BIM Use?

3.5.1.1.1 What are the specific BIM Uses?

The BIM Use Ontology answers the question of what are the specific BIM Uses. It does this by pairing the various purposes of implementing BIM with the characteristics. This pairing creates numerous combinations of BIM Uses which provide the means to communicate the intent of the BIM Use.

3.5.1.1.2 What are the definitions of the BIM Uses?

The definition of the BIM Uses within the BIM Use Ontology are also considered the objective. Each BIM Use Purpose has an objective. In addition to the objective, each BIM Use Purpose has BIM Use Characteristics which are a description to provide detailed information on the purpose. Each characteristic of the BIM Use is a definition and description.

3.5.1.1.3 What are the important attributes of each BIM Use?

The BIM Use Ontology defines the attributes of the BIM Use. These attributes include the purpose, facility phase, facility element, facility discipline, level of development, process, information, infrastructure, resources, and impact. These are the critical attributes that make up the BIM Use.

3.5.1.1.4 What are the classes of BIM Uses?

The BIM Use Ontology provides the various classes of BIM. It primarily provides classes of BIM Use Purposes including five superclasses and eighteen subclasses. Additionally, there are also classes of BIM Use Ontology attributes.

3.5.1.1.5 What is the class hierarchy of the BIM Uses?

The BIM Use Ontology defines the hierarchy of the BIM Uses, which separates the BIM Use into BIM Use Purposes and BIM Use Characteristics. The BIM Use Purpose is divided into five superclasses, each of which have three or four classes. There are three primary classes of characteristics, each of which has its own characteristics. The top levels of the BIM Use Ontology are shown in Figure 3-2.

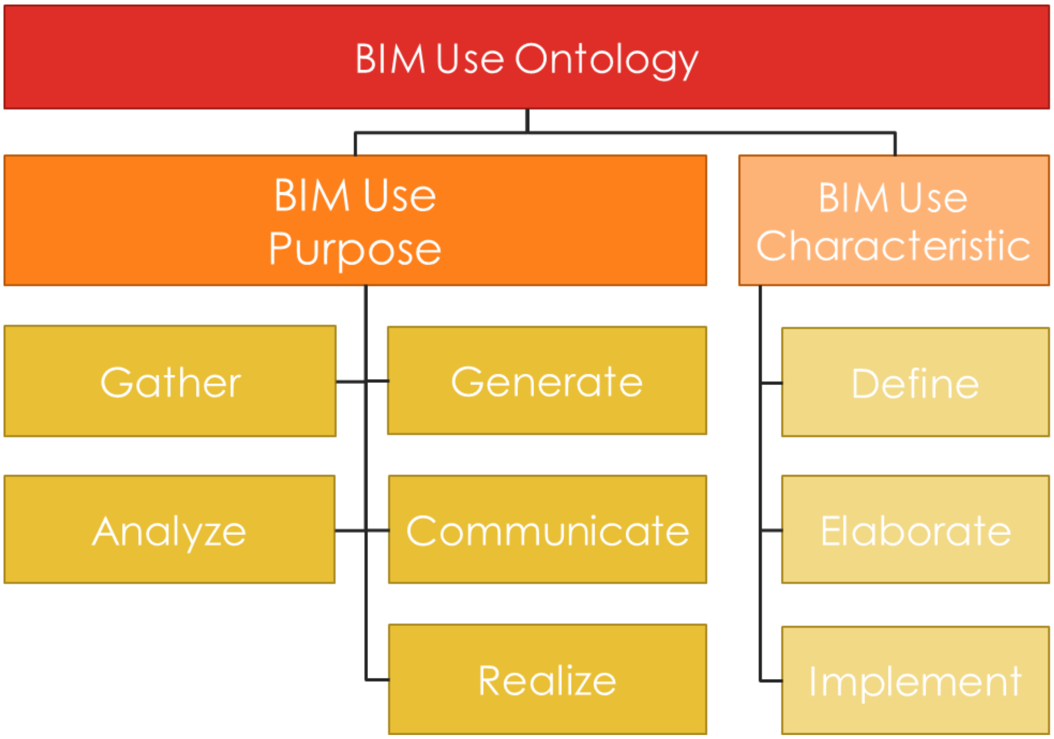


Figure 3-2: Top Levels of BIM Use Ontology Hierarchy

3.5.1.1.6 What is the relationship(s) of one BIM Use to another BIM Use?

Overall, there is a relationship among the BIM Use Purposes. In fact, there is a logical movement from each BIM Use to another. While it varies in the level of complexity, facility information often moves to each of the BIM Use Purposes. For example, facility information is first gathered. Secondly, new information is generated. This information is then analyzed, after which it is communicated and then realized. This process is repeated for the entire facility and it is repeated within an actual BIM Use.

There is also a relationship between the BIM Use Characteristics. When identifying BIM Uses, the characteristics build upon each other. The phase may be dependent upon the element, the discipline may be dependent upon the phase, and the level of development may be dependent on the discipline. The same can be said for the other characteristics. The information builds upon the process, and the infrastructure builds upon the information. All the BIM Use Purposes and characteristics are intricately connected and related.

3.5.1.2 *Map Current Standard BIM Uses to Ontology*

After determining if the BIM Use Ontology answered the original competency questions, the existing BIM Use terms were mapped to the BIM Use Ontology. This was accomplished by reviewing each of the 550 BIM Use terms, and then placing them into a specific BIM Use Purpose. In the majority of cases, the mapping could be accomplished easily because it was a one-to-one relationship between the BIM Use term and BIM Use Purpose.

However, one challenge was that some of these items were not one-to-one relationships and were a one to many relationship, or even a many to one relationship. For example, cost estimating from the original *BIM Project Execution Planning Guide* has a one-to-multiple BIM Use Purpose relationship. Cost estimating is made up of the BIM Use Purposes of financial forecasting and quantifying.

Another challenge was the many-to-one relationship. For example, energy analysis and acoustical analysis are both part of the forecasting BIM Use Purpose. The only difference between the BIM Uses is the facility performance characteristics. Facility performance characteristics are items such as energy, heat flow, cost, and acoustical elements that are non-physical factors that result from the overall status of the facility. A comprehensive listing of performance factors are not currently part of the BIM Use Ontology.

After factoring in these challenges, all of the BIM Use terms were mapped back to the BIM Use Purposes and BIM Use Characteristics. Additionally, if it was determined that an existing industry term better represented the objective of the BIM Use Purpose, that BIM Use term was selected to present the purpose.

3.5.1.3 *Ontology Comparison*

An ontology comparison ensured that all of the rules and standards of ontology creation are considered and followed within the BIM Use Ontology. While these guidelines were applied to develop the initial BIM Use Ontology these rules include:

- Term Bias: Terms do not have unintended bias toward other industry meanings
- Class-Cycling: Subclasses and superclasses do not overlap
- Multiple Inheritance: Subclass is not part of multiple classes
- Subclass Numbers: Proper number of subclasses are present
- Class Alignment: All instances share the same attributes
- Ontology Expansion: Classes allow for additional instances

3.5.1.3.1 Term Bias

It is necessary to ensure that no bias is present in the terms within the BIM Use Ontology and that the terms themselves do not lend themselves to other meanings. Pre-established terms have pre-conceived ideas about each term. Each term may mean something different to different people. To overcome this problem, the core meaning or objective was the focus, rather than the term itself. In the initial ontology, the terms of authoring and executing were applied to describe when new information is generated about the facility and when a physical element is developed using facility information. However, authoring has a bias toward the design phase, and execution has a bias toward the construction. It was necessary to later classify these items into generating and realizing.

3.5.1.3.2 Class-Cycling

Class-cycling, where a subclass is part of a superclass and the superclass is part of the subclass, was also a challenge. To overcome this challenge, it was necessary to ensure that the subclasses and superclasses did not overlap. This helped to ensure that the class hierarchy is correct. To ensure that there was not class-cycling, the definitions of each class were compared to each to other ensure that the definition could not be shared for multiple terms. A term could not be part of the definition of the term in the class above. The original ontological structure contained both generating and authoring, which is an example of class cycling. Either of those classes could have been a subclass to the other therefore creating class cycling. This was corrected during the refinement stage.

3.5.1.3.3 Multiple Inheritance

It is possible to have a class be a part of multiple superclasses. This is called multiple inheritance. This was initially a challenge when developing the classes. The challenge was primarily due to the BIM Uses collected included multiple BIM Use Purposes that were not mutually exclusive. An example of this was trying to determine a location for the BIM Uses related to scheduling. It was challenging to determine the location of scheduling because scheduling could have multiple BIM Uses. Determining that scheduling was a performance characteristic, much like energy usage or acoustics, identified that the BIM Use Ontology should not address scheduling as a BIM Use Purpose.

3.5.1.3.4 Subclass Numbers

Within ontological development research there are rules of thumb that state there should be at least two subclasses and no more than ten to twelve subclasses for each classes. If a class only has one subclass, the subclass maybe incomplete or modeled incorrectly and if it has more than a dozen subclasses, there may be an additional class in between the subclass and superclass (Noy and McGuinness 2001). The BIM Use Ontology throughout its development (except in the original BIM Use term mapping) did not violate these rules of thumb. Moreover as the BIM Use Ontology stabilized, it moved to having between three and five subclasses for each class.

3.5.1.3.5 Class Alignment

It is critical to ensure that all of the classes and instances share the same attributes. The challenge is when to develop new classes versus instance of a class. Rules of thumb to determine if a new class is necessary include when a subclass has "(1) additional properties that the superclass does not have, or (2) has restrictions different from those of the superclass, or (3) participates in different relationships than the superclasses. (Noy and McGuinness 2001)." On the one hand, it is a challenge to determine whether an attribute or property with similar values should be created into a new class. While, on the other hand, it may be possible that an instance of the class is actually a whole class on its own. There needs to be balance between not having enough classes and creating too many classes for the BIM Use Ontology to be useful. This challenge was addressed a number of times through the course of the development of the BIM Use Ontology; especially within the managing (now gathering) and executing (now realizing) classes. Within the managing classes there were numerous subclasses that had a very similar definition such as tracking and monitoring. The question became whether these were different enough to justify separate classes. Another example is within the execution phase with controlling and regulating. It was necessary to differentiate between those BIM Use Purposes that were controlling equipment and those that were controlling the facility. It was these types of decisions that led to the development of the current Ontology.

3.5.1.3.6 Ontology Expansion

While it was critical to limit the scope of the BIM Use Ontology, it was also critical to ensure that the BIM Use Ontology can be expanded. It is not entirely possible to document all information about the particular domain of BIM Uses. The BIM Use Ontology must allow for expansion to include the additional domain information. Therefore, the BIM Use Ontology was developed in such a way as to have logical areas for expansion. In the case of the BIM Use Ontology, it can easily be expanded through the addition of new purposes and characteristics.

3.5.2 Initial Refinement

Where the BIM Use Ontology did not fulfill the criteria set forth in the internal evaluation methods of competency questions, mapping, and comparison, it was updated to meet the necessary criteria. During the internal validation, the BIM Use Ontology was refined incrementally by modifying the terms, objectives, and structure of the BIM Use Ontology. This was to ensure that the BIM Use Ontology was comprehensive, consistent, extensible, and easy to use.

3.5.2.1 Modified BIM Use Purposes

During this validation the BIM Use Ontology's BIM Use Purposes were refined from 43 separate purposes to a more concise list of 37 items. The updated BIM Use Purposes within the BIM Use Ontology are shown in Table 3-10.

Table 3-10: Ontology after Internal Validation and Refinement

BIM Use Purpose					Objective
01	**Authoring**				**to generate new information about the facility**
	01	Prescribing			to determine the need for and select specific facility elements including spaces
	02	Configuring			to determine location and arrangement of facility elements including spaces
	03	Sizing			to determine the size and scale of facility elements
02	**Analyzing**				**to methodically examine elements of the facility to gain a better understanding of it.**
	01	Coordinating			to ensure the efficiency and harmony of the relationship of facility elements
			01	Geometric	to ensure the spatial efficiency of facility elements
			02	Temporal	to ensure the temporal efficiency of facility elements
	02	Forecasting			to predict the future performance of the facility
			01	Energy	to predict future energy use of the facility or facility elements
			02	Financial	to predict the future monetary elements of the facility
			03	Flow	to predict the circulation of the facility systems
			04	Scenario	to predict possible situations within the facility such as crowd flow, evacuation procedures and other disasters
			05	Temporal	to predict the performance of the facility or facility elements over time
	03	Validating			to check or prove accuracy of facility information and that is logical and reasonable
			01	Prescription	to ensure facility contains the necessary facility elements including spaces to meet its desired function
			02	Functionality	to ensure facility is able to be constructed, operated, and perform its established purpose effectively
			03	Compliance	to ensure facility meets established requirements such as Code, Sustainability, and Safety
03	**Communicating**				**to present information about a facility in a method in which it can be shared or exchanged**
	01	Visualizing			to form an image of a facility or facility elements
	02	Modeling			to generate objects with intelligence to emulate the facility and facility elements
	03	Drawing			to make a symbolic representation of the facility and facility elements including proper annotation and detailing
	04	Documenting			to create a record of facility information including the information necessary to precisely specify facility elements
04	**Executing**				**to make a physical element or perform a physical take using facility information**
	01	Regulating			to facility information to control the operation of a facility element or executing equipment
	02	Assembling			to use facility information to fit together the separate elements of a facility
	03	Fabricating			to manufacture the elements of a facility using facility information
05	**Managing**				**to handle or direct the use of facility information**
	01	Tracking			to follow and note the facility elements including spaces
			01	Temporal	to status of a facility element over time
			02	Financial	to follow the finances of a facility and facility element over time
			03	Element	to track an element of a facility over time
	02	Monitoring			to observe the performance of facility elements and systems
	03	Capturing			to represent, or preserve the current status of the facility and facility elements
	04	Quantifying			to express or measure the amount of a facility element
	05	Scheduling			to plan an event to take place at a particular time

3.5.2.2 *Differences Between BIM Use Purposes*

After the completion of the internal validation, changes were included in the updated BIM Use Purposes. Table 3-11 shows the differences between the BIM Use Purposes prior to external validation and after external validation.

Table 3-11: Differences between BIM Use Purposes

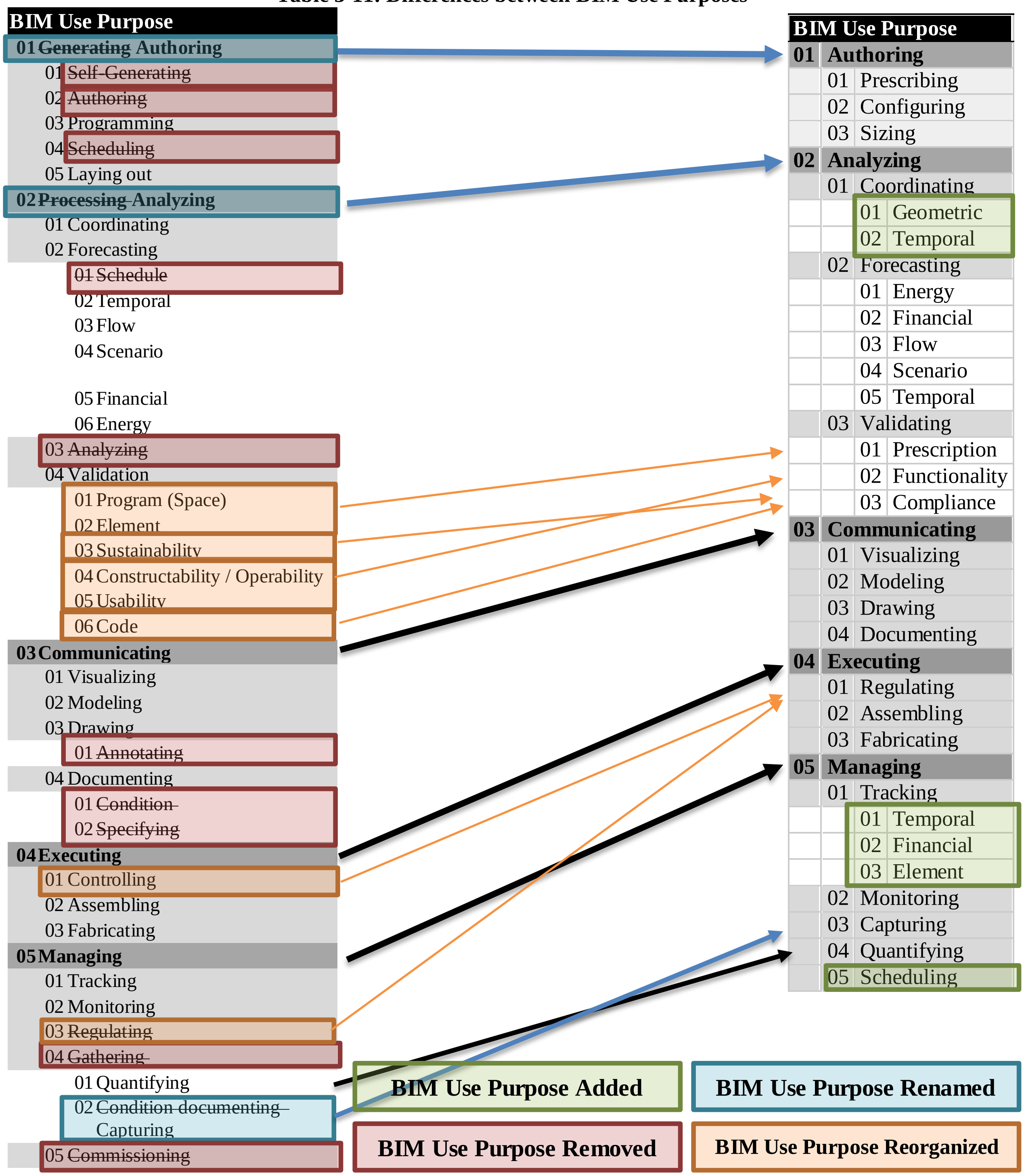


Table 3-12 explains the modifications to the BIM Use Purposes after internal validation and the reason or justification for the modification.

Table 3-12: Modifications to BIM Use Purposes after Internal Validation

Modification	Reason
Rename generating to authoring	Originally authoring was a sub-purpose of generating and when it was removed authoring better represented the objective of the BIM Use Purpose
Removed self-generating	Self-generating was removed because it is actually a level of maturity or level of automation of the generating class
Removed authoring	Authoring and generating were essentially the same BIM Use Purpose therefore creating the issue of class-cycling
Removed scheduling	Scheduling, while an item that is generated, was determined to be non-facility element activity (i.e. it could be performed without interaction with facility elements) and therefore not part of the BIM Use Purpose
Rename processing to analyzing	Originally analyzing was a sub-purpose of processing and when it was removed analyzing better represented the objective of the BIM Use Purpose
Removed analyzing	Analyzing and processing were essentially the same BIM Use Purpose therefore creating the issue of class-cycling
Merged program and element into prescription	Program and element were accomplish the same purpose however on different elements (facility spaces and facility elements)
Merged sustainability and code into compliance	Sustainability and code validation were essentially the same validation the only item that varied was subject being validated. They are both compliance checks.
Merged constructability / operability and usability	Both BIM Use Purposes were validated the functionality of the facility and whether the facility could meet its objective
Removed annotating	BIM Use Purpose is not explicit to drawing and would need to include all other parts of a drawing including lines, points, shapes, as an annotation is only one part of a drawing
Removed condition	Determined that condition capturing more closely aligned with the managing sub-uses. Leaving it in this location would have duplicate the BIM Use Purposes in multiple classes therefore creating multiple inheritance
Removed specifying	After condition was removed, it was determined that specificity and document were essentially the same BIM Use Purpose therefore creating class-cycling
Merged controlling and regulating into regulating	Based on internal validation it was determined the controlling and regulating did not vary enough to be separate classes
Removed gathering	Determine that quantifying and condition documenting were different enough to be in two higher level classes, therefore the gathering class become unnecessary
Renamed condition documenting to capturing	Determined the term capturing better represented the objective of the BIM Use Purpose
Removed commissioning	Determined that commissioning is actually a phase in the facility life therefore not part of the BIM Uses
Added geometric and temporal to coordinating	Determined that time and geometry were item that would be coordinated
Added temporal financial and element to tracking	Determined that time, money, and components were items that would be tracked
Added scheduling	Determined that the scheduling objective best fit within the managing class of BIM Use Purposes

Additionally, some BIM Use Purpose objective definitions were updated, however the objective of each did not change. The language was only refined to be more concise.

3.5.3 External Evaluation and Validation

After the internal validation and refinement was completed, external validation was conducted. This external validation included industry interviews and focus group meeting. Primarily the industry interviews evaluated the ontological structure, while the focus group meetings concentrated on terms and definitions. A description of each external validation method can be found in Table 3-13.

Table 3-13: External Evaluation and Validation Methods

Method		Description
External	**Industry Interviews**	Meeting one-on-one with industry members to review terms and term mapping.
	Focus Group Meeting	Meeting with a large group of industry members to evaluate the overall structure of the BIM Use Ontology as well as the definitions.

3.5.3.1 Piloting Validation Procedures

Prior to implementing the validation procedures each method was piloted on a smaller scale. The interview procedure was validated by three individuals including one member of the Computer Integrated Construction Research Program and two industry members. The focus group member procedure was validated during a Computer Integrated Construction Research Program meeting with members of the group offering feedback.

3.5.3.2 Industry Interviews

Nineteen separate industry interviews were conducted to ensure the validity of the BIM Use Ontology. Those interviewed include members from the various phases of a facility's life including design, construction, and operations. Those interviewed included architects, engineers, contractors, and consultants. The goals was to ensure a wide spectrum of understanding of the life-cycle of a facility. Additionally, all those interviewed had an understanding of the concepts of Building Information Modeling prior to the interviews. In fact, most of those interviewed are very knowledgeable on the subject of BIM and are leading contributors towards advancing the domain.

The interviews consisted of four parts including an overview of the BIM Use Ontology goals and development procedure, an overview of the BIM Use Ontology terms and structure, a BIM Use mapping exercise and a survey. Each interview ranged from three-quarters of an hour to one and half hours, depending on the level of interest of the participant. Interviews were conducted using Go-To-Meeting and Prezi, shown in Figure 3-3, to allow for a screen sharing experiences.

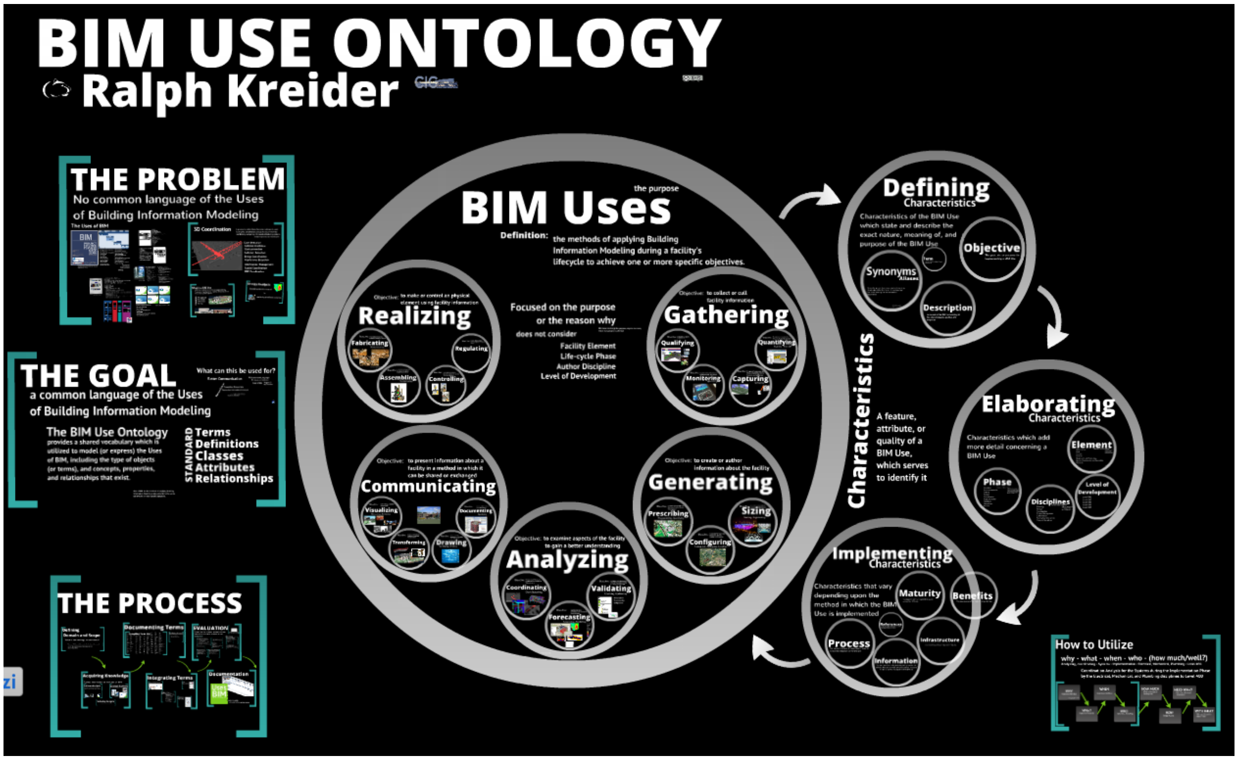


Figure 3-3: BIM Use Ontology Overview Prezi

3.5.3.2.1 Research Goals and Development Process

During the research goals and development portion of the interview, participants were informed of the background of the research and for what purpose the BIM Use Ontology was developed. They were also informed on the existing BIM Use terms that exist within the industry, after which the participants were informed of the process that was applied to develop the BIM Use Ontology as it was described in this chapter. Overall the goals and process of the BIM Use Ontology were well understood and the participants understood the need for developing the BIM Use Ontology.

3.5.3.2.2 Ontology Overview

After the overview of the research goals, participants were introduced to the BIM Use Ontology. This included stepping through each of the BIM Use Purposes, followed by the characteristics. Throughout this process the participants were encouraged to ask questions on the BIM Use Ontology and the concepts that were presented to them. Throughout the interview the participants provided feedback and discussion on the BIM Use Ontology. Based on participant's feedback, most understood the concepts that were presented to them and only disagreed with some of the terms at the lower levels. Based on qualitative feedback from the participants, the overall structure was well received.

3.5.3.2.3 Mapping BIM Uses

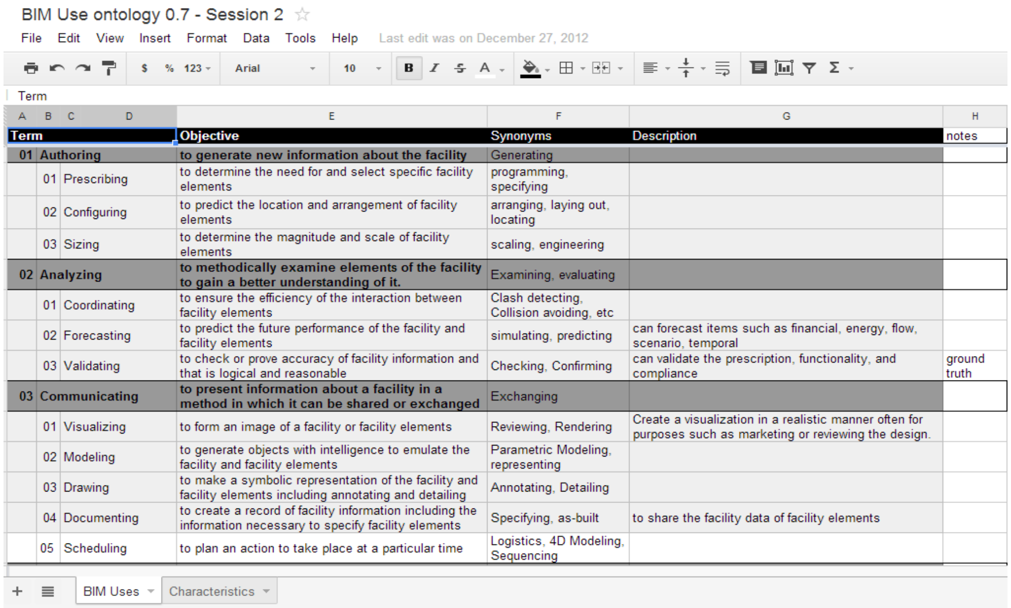
Prior to a detailed discussion of the BIM Use Ontology, interview participants were asked to document three to five BIM Uses. This was done prior to discussing the BIM Use Ontology to ensure that no bias was created toward the terms and BIM Uses within the BIM Uses Ontology. After the BIM Use Ontology was overviewed with the participants, the participants were asked to begin mapping the terms. This was accomplished by the participant first selecting the primary BIM Use Purpose, a secondary BIM Use Purpose, and in some cases a tertiary BIM Use Purpose, after which the participant would further elaborate on the BIM Use by selecting a BIM Use Characteristics that applied to the BIM Use. In most cases the participants were able to map their BIM Uses to the BIM Use Ontology. However, it was common to see that a number of the participants actually documented BIM services rather than individual BIM Use instances. This required the BIM Use to fall into multiple categories. Overall the mapping exercise was successful and there were very few participants that were not able to fully map their BIM Uses.

3.5.3.2.4 Outcomes the Industry Interviews

Based on the industry feedback the BIM Use Ontology was simplified to make it more understandable and implementable. The changes, however, did not occur until after the completion of the focus group meeting. Overall the industry interviews were successful because they allowed the research to gain a third party perspective.

3.5.3.3 Focus Group Meetings

The focus group meetings were designed to review the definitions, classes, and class hierarchy. The process to implement them was similar to industry interviews. During the focus group meetings, the research goals and objectives were reviewed, the BIM Use Purposes and Characteristics were shared, after which each term was reviewed. The terms were reviewed based on consistency, comprehensiveness, extensibility, and ease-of-use. Overall, there were three separate focus group meetings, with each meeting taking between two and three hours. Each of the focus group meetings had between three and six participants representing all sectors of the industry. The focus group meetings were conducted using Prezi, Google Docs Spreadsheet, shown in Figure 3-4, and Go-To-Meeting.



Term		Objective	Synonyms	Description	notes
01	Authoring	to generate new information about the facility	Generating		
01	Prescribing	to determine the need for and select specific facility elements	programming, specifying		
02	Configuring	to predict the location and arrangement of facility elements	arranging, laying out, locating		
03	Sizing	to determine the magnitude and scale of facility elements	scaling, engineering		
02	Analyzing	to methodically examine elements of the facility to gain a better understanding of it.	Examining, evaluating		
01	Coordinating	to ensure the efficiency of the interaction between facility elements	Clash detecting, Collision avoiding, etc		
02	Forecasting	to predict the future performance of the facility and facility elements	simulating, predicting	can forecast items such as financial, energy, flow, scenario, temporal	
03	Validating	to check or prove accuracy of facility information and that is logical and reasonable	Checking, Confirming	can validate the prescription, functionality, and compliance	ground truth
03	Communicating	to present information about a facility in a method in which it can be shared or exchanged	Exchanging		
01	Visualizing	to form an image of a facility or facility elements	Reviewing, Rendering	Create a visualization in a realistic manner often for purposes such as marketing or reviewing the design.	
02	Modeling	to generate objects with intelligence to emulate the facility and facility elements	Parametric Modeling, representing		
03	Drawing	to make a symbolic representation of the facility and facility elements including annotating and detailing	Annotating, Detailing		
04	Documenting	to create a record of facility information including the information necessary to specify facility elements	Specifying, as-built	to share the facility data of facility elements	
05	Scheduling	to plan an action to take place at a particular time	Logistics, 4D Modeling, Sequencing		

Figure 3-4: Example Google Doc from Focus Group Meeting

3.5.3.3.1 Research Goals and Development Process

During the research goals and development portion of the focus group meeting, participants were informed of the background of the research and for what purpose the BIM Use Ontology was developed. Just like the interviews, the participants were also informed on the existing BIM Use terms that exist within the industry. After which, the participants were informed of the process that was employed to develop the BIM Use Ontology as it was described in this chapter. Overall the goals and development process for the BIM Use Ontology were well understood and the participants understood the need for developing the BIM Use Ontology.

3.5.3.3.2 BIM Use Ontology Overview

After the overview of the research goals, participants were introduced to the BIM Use Ontology. This included stepping through each of the BIM Use Purposes, followed by the BIM Use Characteristics. Throughout this the participants were encouraged to ask questions on the BIM Use Ontology and the concepts that were presented to them. Throughout the interview the participants provided feedback and discussion on the BIM Use Ontology. In most cases the participants understood the concepts that were presented to them and only disagreed with some of the terms at the lower levels. The overall structure was well received.

3.5.3.3.3 Reviewing BIM Use Ontology Structure

Before the focus groups concentrated on the individual terms, they were asked to review the structure of the BIM Use Ontology to ensure that the classes were accurate. This included a cursory review of the BIM Use terms. In order to accomplish a review of the structure the researcher reviewed each class with the participants to confirm that the class contains the correct terms. The participants were asked if they believed the terms were in the correct class or if they belonged in a different class. The participants were also asked if terms were missing from the class. If so, what terms were missing? It was critical during these efforts that the researcher remained as the moderator of the conversation and did not provide any direct input or participate in the group.

3.5.3.3.4 Reviewing the Terms Uses and Purposes

After reviewing the BIM Use Ontology structure, the participants were taken through each class of the BIM Use Ontology. This was done term by term. First the participants were ask to review highest level of BIM Use Purpose first. For example, each group reviewed the BIM Use Purposes of Authoring, Analyzing, Communicating, Executing, and Managing first. For each term, the group was to read the term followed by the definition. If the participants, with the researcher only acting as a moderator, did not agree with the term and/or the definition they were asked to suggest revisions to the term. The participants came to a consensus about the terms and definitions. The participants went through all the BIM Use Purposes and then moved on to the BIM Uses characteristics. At the conclusion of the review, the focus group participants had an updated ontology structure, classes, terms, and definitions.

3.5.3.3.5 Benefits and Challenges of Focus Group Meetings

The employment of focus group meetings as a form of validation had many benefits and challenges. The benefits are shown in Table 3-14 and the challenges are shown in Table 3-15.

Table 3-14: Benefits of Focus Group Meetings

Benefit	Description
Participant Integration	The interactions between participants can lead to more conversations and generate more ideas.
Moderator	Moderator has the ability to lead and encourage participation without making decisions.
Adaptability	The moderator has the ability to modify the focus of the meeting based on the dynamics of the participants and meeting.
Even Contributions	With a skilled moderator, the participants have equal rights to provide insight independent of personality style.

Table 3-15: Challenges with Focus Group Meetings

Challenge	Description
Potential Domination	If not properly moderated the group can become dominated by one or two people leading to bias within results.
Predictable outcomes	Prior the beginning of the focus group it is not possible to determine if the focus group will produce anything of value.
Equal Participation	Because of the ways that the groups were developed, some meeting had only a few people while other groups had a large number of participants.

3.5.3.3.6 Outcomes of the Focus Group Meetings

Despite the drawbacks, overall the focus groups employed collaboration skills to successfully evaluate the BIM Use Ontology and provide recommendations for improvement. Each of the three groups provided a more detailed review than would have been possible with just using industry interviews.

3.5.3.4 Survey

After the conclusion of the interviews and focus group meetings, participants were asked to complete a short online survey. The survey requested the following information:

1. Please enter your contact information
2. Please select the most appropriate discipline(s) based on your organization's role
3. Please describe your role within your organization
4. Please rate how familiar are you with the following concepts (including *the U.S. National BIM Standard*, *the BIM Project Execution Planning Guide*, *the BIM Planning Guide for Facility Owners*, and *the Uses of Building Information Modeling*.
5. Please rate the representativeness (or typicality) of the BIM Use Ontology with industry including the terms, definitions, attributes, classes, class hierarchy and the overall ontology.
6. Please rate the comprehensiveness (or completeness) of the main elements of the BIM Use Ontology including the terms, definitions, attributes, classes, class hierarchy and the overall Ontology.
7. Please rate the BIM Use Ontology's consistency on the following elements including the terms, definitions, attributes, classes, class hierarchy and the overall ontology.
8. Please rate the ease of Use of the BIM Use Ontology for the following elements including the terms, definitions, attributes, classes, class hierarchy and the overall ontology.
9. Please rate the BIM Use Ontology overall on the following categories including representativeness, comprehensiveness, consistency and ease-of-use.
10. Please provide additional comments to improve the BIM Use Ontology.

Overall the survey response rate was 53% of the 19 individuals interviewed or 10 participants. However, of those that responded most thought the BIM Use Ontology was representative, comprehensive, and consistent. The only item that did not have consistent feedback is the ease-of-use of the BIM Use Ontology. However at the point of the validation, an implementation procedure had not yet been developed.

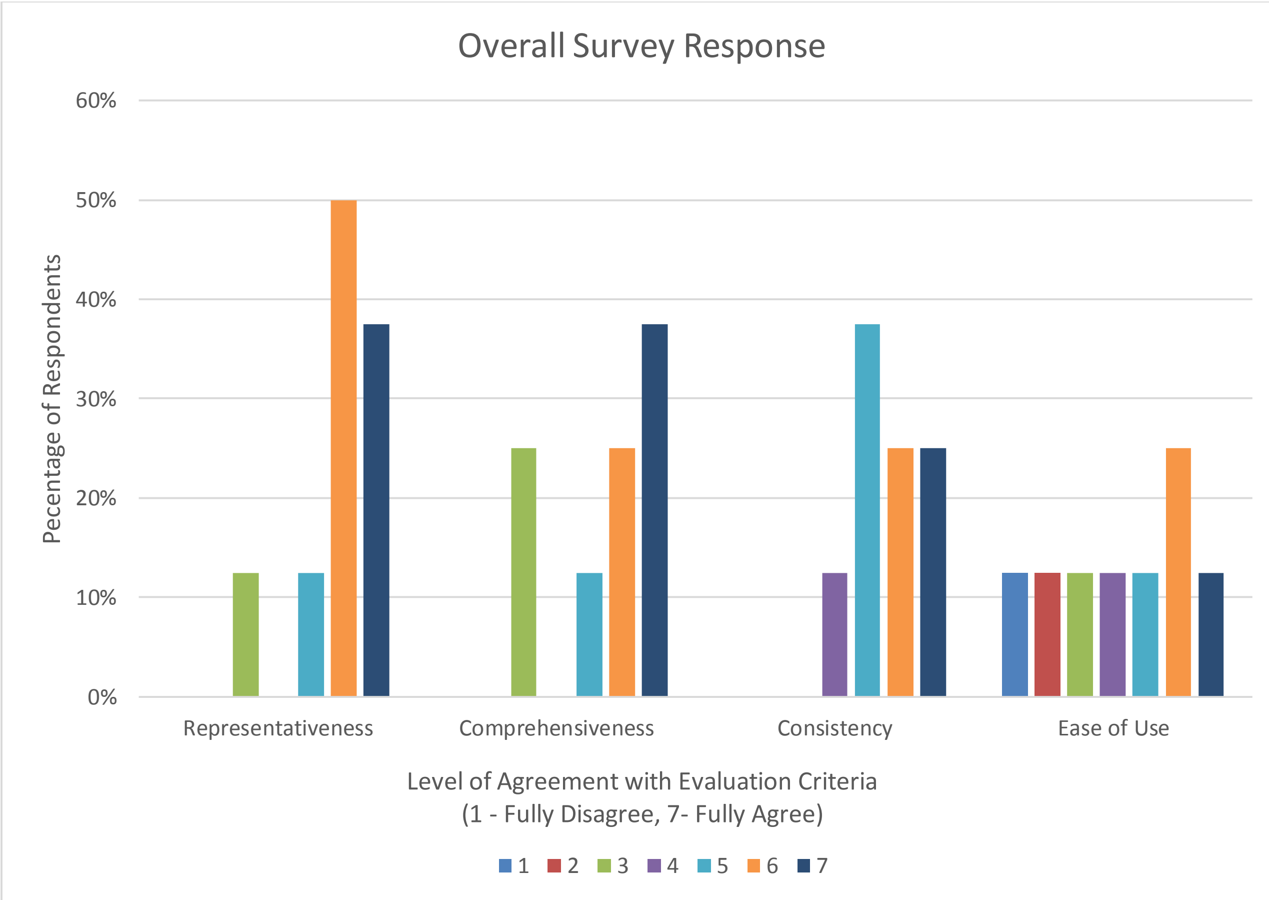


Figure 3-5: Overall Representativeness, Comprehensiveness, Consistency, and Ease-of-Use

The following are sample responses from survey participant:

- “This is a promising start for a contract language, but I'm not sold on [its] adoption for daily use.”
- “The classes are the most intuitive part of the Ontology.”
- “To be honest, the layers of 'terms, definitions, attributes, classes, and class hierarchy' are a little difficult to wrap my head around.”
- “Additional definitions are helpful in relating the Ontology to practical use. Examples would probably go a long way.”
- “I think it is a little hard to use because it is a more detailed way of thinking. You have to be precise in how you explain a term verses the purpose you really mean. Getting clarity across the industry will be good for communication and contracts.”

3.5.3.5 *External Evaluation and Validation Demographics*

Twenty-two individuals explicitly participated in the external evaluation and validation of the BIM Uses Ontology. These individuals were from disciplines representing all phases of a facilities life. Most of the individuals that participated in the validation had a BIM or virtual facility role within their respective organization. This role was selected due to their familiarity with BIM principles and concepts. Figure 3-6 illustrate the Organizational Disciplines and Figure 3-7 illustrates Organizational Roles of the individuals that participated in the validation.

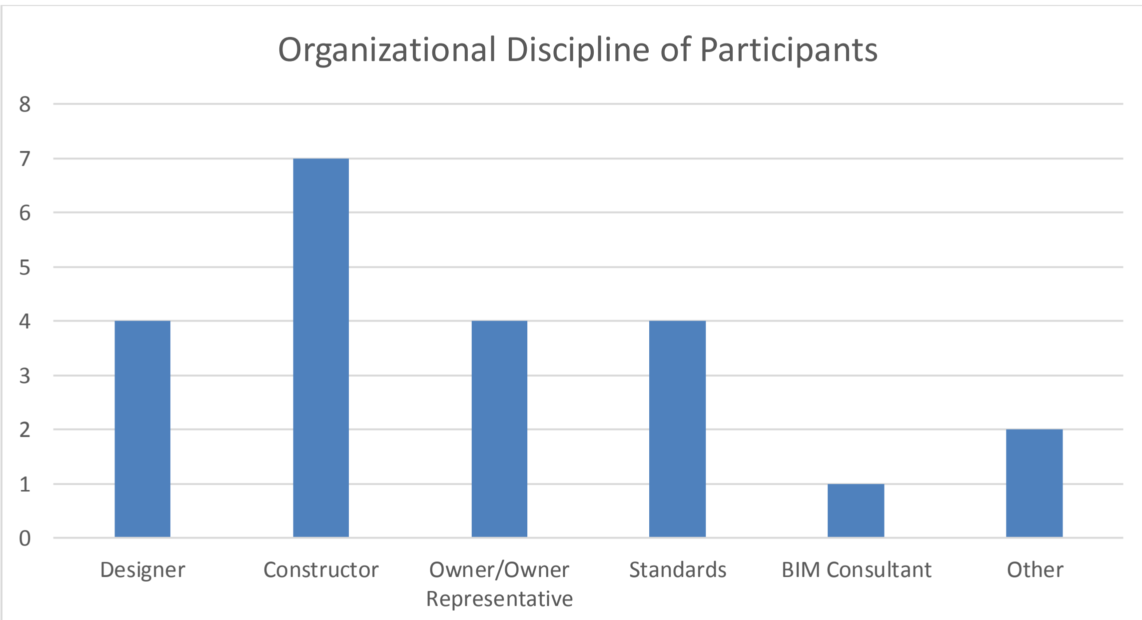


Figure 3-6: Organizational Discipline of External Evaluation Participants

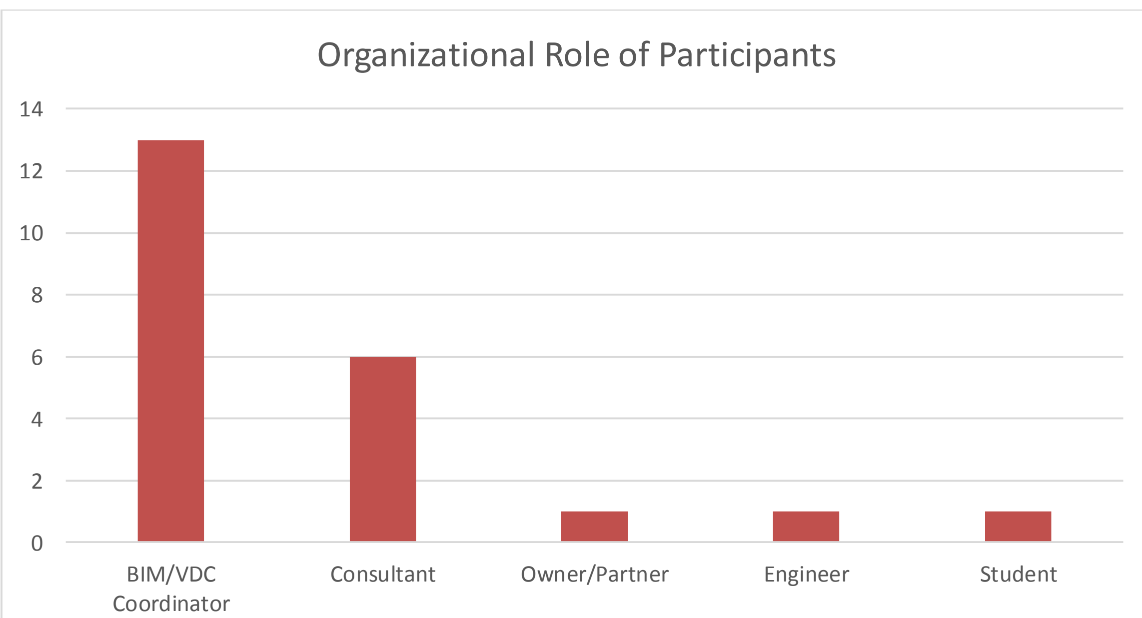


Figure 3-7: Organizational Role of External Evaluation Participants

3.5.4 Final Refinement

After completing all of the external evaluation, the BIM Use Ontology was updated based on the feedback from the focus group meetings and industry interviews. The following table, Table 3-16, shows the BIM Use Ontology prior to external evaluation.

Table 3-16: BIM Use Ontology Prior to External Evaluation

BIM Use Purpose					Objective
01	**Authoring**				**to generate new information about the facility**
	01	Prescribing			to determine the need for and select specific facility elements including spaces
	02	Configuring			to determine location and arrangement of facility elements including spaces
	03	Sizing			to determine the size and scale of facility elements
02	**Analyzing**				**to methodically examine elements of the facility to gain a better understanding of it.**
	01	Coordinating			to ensure the efficiency and harmony of the relationship of facility elements
			01	Geometric	to ensure the spatial efficiency of facility elements
			02	Temporal	to ensure the temporal efficiency of facility elements
	02	Forecasting			to predict the future performance of the facility
			01	Energy	to predict future energy use of the facility or facility elements
			02	Financial	to predict the future monetary elements of the facility
			03	Flow	to predict the circulation of the facility systems
			04	Scenario	to predict possible situations within the facility such as crowd flow, evacuation procedures and other disasters
			05	Temporal	to predict the performance of the facility or facility elements over time
	03	Validating			to check or prove accuracy of facility information and that is logical and reasonable
			01	Prescription	to ensure facility contains the necessary facility elements including spaces to meet its desired function
			02	Functionality	to ensure facility is able to be constructed, operated, and perform its established purpose effectively
			03	Compliance	to ensure facility meets established requirements such as Code, Sustainability, and Safety
03	**Communicating**				**to present information about a facility in a method in which it can be shared or exchanged**
	01	Visualizing			to form an image of a facility or facility elements
	02	Modeling			to generate objects with intelligence to emulate the facility and facility elements
	03	Drawing			to make a symbolic representation of the facility and facility elements including proper annotation and detailing
	04	Documenting			to create a record of facility information including the information necessary to precisely specify facility elements
04	**Executing**				**to make a physical element or perform a physical take using facility information**
	01	Regulating			to facility information to control the operation of a facility element or executing equipment
	02	Assembling			to use facility information to fit together the separate elements of a facility
	03	Fabricating			to manufacture the elements of a facility using facility information
05	**Managing**				**to handle or direct the use of facility information**
	01	Tracking			to follow and note the facility elements including spaces
			01	Temporal	to status of a facility element over time
			02	Financial	to follow the finances of a facility and facility element over time
			03	Element	to track an element of a facility over time
	02	Monitoring			to observe the performance of facility elements and systems
	03	Capturing			to represent, or preserve the current status of the facility and facility elements
	04	Quantifying			to express or measure the amount of a facility element
	05	Scheduling			to plan an event to take place at a particular time

3.5.4.1 *MODIFIED BIM USES*

The following table, Table 3-17, contains the revised BIM Use Purpose. These are the BIM Use Purposes that have been documented and balloted for the National BIM Standard.

Table 3-17: Revised/Final BIM Use Purposes

BIM Use Purpose		BIM Use Objective	Synonyms
01	**Gather**	**to collect or organize facility information**	administer, collect, manage, acquire
01	Capture	to represent or preserve the current status of the facility and facility elements	collect
02	Quantify	to express or measure the amount of a facility element	quantity take-off
03	Monitor	to collect information regarding the performance of facility elements and systems	observe, measure
04	Qualify	to characterize or identify facility elements' status	follow, track, identify
02	**Generate**	**to create or author information about the facility**	create, author, model
01	Prescribe	to determine the need for and select specific facility elements	program, specify
02	Arrange	to determine location and placement of facility elements	configure, lay out, locate, place
03	Size	to determine the magnitude and scale of facility elements	scale, engineer
03	**Analyze**	**to examine elements of the facility to gain a better understanding of the elements**	examine, evaluate
01	Coordinate	to ensure the efficiency and harmony of the relationship of facility elements	detect, avoid
02	Forecast	to predict the future performance of the facility and facility elements	simulate, predict
03	Validate	to check or prove accuracy of facility information and that is logical and reasonable	check, confirm
04	**Communicate**	**to present information about a facility in a method in which it can be shared or exchanged**	exchange
01	Visualize	to form a realistic representation of a facility or facility elements	review
02	Transform	to modify and translate information to be received by another process	translate
03	Draw	to fashion a symbolic representation of the facility and facility elements	draft, annotate, detail
04	Document	to create a record of facility information including the information necessary to precisely specify facility elements	specify, submit, schedule, report.
05	**Realize**	**to make or control a physical element using facility information**	implement, perform, execute,
01	Fabricate	to manufacture the elements of a facility using facility information	manufacture
02	Assemble	to bring together the separate elements of a facility using facility information	prefabricate
03	Control	to physically manipulate the operation of executing equipment using facility information	manipulate
04	Regulate	to inform the operation of a facility element using facility information	direct

3.5.4.2 *Differences Between BIM Use Purposes*

After the completion of the external validation, a number of changes were included in updated BIM Use Purposes. The following table, Table 3-18, shows the differences between the BIM Use Purposes prior to external validation and after external validation.

Table 3-18: Differences between BIM Use Purposes

Intermediate BIM Use Purpose			
~~01~~ 02	**~~Authoring~~ Generate**		
	01	Prescribing	
	02	~~Configuring~~ Arrange	
	03	Sizing	
~~02~~ 03	**Analyzing**		
	01	Coordinating	
		~~01~~	~~Geometric~~
		~~02~~	~~Temporal~~
	02	Forecasting	
		~~01~~	~~Energy~~
		~~02~~	~~Financial~~
		~~03~~	~~Flow~~
		~~04~~	~~Scenario~~
		~~05~~	~~Temporal~~
	03	Validating	
		~~01~~	~~Prescription~~
		~~02~~	~~Functionality~~
		~~03~~	~~Compliance~~
~~03~~ 04	**Communicating**		
	01	Visualizing	
	02	~~Modeling~~	
	03	Drawing	
	04	Documenting	
~~04~~ 05	**Executing**		
	01	Regulating	
	02	Assembling	
	03	Fabricating	
~~05~~ 01	**~~Managing~~ Gather**		
	01	~~Tracking~~ Qualify	
		~~01~~	~~Temporal~~
		~~02~~	~~Financial~~
		~~03~~	~~Element~~
	02	Monitoring	
	03	Capturing	
	04	Quantifying	
	05	~~Scheduling~~	

Final BIM Use Purpose		
01	**Gather**	
	01	Capture
	02	Quantify
	03	Monitor
	04	Qualify
02	**Generate**	
	01	Prescribe
	02	Arrange
	03	Size
03	**Analyze**	
	01	Coordinate
	02	Forecast
	03	Validate
04	**Communicate**	
	01	Visualize
	02	Transform
	03	Draw
	04	Document
05	**Realize**	
	01	Fabricate
	02	Assemble
	03	Control
	04	Regulate

BIM Use Purpose Added

BIM Use Purpose Removed

BIM Use Purpose Renamed

Table 3-19 explains the modifications to the BIM Use Purposes after external validation and the reason or justification for the modification.

Table 3-19: Modifications to BIM Use Purposes after External Validation

Modification	Reason
Removed the present participle (ing) from all of the BIM Use Purposes	To simplify language of Purposes and increase the ease in which the Purpose is applied
Removed the third level of BIM Use Purposes dues	The third level of BIM Use Purposes in the prior Purpose list were primarily performance characteristic the facility. Performance characteristics are not currently well defined in literature and are outside of the scope of this research because the performance characteristics apply to the entire facility
Revised **managing** to **gather**	Based on feedback from the focus group meeting, gather was deemed more appropriate for the subclass of BIM Uses within this BIM Use Purpose Class. Managing also had a bias toward the operations phase of the facility
Moved **gather** to the top of the list	Gather is typically an input to other BIM Use Purpose such as generate or analyze
Revised **authoring** to **generate**	Based on feedback from the focus group, the term authoring has bias toward design phase, whereas generate did not evoke any predisposition to any particular phase
Revised **executing** to **realize**	Based on feedback from the focus group, the term executing has bias toward construction phase, whereas realize did not evoke any predisposition to any particular phase
Revised **tracking** to **qualify**	Based on feedback from the focus group, it was determined that the term qualify better represents the objective of the BIM Use Purpose which is to characterize, or identify a facility element status
Removed **scheduling**	Scheduling was determined to be a performance characteristic of the facility and outside of the scope of this research
Revised **configuring** to **arrange**	Based on feedback from the focus group, it was determined that the term arrange better represents the objective of the BIM Use Purpose which is to determine location and placement of facility elements
Removed **modeling**	Based on feedback from both focus groups and industry interviews, it was determined that because of the fundamental definition of BIM all BIM Uses could be considered modeling and therefore if modeling were included it would create class cycling issue.
Added **Transform**	Based on feedback from both focus groups and industry interviews, it was determined that BIM is often implement for the necessity of translating information from one format to another to make it useful to the recipient.
Divided **regulating** into two classes of **control** and **regulate**	Based on feedback from the focus groups, it was determine that there was a fundamental difference in the objectives in which a piece of equipment working on the facility is controlled by BIM and when a piece of equipment that makes up part of the facility is regulated.

Additionally, some BIM Use Purpose objective definitions were updated, however the objective of each BIM Use Purpose that did not change the language was only refined to be more representative of the objective.

3.5.4.3 Revised Characteristics

During the final stage of refinement the core BIM Use Characteristics were refined. These characteristics, as shown in Table 3-20, include facility element, facility phase, discipline, and level of development.

Table 3-20: Finalized BIM Use Characteristics

Characteristics	Description
Facility Element	The system of the facility on which the BIM Use will be implemented
Facility Phase	The point in the facility's life-cycle at which the BIM Use will be implemented
Discipline	The party by whom the BIM Use will be implemented
Level of Development	The degree of reliability to which the BIM Use will be implemented

In addition to primary BIM Use Characteristics, the secondary BIM Use Characteristics were validated which included the process, information, infrastructure, maturity, impacts, and references. Details of each characteristic are included in later chapters of this dissertation.

3.5.5 Further / Future Validation

In addition to the internal and external validation that was conducted, two forms of validation are currently being implemented. These include implementing the BIM Use Ontology within organizations and on projects and having it adopted into the United States National BIM Standard.

3.5.5.1 Implementing with organizations and Projects

The BIM Use Ontology is currently being implemented with a construction management firm to refine how they perform Building Information Modeling. It is all being implemented on a renovation project for a large facility owner. Additionally other organizations are considering adopting the BIM Use Ontology into their standard practices. So far the limited implementations have been successful, however the facilities have not yet fully implemented the BIM Use Ontology. It will take some time for these organizations to transition their organizations and projects around viewing their implementation of BIM based on the BIM Use Ontology.

3.5.5.2 Adoption into a National BIM Standard

Currently, the BIM Use Ontology has been balloted for the United States National BIM Standard. Having the BIM Use Ontology balloted has a number of benefits including exposure to the wide audience using the *U.S. National BIM Standard*. A challenge of the balloting is the broad degree of consensus the ballot needs to go through prior acceptance. While this test will serve to ensure the validity of the BIM Use Ontology, it is also challenging to gain the consensus with those less familiar with the BIM Use Ontology.

To ballot the BIM Use Ontology for *the U.S. National BIM Standard*, the BIM Use Ontology was documented within a guide (Kreider and Messner 2013) that presents a method for implementation of the BIM Use Ontology. The documentation has currently been balloted to *U.S. National BIM Standard* which is project of the buildingSMART alliance. Upon receipt of the documentation, the BIM Use Ontology is in the process of being reviewed by the implementation subcommittee of the National BIM Standard Committee. During this time, each ballot author is given the opportunity to present their ballot to the committee, after which it is voted on for approval by the committee. If approved for inclusion into the standard by the implementation committee, it will then be opened for commenting by the entire membership of the buildingSMART alliance. After which, the membership of the buildingSMART alliance votes on the inclusion of the ballot into the document. If approved, the BIM Use Ontology will be part of the National BIM Standard. At this point, the ballot for the BIM Uses is being reviewed by implementation.

3.5.6 Summary of Evaluation and Validation

The evaluation and validation of the BIM Use Ontology was extensive. It included both internal and external validation. The steps included competency questions, mapping, comparison, expert interviews, and focus group meeting. These were grouped into two stages: first, self-evaluation (including competency questions, mapping, and comparison) and second, external evaluation (including expert interviews and focus group meetings). After the internal review, the BIM Use Ontology was refined prior to the external review. After the external evaluation, the BIM Use Ontology was updated yet again to reflect its current form. Additionally, at this time the BIM Use Ontology is being balloted for the National BIM Standards which includes a public commenting period to allow for further feedback, and it is being implemented on projects and within organizations.

The goal of the evaluation and validation was to ensure that the BIM Use Ontology is comprehensive, consistent, extensible, and easy to use. In the following table, Table 3-21, is a brief description of each goal:

Table 3-21: Goals of the Validation of the BIM Use Ontology

Goal	Description
Comprehensive	The BIM Use Ontology’s ability cover the main concepts within the domain
Consistent	The BIM Use Ontology’s ability to be free from variation in the style of the representation of objects within the BIM Use Ontology
Extensible	The BIM Use Ontology’s ability to be amended in a systematic many with relatively little effort required
Ease-of-Use	The BIM Use Ontology’s ability to be understood, navigated, and implemented

In all the tests for comprehensiveness of the BIM Use Ontology was considered to have included all the necessary components. During the refinement only one new concept (purpose) was added and a few divided and consolidated.

The BIM Use Ontology tested well for consistency. This has to do primarily with the detailed methodology applied to develop the BIM Use Ontology. The consistency was improved through modifying the language of the objectives. It was also improved with the reorganization of the BIM Use Ontology and the refinement of the terms.

The BIM Use Ontology tested well for extensibility. The ability to map current and new BIM Use terms to the BIM Use Ontology is a good method for testing the extensibility of the BIM Use Ontology. Another area that the BIM Use Ontology could be made more extensible is by better defining the performance characteristics of a facility.

The ease-of-use did not test as well as the other goals of the BIM Use Ontology. When originally introduced to industry, a large number of the participants could not grasp the alternative method of communicating the intent of implementing BIM. Hopefully, the simplified documentation that has been balloted for inclusion in the *U.S. National BIM Standard* will allow for more consistent application of the BIM Uses.

Overall, the validation and refinement of the BIM Use Ontology did show that the BIM Use Ontology can be applied to communicate the BIM Uses throughout the life-cycle of a facility.

3.6 DOCUMENTING

The documentation of the BIM Use Ontology that occurred throughout the research, included the domain, purpose, scope, uses, knowledge acquisition, domain terms, integration, and evaluation processes of the BIM Ontology. After these steps were completed, the BIM Use Ontology was documented so that it could be understood by those outside of the development of the BIM Use Ontology. This documentation includes two primary documents, first this dissertation and second an implementation document that has been balloted for *the U.S. National BIM Standard*.

3.6.1 DEVELOP PROCEDURE FOR IMPLEMENTING THE BIM USE ONTOLOGY

As part of the implementation document that balloted for *the U.S. National BIM Standard*, a procedure for implementing the BIM Use Ontology was developed and documented. This procedure includes determining the BIM Use Purpose followed by identifying all of the BIM Use Characteristics for the specific project or organization. The procedure was developed as an alternative to the second chapter of the Penn State *BIM Project Execution Planning Guide*. Therefore, it also included a general discussion on how to determine a BIM strategy. The details of this implementation procedure are included later in the dissertation.

3.6.2 Refine BIM Use Description

As part of developing the implementation document, a more detailed description of each BIM Use Purpose was documented beyond the objective and synonyms. The descriptions are designed to be an alternative to the BIM Use descriptions within the *BIM Project Execution Planning Guide*. Eventually, the BIM Uses within the *BIM Project Execution Planning Guide* should be replaced with these BIM Uses. This can be accomplished through a process of first reorganizing the BIM Uses within the *BIM Project Execution Planning Guide* based on the BIM Use Purposes (see mapping of Ontology to *BIM Project Execution Planning Guide* with Appendix C). After some time the BIM Use Characteristics can be added.

3.7 Summary

The methodology employed to develop the BIM Use Ontology was a combination of various ontology development methods documented in ontology creation literature. The steps that were employed to develop the BIM Use Ontology include:

1. Defining domain and scope of what is a BIM Use;
2. Acquiring knowledge through collection of BIM Uses;
3. Documenting domain terms by creating a list of BIM Uses and terms;
4. Integrating domain terms by creating the initial BIM Use Ontology;
5. Evaluating (refining and validating) the BIM Use Ontology; and
6. Documenting the BIM Use Ontology so that it is understandable.

In general, the research applied content analysis, focus group meetings, industry expert interviews, and surveys to accomplish the objectives of this research. Figure 3-8 displays an overview of the research steps.

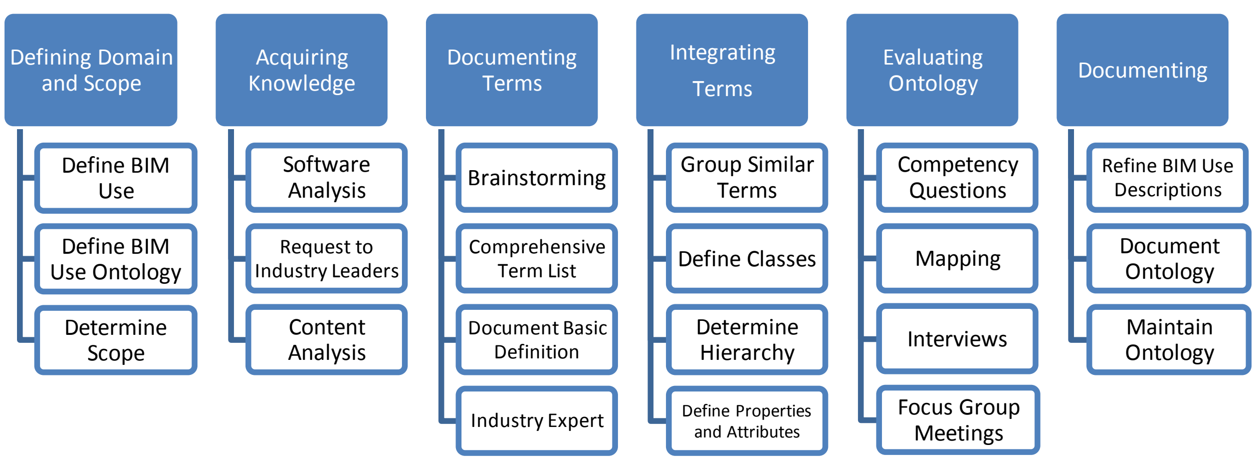


Figure 3-8: Methodology Employed Develop BIM Use Ontology

Overall, these steps lead to the development of a comprehensive BIM Use Ontology that can be applied to communicate the BIM Uses throughout the life a facility.

CHAPTER 4: BIM USE PURPOSES AND OBJECTIVES

The BIM Use Ontology categorizes the BIM Uses primarily by the purpose and objective of the BIM Use. A BIM Use Purpose is *the specific objective to be achieved when applying Building Information Modeling during a facility's life.* The purposes and objectives for implementing a BIM Use, as shown in Table 4-1, are divided into five major categories and 18 subcategories.

Table 4-1: BIM Uses Purposes and Objectives

BIM Use Purpose				BIM Use Objective	Synonyms
01	**Gather**			**to collect or organize facility information**	administer, collect, manage, acquire
	01	Capture		to represent or preserve the current status of the facility and facility elements	collect
	02	Quantify		to express or measure the amount of a facility element	quantity take-off
	03	Monitor		to collect information regarding the performance of facility elements and systems	observe, measure
	04	Qualify		to characterize or identify facility elements' status	follow, track, identify
02	**Generate**			**to create or author information about the facility**	create, author, model
	01	Prescribe		to determine the need for and select specific facility elements	program, specify
	02	Arrange		to determine location and placement of facility elements	configure, lay out, locate, place
	03	Size		to determine the magnitude and scale of facility elements	scale, engineer
03	**Analyze**			**to examine elements of the facility to gain a better understanding of the elements**	examine, evaluate
	01	Coordinate		to ensure the efficiency and harmony of the relationship of facility elements	detect, avoid
	02	Forecast		to predict the future performance of the facility and facility elements	simulate, predict
	03	Validate		to check or prove accuracy of facility information and that the information is logical and reasonable	check, confirm
04	**Communicate**			**to present information about a facility in a method in which it can be shared or exchanged**	exchange
	01	Visualize		to form a realistic representation of a facility or facility elements	review
	02	Transform		to modify and translate information to be received by another process	translate
	03	Draw		to fashion a symbolic representation of the facility and facility elements	draft, annotate, detail
	04	Document		to create a record of facility information including the information necessary to precisely specify facility elements	specify, submit, schedule, report
05	**Realize**			**to make or control a physical element using facility information**	implement, perform, execute
	01	Fabricate		to manufacture the elements of a facility using facility information	manufacture
	02	Assemble		to bring together the separate elements of a facility using facility information	prefabricate
	03	Control		to physically manipulate the operation of executing equipment using facility information	manipulate
	04	Regulate		to inform the operation of a facility element using facility information	direct

Each purpose is defined using the purpose term, an objective, synonyms, and a description (see Table 4-2).

Table 4-2: BIM Use Defining Attributes

Attribute	Description
Term	A word or phrase applied to describe a thing or to express a concept
Objective	The goal, aim or purpose for implementing a BIM Use
Description	An account of the BIM Use including all the relevant aspects, qualities, and properties
Synonyms	A word or phrase that means nearly the same as standardized BIM Use Term. It may have had the same meaning but has since been superseded

4.1 GATHER

Objective: to collect or cull facility information.

Synonyms: administer, collect, manage, and acquire.

Description: BIM is often applied to gather information about a facility at various phases during the life of a facility. Whether that is to count the specific number of an element or determine the current status of a facility element in order to properly manage that asset, the application of BIM can greatly assist in this effort. The sub-purposes of the BIM Use Purpose include: *Capture*, *Quantify*, *Qualify*, and *Monitor*. In this primary BIM Use Purpose, the implementor is collecting, gathering and organizing information about the facility. This BIM Use Purpose does not determine the meaning or make inferences about the meaning of the information gathered, rather it is solely focused on the collection and organization of the information. This is often the first step of a comprehensive series of BIM processes.

4.1.1 Capture

Objective: to represent, or preserve the current status of the facility and facility elements.

Synonyms: collect.

Description: BIM is often applied to capture geometric and attribute data about a facility. This can be done using a number of methods and at a number of points during the life of a facility; the elements of the site prior to the development of a new facility, or the conditions of an existing facility prior to renovation. Data may be captured using a laser scanner or recorded manually by inputting model and serial numbers into a spreadsheet. The common factor within this purposes of BIM Uses is that data is captured where no data existed prior. However, it is not newly generated information, rather creating a record of the facility elements that already exist.

4.1.2 Quantify

Objective: to express or measure the amount of a facility element.

Synonyms: take-off, count.

Description: In this BIM Use Purpose, BIM is applied for counting or collecting the number of specific facility elements. This BIM Use Purpose is often applied as part of the estimating and cost forecasting process. Within the BIM Use Purpose of *Quantify*, quantifiable information is extracted from a model. During the design phase of a facility, quantities maybe be defined broadly, represented by a range, and subject to change. In the construction phase, quantities become more certain and in the operations phase, quantities of elements can be readily calculated. For instance, the exact area and dimensions should be known for the area of a space in which the carpet is to be replaced or that of a vacant space which is available and rentable.

4.1.3 Monitor

Objective: to observe the performance of facility elements and systems.

Synonyms: observe, measure.

Description: BIM can be applied to monitor real-time performance data of facility elements and facility activities. This BIM Use Purpose includes the BIM Uses in which BIM is implemented to understand the performance of particular facility elements or processes. For example, during the operations phase of a facility, BIM can be applied to monitor the temperature of a space. The BIM Use Purpose of *Monitor* varies from the *Control* BIM Use Purpose in that *Monitor* only collects the information, whereas *Control* physically manipulates elements of the facility. It is in this BIM Use Purpose where Building Automation System sensor data is integrated with the BIM data. In construction, BIM could be applied to monitor the productivity of a construction process. It is in this BIM Use Purpose that dynamic real-time data is collected to support decision making.

4.1.4 QUALIFY

Objective: to characterize, or identify a facility element status.

Synonyms: follow, track, identify.

Description: For this BIM Use Purpose, the status of a facility element is tracked. Within the BIM Use Purpose of *Qualify*, qualifiable or subjective information is extracted from a model. This includes information such as: does this element exist within the facility and how is it working? This BIM Use Purpose tracks facility elements over time. For example, in design, what the element's level of development? In construction, has the element been fabricated? Is it installed? Is it damaged? During operations, this BIM Use Purpose can collect warranty information on the element and whether or not the element is reaching the end of its useful life.

4.2 GENERATE

Objective: to create or author information about the facility.

Synonyms: create, author, model.

Description: Within the life-cycle of a facility almost every discipline that interacts with the facility will generate information about the facility. This BIM Use Purpose includes those to which BIM is applied to create or author information about the facility. The BIM Use Purpose of *Generate* includes *Prescribing*, *Arranging*, and *Sizing* facility elements to various levels of development. Within the design phase, the design team will be the primary generators of information, while in the construction phase, the subcontractors will generate most of the information. Additionally, in the operations phase, that information could be generated by those maintaining the facility when they update or change that facility. Anytime new information is authored, modeled, or created, it is generated.

4.2.1 PRESCRIBE

Objective: to determine the need for and select specific facility elements.

Synonyms: program, specify, select.

Description: The BIM Use Purpose of *Prescribe* is applied when a generator determines a need for a specific facility element. The programmer or architect of the facility may prescribe the need for certain rooms or spaces in the facility. While the mechanical engineer may prescribe the need for a specific HVAC system. The contractor could determine the need for a temporary construction element such as a tower crane, and the operator of the facility may prescribe a specific replacement part for the facility. The element prescribed depends on a number of factors such as phase, discipline, and level of development.

4.2.2 ARRANGE

Objective: to determine location and placement of facility elements.

Synonyms: configure, lay out, locate, place.

Description: The BIM Use Purpose of *Arrange* includes those BIM Uses in which a location or configuration of a facility element is determined. During the planning phase of a facility's life, this could be the arrangement or adjacency of specific spaces within a proposed facility. During the design phase, the BIM Use Purpose of *Arrange* could be applied to identify the general location of fire protection piping. While in the construction phase, the Purpose could include the placement of the hangers that support piping. This could also be applied during the operations phase to determine the placement of furniture systems. In general terms, any time a geometric location of element is determine, it is being arranged.

4.2.3 SIZE

Objective: to determine the magnitude and scale of facility elements.

Synonyms: scale, engineer.

Description: The BIM Use Purpose of *Size* is employed to determine the magnitude of a facility element. Some of those elements during design could include the dimensions of spaces, the shape of a steel beam, or the size of ductwork. During construction, it could include the size of a crane or the thickness of duct insulation. Additionally, during operations, facility managers could record the size of replacement parts or modifications to the facility.

4.3 ANALYZE

Objective: to examine elements of the facility to gain a better understanding of the element.

Synonyms: examine, evaluate.

Description: Elements of the facility often require further analysis to determine their viability for the facility. The BIM Use Purpose of *Analyze* includes those BIM Uses in which a methodical examination of the facility elements is needed. This BIM Use Purpose includes *Coordinating*, *Forecasting*, and *Validating*. It is for this BIM Use Purpose that data is often pulled from what was gathered or generated and put into the format in which it can be applied for decision making.

4.3.1 COORDINATE

Objective: to ensure the efficiency and harmony of the relationship of facility elements

Synonyms: detect, avoid.

Description: The BIM Use Purpose of *Coordinate* includes those BIM Uses in which facility elements are analyzed to ensure their relationship to other elements is effective and in harmony. This BIM Use Purpose is often called clash detection, collision avoidance, design coordination, and interference management, among others. Ultimately, all of the facility elements should work in conjunction with one another. This can include coordinating design intent of various systems during design, coordinating fabrication and installation during construction or coordinating existing operations while renovations are underway. Overall this purpose of BIM Use is to ensure that the facility will fit together as it is planned and that all the various systems have been considered.

4.3.2 FORECAST

Objective: to predict the future performance of the facility and facility elements.

Synonyms: simulate, predict.

Description: This BIM Use Purpose is one of the largest and has the most variance in its application from element to element. Within this BIM Use Purpose, detailed analysis is conducted to predict future performance of the facility and facility elements. Some of the primary performance characteristics that should be considered include financial, energy, flow, scenario, and temporal. Financial forecasting includes cost estimation of first cost of construction as well as the life-cycle cost of a facility. Energy forecasting predicts how future energy consumption and flow forecasting predicts performance such as air flow or occupant/crowd circulation. Scenario forecasting predicts performance of the facility during emergencies, such as fire, flood, evacuation, and others. Temporal forecasting predicts the performance of the facility over time to include building degradation and the timing for element replacement. Together this BIM Use Purpose examines multiple facility variables and predicts facility performance.

4.3.3 Validate

Objective: to check or prove accuracy of facility information and that is logical and reasonable.

Synonyms: check, confirm.

Description: This BIM Use Purpose is implemented to validate facility information. This purpose includes checking facility information for accuracy to ensure that it is logical and reasonable. The BIM Use Purpose of *Validate* falls into three primary areas: prescription, functionality, and compliance validation. Prescription validation ensures the facility has the elements that were specified and programmed within the facility including facility spaces or rooms. Functionality validation is to ensure that the facility is constructible, maintainable, and usable. Will the facility perform the purpose for which it has been designed? Compliance validation confirms a facility's compliance with codes and standards to include building codes, ADA standards, sustainability standards and others. Anytime facility information that was developed in another process is checked for accuracy, it falls into the category of validating.

4.4 Communicate

Objective: to present information about a facility in a method in which it can be shared or exchanged.

Synonyms: exchange.

Description: One of the primary BIM Use Purposes is to communicate facility information. The BIM Use Purpose of *Communicate* is intended to present information about a facility in a method which can be shared or exchanged. This is often the last step of many other processes when a visualization, transformation, drawing, or document is developed to communicate information from that process to the next user of that information. This is one of the most valuable BIM Uses. It promotes and enhances communication and often reduces the time it takes to communicate. Additionally, communication of the data is often a by-product of the processes to accomplish other BIM Uses.

4.4.1 VISUALIZE

Objective: to form a realistic representation of a facility or facility elements

Synonyms: review.

Description: As part of the BIM Use Purpose of *Visualize* is to employ BIM to better visualize a facility is very powerful. This BIM Use Purpose is especially powerful for those who have not been trained within the design and construction industry but are critical stakeholders and decision makers. The BIM Use Purpose of *Visualize* includes those BIM Uses which are implemented to form a representation of the facility or facility elements. Often this visualization can be very realistic and detailed in nature. Visualization is often applied to support decision making about the facility's design or construction as well as support marketing efforts. This Purpose can include walkthroughs, renderings, and schedule visualizations. The fact that the visualization is a by-product of other BIM processes improves the ability of individuals to share facility information in a more effective manner with little additional effort.

4.4.2 TRANSFORM

Objective: to modify and translate information to be received by another process.

Synonyms: translate.

Description: Often within the BIM process, facility information needs to be taken from one form to another so that it can be received and applied by another process. This translation or transformation of data allows for interoperability between different systems. It also allows legacy data to be applied by current infrastructure. Some examples include developing spooling information, developing layout data, and developing industry standard formats. Often this translated data is in a manner in which it is not human-interoperable, but readable by machine.

4.4.3 DRAW

Objective: to fashion a symbolic representation of the facility and facility elements.

Synonyms: draft, annotate, detail.

Description: While it might be possible to one day rid the industry of drawings and paper, this is not the case today. With that said, BIM improves the ability to develop drawings including detailing and annotating them. These are developed in a parametric method rather than through static methods. For example, when the BIM model is updated, the corresponding drawings and sheets are also updated. Anytime a symbolic representation is developed from an intelligent model, it is considered a drawing. This includes isometric, one-line diagrams, figures and all other symbolic representations.

4.4.4 DOCUMENT

Objective: to create a record of facility information including the information necessary to precisely specify facility elements.

Synonyms: specify, submit, schedule, report.

Description: Often times it is necessary to record facility data in a written narrative or tabular format. The BIM Use Purpose of *Document* includes those BIM Uses in which a record of facility data is created. This includes those BIM Uses necessary to precisely specify facility elements. The output of this BIM Use Purpose often includes specifications, submittals, design schedules, and other reporting of facility data.

4.5 REALIZE

Objective: to make or control a physical element using facility information.

Synonyms: implement, perform, execute.

Description: BIM is beginning to allow the industry to remove the direct input of human interaction to develop specific elements of the facility. The BIM Use Purpose of *Realize* includes those BIM Uses in which facility data (BIM data) is applied to make or control a physical element of the facility. This BIM Use Purpose gives the industry the ability to *Fabricate*, *Assemble, Control*, and *Regulate* elements of the facility. It is this ability that could eventually lead to the improved productivity of both construction and operations of facilities.

4.5.1 FABRICATE

Objective: to use facility information to manufacture the elements of a facility.

Synonyms: manufacture.

Description: BIM is allowing the industry to develop facility elements that were not possible prior to detailed product modeling. The BIM Use Purpose of *Fabricate* includes those BIM Uses in which facility information is directly applied to manufacture elements of the facility. For example, facility information can be applied to directly fabricate structural steel shapes from a computer numerical control (CNC) machine or directly fabricate ductwork or cut piping. Within the design phase, BIM can be applied to quickly generate prototypes of future facility elements, while in operations it could be applied to quickly fabricate replacement parts.

4.5.2 Assemble

Objective: to bring together the separate elements of a facility using facility information.

Synonyms: prefabricate.

Description: The BIM Use Purpose of *Assemble* includes those BIM Uses through which facility information is applied to bring together the separate elements of a facility. While still somewhat of a manual process, the precision that BIM allows, ensures that different systems can be prefabricated. It even gives the ability to fit together systems that were traditionally very separate. Some common examples include curtain wall systems, energy/MEP cores, and restrooms.

4.5.3 Control

Objective: to physically manipulate the operation of executing equipment using facility information.

Synonyms: manipulate.

Description: BIM affords the ability to employ facility information to control equipment operations. The BIM Use Purpose of *Control* includes those BIM Uses in which facility information is applied to physically manipulate the operation of executing equipment. Some common examples include using facility information to lay-out future work within a facility such as the location of walls or the future placement of imbeds in composite decks. Another example is using facility information to control executing equipment: determining stakeout area using GPS systems which is tied to excavating equipment. The ability to control executing equipment could one day lead to the automated construction site.

4.5.4 Regulate

Objective: to inform the operation of a facility element using facility information.

Synonyms: direct.

Description: The application of BIM to regulate facility elements potentially allows facility operators to optimize their operations. The BIM Use Purpose of *Regulate* includes those BIM Uses in which facility information is applied to inform the operation of a facility element. A common example of this is when information gathered from a temperature monitor (or thermostat) is applied to alter the output of the HVAC system. A critical component of the process is that the data is tied to intelligent monitoring systems and the Building Information Model. This allows the systems to make informed decisions based on the entire system. This BIM Use Purpose could eventually lead to fully automated operations of a facility.

CHAPTER 5: BIM USE CHARACTERISTICS

BIM Use Characteristics are applied to more precisely define the BIM Use beyond the purpose and objective alone. The characteristics to be defined, as shown in Table 5-1, include the facility element(s), facility phase(s), discipline(s), and level of development.

Table 5-1: BIM Use Characteristics

Characteristics	Description
Facility Element	The system of the facility on which the BIM Use will be implemented
Facility Phase	The point in the facility's life-cycle at which the BIM Use will be implemented
Discipline	The party by whom the BIM Use will be implemented
Level of Development	The degree of reliability to which the BIM Use will be implemented

Adding these characteristics moves a BIM Use beyond answering "why?" to a more distinct description which could be applied in procurement efforts. Additionally, when BIM planning, a team can communicate to all the stakeholders exactly who, what, when, and to what degree the BIM Use will be implemented. Depending on the facility's BIM utilization, it is possible to have multiple disciplines implement multiple BIM Use Purposes during multiple phases on multiple facility elements to multiple levels of development. For example, *Coordination Analysis* can be implemented during design and construction by the designer and contractor to a level of development 300 and 400, thereby creating two separate instances of a BIM Use.

5.1 FACILITY ELEMENT

When implementing the BIM Use Ontology is necessary to determine on which facility elements the BIM Use(s) will be executed. OmniClass Table 21: Elements (OCCS Development Committee Secretariat 2012a) or other applicable structure can be employed to breakdown the elements of a facility which are part of the BIM Use. For example, a planning team may determine that it only necessary to develop a schedule visualization of the substructure and superstructure and not the systems of the facility. The top level of this table include: 01) Substructure, 02) Shell, 03) Interiors, 04) Services, 05) Equipment and Furnishings, 06) Special Construction and Demolition, and 07) Sitework. Some other element breakdowns include OmniClass Table 22 – Work Results, and OmniClass Table 23 – Products are viable options along with CSI UniFormat II (Charette and Marshall 1999) and MasterFormat (Construction Specifications Institute 2004).

5.2 FACILITY PHASE

The BIM Use Characteristics include the facility phase in which the BIM Uses is implemented. It is possible that a BIM Use Purpose can be implemented in multiple facility phases by different disciplines. For example, the design team may be responsible for coordination analysis during the design phase and the construction team may be responsible for the coordination analysis during the construction phase. OmniClass Table 31: Phases (OCCS Development Committee Secretariat 2012c) or other applied phase structure could be employed to designate phases: These current phases within this table include: 10) Inception Phase, 20) Conceptualization Phase, 30) Criteria Definition Phase, 40) Design Phase, 50) Coordination Phase, 60) Implementation Phase, 70) Handover Phase, 80) Operations Phase, 90) Closure Phase.

5.3 DISCIPLINE

The discipline is also synonymous with the responsible party for the BIM Use. OmniClass Table 33: Disciplines (OCCS Development Committee Secretariat 2012b) presents standard disciplines. These disciplines could also correspond with the various project roles. At a top level, the disciplines currently in this table include planning, design, investigation, project management, construction, facility use, and support. While the primary discipline may be identified, this does not preclude other disciplines from being responsible for part of the BIM Use. Additionally it is possible to have multiple disciplines responsible for the BIM Use. This would then make for separate BIM Uses.

5.4 LEVEL OF DEVELOPMENT

For each of the BIM Uses, the level of development (LOD) should be identified in order to maximize the benefit from the BIM Use. The level of development describes the degree of granularity to which a model element is developed. AIA / BIMForum has recently released a major revision to the level of development specification (BIMForum 2013). In LOD specification, LOD is defined as *the degree to which a model element's geometry and attached information has been thought through – the degree to which project team members may rely on the information when using the model.* In other words level of development is the degree of reliability on model elements. This revision further specifies level of development for specific elements of the facility. Table 5-2 shows a description of the Level of Development definitions.

Table 5-2: Level of Development (LOD) Definitions
(BIMForum 2013)

Level of Development	Description
LOD 100	The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.
LOD 200	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 300	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 350	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.
LOD 400	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.
LOD 500	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

In the future it may be possible to inherently understand the level of development based on other BIM Use Characteristics including elements, phases, and discipline. However this is not currently possible due to the maturity of BIM implementation within the Industry. Until the point where BIM implementation becomes more standardized, the level of development should be determine based on the Purpose for a specific element during a specific phase by a specific discipline.

5.5 ADDITIONAL BIM USE IMPLEMENTATION CHARACTERISTICS

Above the four primary BIM Use Characteristics, when implementing a BIM Use it may be necessary elaborate on additional BIM Use Characteristics based on the implementation of BIM. These items are often defined in the latter steps of the BIM Project Execution Planning Procedure. These items will vary depending on the specific implementation of the BIM Use. Each implementation of BIM Use will include, as illustrated in Table 5-3, the following items:

Table 5-3: BIM Use Implementation Characteristics

Item	Description
Process	The series of actions or steps take in order to achieve the objective of the BIM Use
Information	The data about the facility necessary in order to achieve the objective of the BIM Use
Infrastructure	the software, hardware and spaces necessary to implement a BIM Use
Maturity	the degree to which an organization excels performing a BIM Use
Impact	The advantage or disadvantage gained by implementing a BIM Use
References	a source for addition information concerning the implementation of a BIM Use

5.5.1 PROCESS

Mapping the process allows for the implementer to understand not only the overall flow of information through the facility, project, or organization, but also the details within each BIM Use.

5.5.1.1 METHODS OF DOCUMENTATION

There are several methods that can be applied to map processes. Some of the more commonly applied methods include integrated definition (IDEF) with IDEF0 Functional Modeling, Unified Modeling Language (UML), and Business Process Modeling Notation (BPMN). Each process modeling technique has its own benefits and purpose; and one is not necessarily better than another. Each organization should select a standard to offer consistency throughout the organization. Most organizations already have a standard in place and should continue with that standard. The *BIM Project Execution Planning Guide*'s maps are based on Business Process Modeling Notation. An explanation of symbols within that notation can be found in the *BIM Project Execution Planning Guide*. Additionally, example process maps for a select number of the BIM Uses can be found on the website (http://bim.psu.edu).

5.5.1.2 Facility – Project Processes

Within Facility / Project BIM Process there are two levels of process to consider including life-cycle and BIM Use specific. At the facility life-cycle level, planning teams consider the BIM Uses over the entire life of the facility. This includes how BIM will be applied during operations, construction, design, and planning. The next level is to map the detailed implementation through a specific BIM Use.

5.5.1.2.1 Level 1: Facility Life-Cycle Process Map

The Facility Life-cycle Process Map illustrates the relationship of the BIM Uses that will be employed through the life of the facility. This process map also contains the information exchanges that occur throughout the facility life-cycle.

5.5.1.2.2 Level 2: BIM Use Process Maps

BIM Use Process Maps are created for each identified BIM Use on the facility to specify define the sequence of various processes to be performed. These maps also identify the responsible parties for each process, reference information content, and the information exchanges which will be created and shared with other processes.

5.5.1.3 Organizational Processes

Unlike facility or project, which typically has a finite beginning and end, the organizational processes may consist of many repeatable processes. The organizations are continually operating. In most cases, the organizational implementation of BIM Uses will replace other tasks. To successfully design organizational processes, organizations must first document and understand their current processes, document BIM-enable processes, and then develop an advancement plan to move them from one process to the next. Sometimes within an organizations, the organization is structured around services. These services may or may not align with BIM Uses.

There are several methods to document the organizational structure. In some cases, organizations have their structure already documented. This documentation may or may not include tasks and responsibilities. If an organization already has its structure defined with the necessary elements of task and responsibilities, the structure is simply updated to ensure that it is current. Alternatively, planning groups can meet with the separate entities within an organization to identify roles and responsibilities. Based on the roles and responsibilities, planning teams can determine how to integrate the BIM Uses into the tasks and responsibilities.

5.5.1.4 Current Processes

In the specific application BIM Use Ontology for BIM Panning, planning teams should map current processes to provide a basic understanding of the current task and to help with developing a transition process. The processes are documented through meeting with the various entities within the organization with the implementers of the process. Another way to document the process is through observation of the tasks. This process documentation includes the information exchanges between various organizational entities.

5.5.1.5 Target Processes

In the specific application BIM Use Ontology for BIM Panning, planning teams develop revised BIM-Enabled process that implement the BIM Uses. To accomplish this, planning teams revise the current process maps to include the integration of BIM. This is done by replacing, adding, or editing processes within the map. The process map also includes any new or revised information exchanges.

5.5.1.6 BIM Use Transition Processes

To improve the transition between current processes, a detailed transition processes for each of the BIM Uses is identified. The transition processes identify the steps required to transition the process to a BIM-Enable process. The steps include measureable outcomes and milestones with a timeline for the competition of each transition. Some items considered include purchasing software, training, setting-up new systems, creating process guidelines, and progress checks. Tasks are determined based on the status of the organization and the specific task, which is being transitioned. There are several ways to display this transition process including, for example, a process mapping notation, or a critical path method (CPM) schedule.

5.5.1.7 Organizational Transition Processes

In the specific application BIM Use Ontology for BIM Panning, after the detailed transition plan for each BIM Use has been documented, an overall transition map for the organization is created. This process map includes the adoption of each BIM Use at every level of maturity, along with other critical milestones. The Organizational Transition process includes a timeline for completion of the milestones and can be displayed using several methods including process mapping notation or a CPM schedule. The timeline reflects the transitions in the process over the planning period.

5.5.2 Information

When implementing BIM Uses, the information contained within a specific BIM Use is a BIM Use Characteristic. When applying the BIM Use Ontology for planning the implementation of BIM, the geometric model and facility data requirements are defined and documented. The information requirements are summarized and complied into overall facility information requirements. The two primary items considered when determining information needs include the geometric model and facility data. The geometric model is an electronic, three-dimensional representation of facility elements with associated intelligent attribute data (facility data) (USACE/Industry BIM Advisory Committee 2011). Facility data is non-graphical information that can be stored for objects within the geometric model that defines various characteristics of the element. Facility data can include properties or attributes such as manufacturing data, materials, and project identification numbers. Considering both types of information is important to defining information needs and requirements.

5.5.2.1 Determining Facility Data Needs

The Level of Development does not specify the facility data needed about each facility element. The facility data, attributes, and properties, are specified about each element within a BIM Use. Often these facility data elements can be shared across multiple BIM Uses. OmniClass Table 49 – Properties is one source employed to specify facility data attributes. The Construction Operations Building Information Exchange (COBie) is a method for exchanging facility data through the various phases of the facility life. COBie is designed to enable information exchanges between data sources by providing a standard structure for facility data. It does not however specify what properties an organization needs to track and populate.

Figure 5-1 shows an example the properties in the component tabs of COBie 2.4.

Name	CreatedBy	CreatedOn	TypeName	Space	Description	ExtSystem	ExtObject	ExtIdentifier	SerialNumber	InstallationDate	WarrantyStartDate	TagNumber	BarCode	AssetIdentifier

Figure 5-1: Example of the Components Tab Properties in COBie 2.4

(East 2013)

5.5.3 Infrastructure

BIM Use Characteristic of infrastructure includes items such as hardware and software to support each BIM Use implement. In some cases, one piece of infrastructure will on only support one BIM Use or a part of a BIM Use process. In other cases the infrastructure can support multiple BIM Uses. The infrastructure supports the BIM Uses Purposes and Characteristics.

5.5.3.1 Software

Having proper software is a critical factors to successful BIM implementation. There are many factors considered when selecting software. Before purchasing software, it is necessary to ensure the software supports the BIM Use Purpose.

Chau (1995) has defined the following factors for consideration when selecting software:

Table 5-4: Factors to Consider when Selecting Software Systems
(Chau 1995)

Variable	Factor
Software (technical)	-Availability of an integrated hardware/ software package -Compatibility with existing hardware/software -Ease-of-use /user-friendliness -Availability of source code
Software (non-technical)	-Price (initial cost and maintenance/upgrades) -Popularity
Vendor (technical)	-Technical support -User training -Technical skills -Experience of using products developed by the same vendor
Vendor (non-technical)	-Reputation -Business skills -References -Past business experience with the vendor
Opinions (technical sources)	-Potential vendors/sales representatives -In-house "experts" -External consultants -Public Reviews
Opinions (non-technical sources)	-Subordinates -End-users -Outside personal acquaintances

5.5.4 HARDWARE

BIM Use Characteristic of infrastructure includes the hardware to support the BIM Uses. If the proper hardware is employed, it should go almost unnoticed. However if the proper hardware is not employed, that hardware can significantly impact the success of the implementation of BIM. Hardware should be selected based on how the users will interact with the data and the computing power or specifications. Some critical specifications consider include: RAM, Processing speed, graphics cards, and screen size/resolution. While it may be possible for a piece of hardware to support multiple BIM Uses, it may be necessary to have certain hardware specifically for one particular BIM Use. Hardware should be selected based on the BIM Uses and the selection of BIM Uses should not be based upon available hardware.

5.5.4.1 INTERACTING WITH FACILITY DATA

The planning teams consider how the end-users will interact with the data. This interaction includes both the device and physical space. The three workstations types considered include mobile, fixed, and collaborative. Each type has benefits and drawbacks.

5.5.4.1.1 Mobile Workstations

In some cases, it is possible to implement the BIM Use via a mobile device such as a smart phone or table. A number of software vendors supply mobile versions to access facility data from the cloud. These versions allow for ease of access of the facility data and the ability to update information in the location in which the task is being performed. Tablets and smart phones often have a smaller learning curve than a personal computer.

5.5.4.1.2 Fixed/Semi-Fixed Workstations

In some cases, laptop or desktop computer are the logical choice to implement a BIM Use. A personal computer usually affords the user more processing power and higher functionality of software. The processor speed, the amount of RAM, and the graphics card are considered the critical specifications. Large format display and/or multiple monitors allow for productivity improvements.

5.5.4.1.3 Collaborative Workstations

Infrastructure also includes how BIM implementers will interact with one another. It is valuable to develop collaborative spaces to allow for interacting with the data in larger groups.

5.5.4.2 MAINTAINING FACILITY DATA

A hardware backbone also supports the interaction with the facility data. Two critical pieces of the backbone include the network and servers.

5.5.5 Maturity

The BIM Use Maturity Levels are the degree to which an organization or project team excels performing a BIM Use. The BIM Use Maturity Levels, based on Capability Maturity Model Integration (CMMI) for Services (Forrester et al. 2011), include (0) Non-Existent (1) Initial, (2) Managed, (3) Defined, (4) Quantitatively Managed, (5) Optimizing. Table 5-5 shows an explanation of the BIM Use Maturity Levels.

Table 5-5: Explanation of the BIM Use Maturity Levels

Maturity Level	Description
(0) Non-Existent	At this maturity level, a process has not yet been incorporated into current business processes and does not yet have established goals and objectives.
(1) Initial	At this maturity level, a process produces results in which the specific goals are satisfied, however, they are usually ad hoc and chaotic. There is no stable environment to support processes with the inability to repeat such and possible abandonment in time of crisis.
(2) Managed	At this maturity level, a process is planned and executed in accordance with policy; employs skilled people having adequate resources to produce controlled outputs; involves relevant stakeholders; is monitored, controlled, and reviewed; and is evaluated for adherence to its process description.
(3) Defined	At this Maturity level, a process is tailored to the organization's standard processes according to the organization's guidelines; has a maintained process description; and contributes process related experiences to the organizational process assets.
(4) Quantitatively Managed	A this maturity level, a process is managed using statistical and other quantitative techniques to build an understanding of the performance or predicted performance of processes in comparison to the project's or work group's quality and process performance objectives, and identifying corrective action that may need to be taken.
(5) Optimizing	At this maturity level, a process is continually improved through incremental and innovative processes and technological improvements based on a quantitative understanding of its business objectives and performance needs and tied to the overall organizational performance.

Teams should achieve and sustain one maturity level before moving onto a more advanced level. It is not recommended that an organization try to obtain a high maturity level without first achieving the lower levels. Each advancement in maturity levels builds upon the foundation of the maturity level below it, which makes skipping levels challenging. It is possible to advance the BIM Use's maturity level several steps during the course of the BIM plan's timeframe. This is done by using each of the maturity levels as a milestone and by moving through the maturity levels to accomplish the desire maturity level rather than attempting to skip to the higher level.

5.5.6 IMPACTS

The impacts of BIM can vary from facility to facility and from organization to organization. Impacts are both benefits and drawbacks. While some impacts of particular BIM Uses are particular to a specific facility, other benefits are universal no matter when the BIM Use is implemented. It is important for each team to determine the impact of the BIM Uses to assess the importance of implementing it on the facility.

5.5.7 REFERENCES

References are sources of information that are applicable to a particular BIM Use. The maturity of the BIM Use within industry determine the number and quality of references available.

5.6 BIM CHARACTERISTICS SUMMARY

In Summary, BIM Use Characteristics are applied to more precisely define the BIM Use beyond the BIM Use Purpose and BIM Use Objective. The primary characteristics to be defined include the facility element(s), facility phase(s), discipline(s), and level(s) of development. Additional BIM Use characteristics include: process, information, infrastructure, maturity, impact, and references.

CHAPTER 6: AN APPLICATION OF THE BIM USE ONTOLOGY

This chapter provides a method for applying the BIM Use Ontology to select BIM Uses for a facility or an organization. This is only one of the many applications of the BIM Use Ontology. The primary application of the BIM Use Ontology is to provide the fundamental terminology and organizational structure for the BIM Uses. This terminology and structure is employed to provide the common language for the BIM Uses. In addition to selecting BIM Uses during BIM Planning, the BIM Use Ontology can be used to develop standards, develop common process frameworks, and describe software functionality.

As stated earlier, a common application of the BIM Use Ontology is to select BIM Uses. To assist in that selection, the following procedure was developed. When selecting BIM Uses a planning team identifies appropriate BIM Uses based on the overall BIM strategy including the mission, vision, goals, and objectives for a project or organization. One of the challenges and opportunities facing an early facility planning team is identifying appropriate Uses for BIM given the specific facility characteristics. Many different traditional tasks can beneficially be replaced by the implementation of BIM. The steps to determine BIM Uses, as shown in Figure 6-1, include defining the purpose and additional characteristics for each BIM Use.

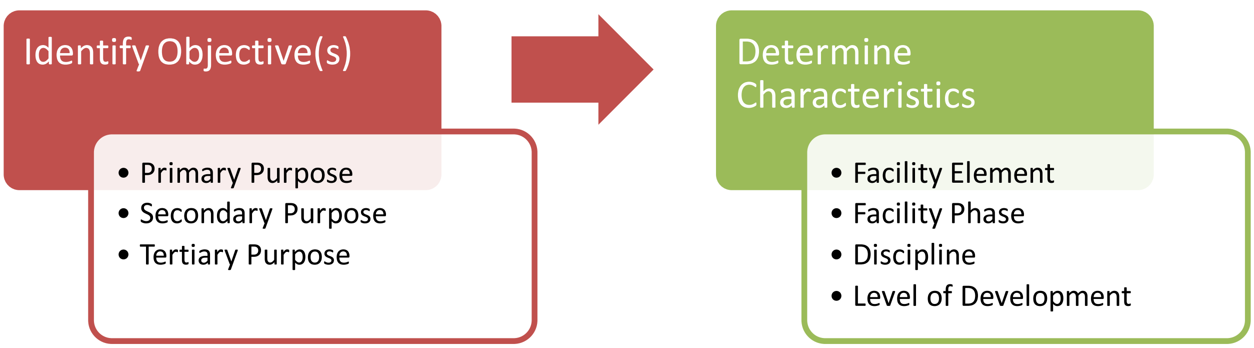


Figure 6-1: BIM Use Selection Procedure

> ***Note:*** Within this chapter is an example adapted from the development of a BIM Project Execution Plan for an office building. This example illustrates the application of the BIM Use Ontology during the planning of a facility and project.

6.1 DETERMINING BIM STRATEGY

Before determining how a facility will implement BIM it is important to understand and document the facility's BIM strategy. The strategy includes establishing a mission, a vision, goals and objectives. While BIM may enable a facility to accomplish its goals, BIM itself is not the goal. A brief description of each includes:

- Mission: Defines the purpose of the facility or organization.
- Vision: The picture of the facility or organization after it has integrated BIM.
- Goals: Specific aims which the project wishes to accomplish.
- Objectives: Specific BIM tasks or steps that when accomplished move toward goals.

6.1.1 EVALUATE THE FACILITY OR ORGANIZATIONAL MISSION

Prior to determining how the facility will implement BIM, a facility mission is established. A facility mission or mission statement defines the purpose for the existence of the facility. An organizational mission or mission statement defines the purpose for the existence of the organization. If the facility or organization does not have a mission statement, the planning team determines and documents a mission in one concise sentence or paragraph. A mission statement expresses an association's reason for being, conveys the facility's identity, and articulates purpose, focus, and direction.

Facility Mission

The purpose of the facility is to optimize the business practices of the organization by providing a high performance and flexible functioning facility.

6.1.2 ESTABLISH THE BIM VISION

Based on the mission of the facility, a BIM Vision is established for the duration of the facility. The vision statement differs from a mission statement, in that a vision statement is "a picture of what a facility or organization is striving to become". A vision statement pushes the facility or organization toward a future goal or objective, while a mission statement guides current decision-making. In this case, a BIM vision statement is the picture of the facility life-cycle process after integration of BIM, or how the facility envisions operating after integrating BIM. The advantage of establishing a vision statement is creating a sense of direction for the project / facility. A vision can enhance a wide range of performance measures, promote change, provide the basis for a plan, motivate individuals, and help keep decision making in context.

BIM Vision

Create an accurate, valuable, and reusable Building Information Model that assists with the design and construction process, as well as optimizes the operations of the facility.

6.1.3 Determine Facility Goals

After the mission and vision are established, the goals which will be accomplished during the course of the facility's life are generated and documented. Goals, like the mission, are at a project / facility level and are not necessarily specific to BIM; rather, Goals are specific aims, which a planning team wishes to accomplish. The goal is not to accomplish BIM implementation, but receiving the benefits that may come from implementing BIM. The project goals are 'S.M.A.R.T.', in that they are specific, measurable, attainable, realistic, and timely. Goals often provide a source of motivation and the reasons a planning team is integrating BIM.

Facility Goals

- Decrease the management cost of the facility over its life compared to typical office buildings
- Reduce the duration of the design and construction process compared to previous projects of this size
- Distinctly document the conditions of the facility over its life
- Optimize the facility stakeholders ability to review the facility prior to its construction
- Optimize the facility stakeholders ability to review and understand the construction process prior to commencement of construction
- Optimize Communication between facility stakeholders

6.1.4 Form Clear BIM Objectives

In many cases BIM provides an efficient and effective means to accomplish facility goals. Specific BIM objectives are defined leading to accomplishing the facility / organizational goals. Objectives are specific results that when accomplished move the facility team toward their goals. BIM objectives accomplish the goals through the multiple BIM Uses. Like goals, objectives should also be S.M.A.R.T. Objectives can tie directly to the integration of a BIM Use within a facility process.

BIM Objectives

- Implement BIM to reduce the overall life-cycle cost of facility management compared to the facility management costs of other facilities.
- Use BIM to explore methods to reduce the design and construction process compared to similar renovation
- Use BIM to develop a record of the facility conditions over the life of the facility.
- Use BIM to enable review of the facility prior to its renovation by the facility stakeholders.
- Use BIM to enable communication of the construction process to facility stakeholders
- Use BIM to communicate facility information between project stakeholders

6.2 DETERMINE THE PURPOSE FOR IMPLEMENTING

Based on the overall strategy, the planning team begins to determine how the facility team will implement BIM during the facility life-cycle. A planning team considers how the facility team will employ information during the life of the facility, including how the team will:

- Gather,
- Generate,
- Analyze,
- Communicate, and
- Realize.

Often these tasks or purposes are implemented using "traditional" processes. The facility team is to determine if the team will implement these tasks using BIM. It is important that a planning team consider each of potential BIM Use Purposes (as shown in Table 6-1) and consider the relationship with the facility goals.

BEGIN WITH THE END IN MIND

In his book, *Seven Habits of High Effective People*, Covey shares the philosophy of 'begin with the end in mind' (Covey 2004). This habit means to establish the clear vision for the end state, and then establish the steps to be taken to achieve that end state. This philosophy can be applied to BIM Planning.

When planning for the implementation of BIM it is critical to consider the entire life of the facility. The planning team should strive to understand how all facility stakeholders will be implementing BIM. The planning team should consider how the facility owners are going to be using BIM first and then work their way back through construction, through design and into planning.

Table 6-1: BIM Use Purposes and Objectives

BIM Use Purpose			BIM Use Objective	Synonyms
01	**Gather**		**to collect or organize facility information**	administer, collect, manage, acquire
	01	Capture	to represent or preserve the current status of the facility and facility elements	collect
	02	Quantify	to express or measure the amount of a facility element	quantity take-off
	03	Monitor	to collect information regarding the performance of facility elements and systems	observe, measure
	04	Qualify	to characterize or identify facility elements' status	follow, track, identify
02	**Generate**		**to create or author information about the facility**	create, author, model
	01	Prescribe	to determine the need for and select specific facility elements	program, specify
	02	Arrange	to determine location and placement of facility elements	configure, lay out, locate, place
	03	Size	to determine the magnitude and scale of facility elements	scale, engineer
03	**Analyze**		**to examine elements of the facility to gain a better understanding of the elements**	examine, evaluate
	01	Coordinate	to ensure the efficiency and harmony of the relationship of facility elements	detect, avoid
	02	Forecast	to predict the future performance of the facility and facility elements	simulate, predict
	03	Validate	to check or prove accuracy of facility information and that is logical and reasonable	check, confirm
04	**Communicate**		**to present information about a facility in a method in which it can be shared or exchanged**	exchange
	01	Visualize	to form a realistic representation of a facility or facility elements	review
	02	Transform	to modify and translate information to be received by another process	translate
	03	Draw	to fashion a symbolic representation of the facility and facility elements	draft, annotate, detail
	04	Document	to create a record of facility information including the information necessary to precisely specify facility elements	specify, submit, schedule, report.
05	**Realize**		**to make or control a physical element using facility information**	implement, perform, execute,
	01	Fabricate	to manufacture the elements of a facility using facility information	manufacture
	02	Assemble	to bring together the separate elements of a facility using facility information	prefabricate
	03	Control	to physically manipulate the operation of executing equipment using facility information	manipulate
	04	Regulate	to inform the operation of a facility element using facility information	direct

When determining whether a facility team will implement BIM for these BIM Use Purposes, a planning team considers the BIM resources, competency, and experience of the team. The resources include software, hardware, and IT support. When determining competency and experience, a planning team considers past performance and overall ability. If the facility team does not possess the necessary skills to successfully implement a particular BIM Use, pushing the implementation before the team is able could hinder the overall adoption of BIM and impact the facility as a whole. At the end of this effort, a planning team is able to make a "go / no go" decision on each of the BIM Use Purposes prior to elaborating on each BIM Use.

Based on the Goals of the facility, BIM Use Purposes were selected understanding the experience of many stakeholders is very limited including the owner of the facility.

Table 6-2: Example BIM Use Purpose Identification

BIM Use Purpose			BIM Use Objective	Notes	Yes / No / Maybe
01	**Gather**		**to collect or organize facility information**	See Sub-Purposes	
	01	Capture	to represent or preserve the current status of the facility and facility elements	Use laser scan to develop an existing conditions model	YES
	02	Quantify	to express or measure the amount of a facility element	Use quantifying to assist in identifying facility elements to assist with cost estimation	YES
	03	Monitor	to collect information regarding the performance of facility elements and systems	Use BIM to monitor the construction or operational process	NO
	04	Qualify	to characterize or identify facility elements' status	To use BIM to manage the assets of the facility	NO
02	**Generate**		**to create or author information about the facility**	Use BIM to generate all facility elements Yes	
	01	Prescribe	to determine the need for and select specific facility elements	Use BIM to select facility elements	Yes
	02	Arrange	to determine location and placement of facility elements	Use BIM to layout the various facility elements	Yes
	03	Size	to determine the magnitude and scale of facility elements	Use BIM to size facility elements (some Elements)	Maybe
03	**Analyze**		**to examine elements of the facility to gain a better understanding of the elements**	See Sub-Purposes	
	01	Coordinate	to ensure the efficiency and harmony of the relationship of facility elements	Use BIM to ensure the facility is coordinated	Yes
	02	Forecast	to predict the future performance of the facility and facility elements	Use BIM to forecast energy usage	No
	03	Validate	to check or prove accuracy of facility information and that is logical and reasonable	Use BIM to validate the space program	Yes
04	**Communicate**		**to present information about a facility in a method in which it can be shared or exchanged**	See Sub-Purposes	
	01	Visualize	to form a realistic representation of a facility or facility elements	Visualization to review design process	YES
	02	Transform	to modify and translate information to be received by another process	Translate information for one for to another (COBie)	YES
	03	Draw	to fashion a symbolic representation of the facility and facility elements	Develop a set of construction documents	YES
	04	Document	to create a record of facility information including the information necessary to precisely specify facility elements	Use BIM to develop the specifications	NO
05	**Realize**		**to make or control a physical element using facility information**	See Sub-Purposes	
	01	Fabricate	to manufacture the elements of a facility using facility information	Use BIM to fabricate facility elements (Systems)	YES
	02	Assemble	to bring together the separate elements of a facility using facility information	Use BIM to Assemble the various element of the facility	YES
	03	Control	to physically manipulate the operation of executing equipment using facility information	Use BIM to layout the facility	NO
	04	Regulate	to inform the operation of a facility element using facility information	Use BIM to regulate the use of the facility	NO

6.3 ELABORATE ON WHO, WHAT, WHEN, AND TO WHAT LEVEL

After a planning team determines the purposes for which facility will be implementing BIM, a planning team determines, as shown in Table 6-3, which discipline, phase, facility elements, and level of development the selected BIM Use Purposes will be implemented.

Table 6-3: BIM Use Characteristics

Characteristic	Description
Facility Element	The system of the facility on which the BIM Use will be implemented.
Facility Phase	The point in the facility's life at which the BIM Use will be implemented.
Discipline	The party by whom the BIM Use will be implemented.
Level of Development	The degree of reliability to which a model element is developed.

Adding this detail elaborates on the BIM Uses beyond the purpose. It is possible to have multiples of each characteristic for each BIM Use Purpose. For example, multiple disciplines can implement multiple BIM Use Purposes during multiple phases on multiple facility elements. Therefore at the conclusion of the effort, a facility team may have as few as five elaborated BIM Uses or as many as 50 or more elaborated BIM Uses depending on the level of implementation. At the conclusion of the effort, the planning team is able to describe all the Uses in terms of discipline, phase, elements, level of development, and purpose. Often after elaborating on the characteristics of the BIM Use, a planning team determines that they have more BIM Uses than initially considered.

Table 6-4 illustrates an example of how a planning team would select the characteristics of a BIM Use. For this example the standards applied to define the characteristics include OmniClass Table 21 for Elements, Basics facility phases of plan, design, construct, and operate; and OmniClass Table 33: for Elements. For this example only the top level of the standard was identified. When developing a detailed implementation, it may be necessary to implement lower levels of the standard. Figure 6-2 illustrates the example BIM Process within a BPMN process map.

Table 6-4: Example of BIM Use Characteristic Selection

BIM Use Purpose			Facility Element	Facility Phase	Facility Discipline	Final LoD	Description
01	**Gather**						See Sub-Purposes
	01	Capture	ALL	Plan	investigation	400	Develop an existing condition model using laser scanning
	02	Quantify	01) Substructure	Construct	Construction	200	Quantify Substructure to assist in estimating
			02) Shell	Construct	Construction	200	Quantify Shell to assist in estimating
			03) Interiors	Construct	Construction	200	Quantify Interior to assist in estimating
			04) Services	Construct	Construction	200	Quantify Services to assist in estimating during construction
			05) Equipment and Furnishings	Construct	Construction	200	Quantify E & F to assist in estimating during construction
02	**Generate**		SPACE	Plan		100	Generate a model of Spaces
			ALL	Design	Design	300	Generate a design intent model
			ALL	Construct	Construction	400	Generate a fabrication model
			ALL	Operate	Facility Use	500	Generate Model that is representative of existing
03	**Analyze**		--See Below				See Sub-Purposes
	01	Coordinate	01) Substructure	Design	Design	300	Coordinate the Substructure with other facility elements during design
				Construct	Construction	400	Coordinate the Substructure with other facility elements during Construction
			02) Shell	Design	Design	300	Coordinate the Shell with other facility elements during design
				Construct	Construction	400	Coordinate the Shell with other facility elements during Construction
			03) Interiors	Design	Design	300	Coordinate the Interiors with other facility elements during design
				Construct	Construction	400	Coordinate the Interiors with other facility elements during Construction
			04) Services	Design	Design	300	Coordinate the Services with other facility elements during design
				Construct	Construction	400	Coordinate the Services with other facility elements during Construction
	03	Validate	SPACES	Design	Design	300	Validate the Spaces within the facility align with the specified program
04	**Communicate**		--See Below				See Sub-Purposes
	01	Visualize	ALL	Design	Design	300	Visualize facility for design review by stakeholder
			ALL	Construct	Construction	100	Visualize schedule for milestones during construction
	02	Transform	04) Services	Operate	Facility Use	500	Transform facility data to Facility Use (Facility data transfer)
	03	Draw	ALL	Design	Design	300	Draw constructions drawing generate from the facility model
05	**Realize**		---See Below				See Sub-Purposes
	01	Fabricate	02) Shell,	Construct	Construction	400	Fabricate shell elements via machinery
			04) Services	Construct	Construction	400	Fabricate services elements via machinery
	02	Assemble	04) Services	Construct	Construction	400	Assemble services elements for prefabrication

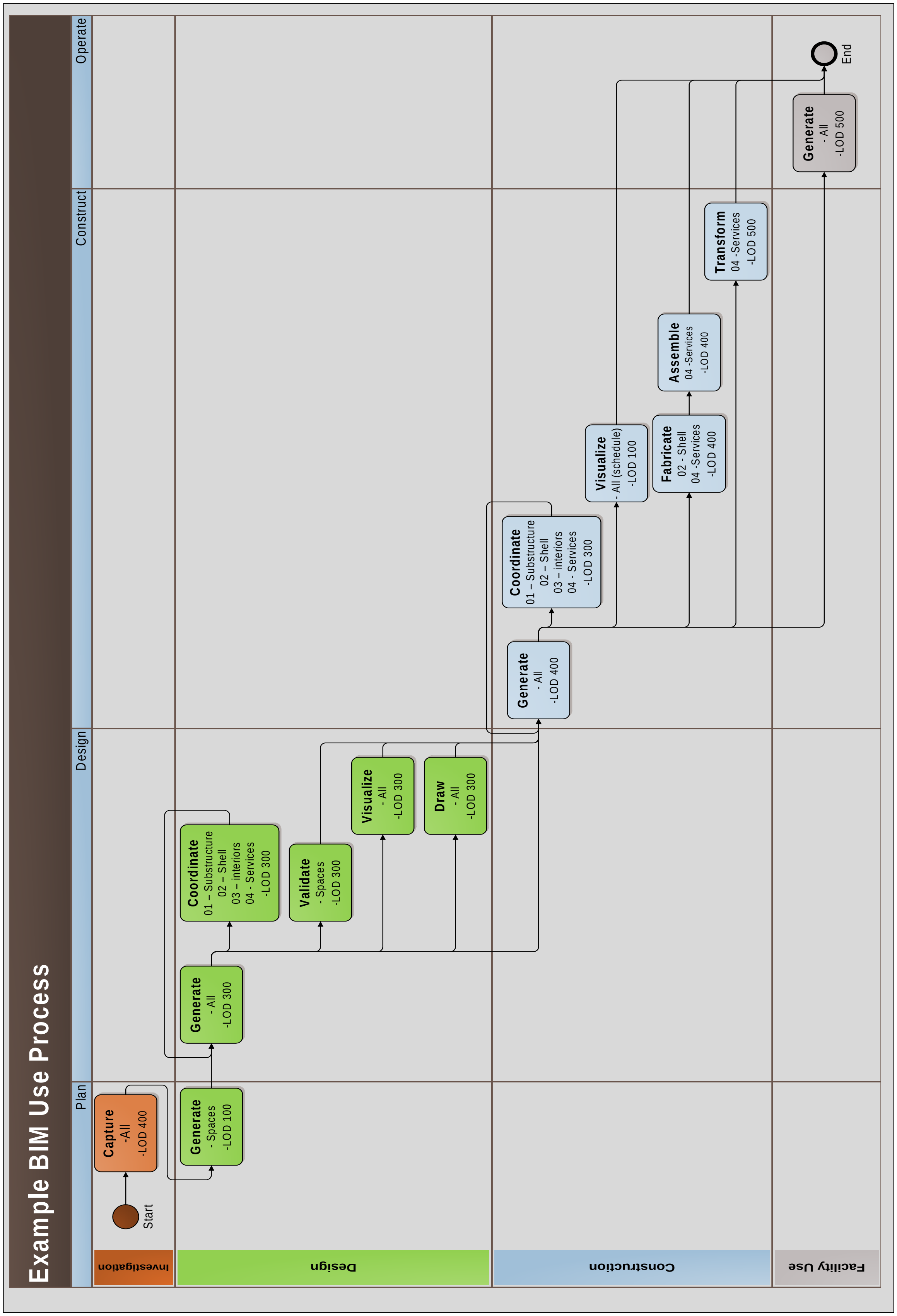


Figure 6-2: Example BIM Use Process

Table 6-5 compares the BIM Use selected in the example to the BIM Uses with the *BIM Project Execution Planning Guide* Version 2.0.

Table 6-5: Comparison of Ontology BIM Uses to BIM PxP BIM Uses Selection

BIM Use Purpose				Facility Element	Facility Phase	Facility Discipline	Final LoD	Description
01	**Gather**							---
	01	Capture		ALL	Plan	investigation	400	Existing Conditions
	02	Quantify		01) Substructure	Construct	Construction	200	Part of Cost Estimation
				02) Shell	Construct	Construction	200	Part of Cost Estimation
				03) Interiors	Construct	Construction	200	Part of Cost Estimation
				04) Services	Construct	Construction	200	Part of Cost Estimation
				05) Equipment and Furnishings	Construct	Construction	200	Part of Cost Estimation
02	**Generate**			SPACE	Plan		100	Programming
				ALL	Design	Design	300	Design Authoring
				ALL	Construct	Construction	400	Design Authoring
				ALL	Operate	Facility Use	500	Record Modeling
03	**Analyze**			---See Below	----	-----	---	-----
	01	Coordinate		01) Substructure	Design	Design	300	3D Coordination
					Construct	Construction	400	3D Coordination
				02) Shell	Design	Design	300	3D Coordination
					Construct	Construction	400	3D Coordination
				03) Interiors	Design	Design	300	3D Coordination
					Construct	Construction	400	3D Coordination
				04) Services	Design	Design	300	3D Coordination
					Construct	Construction	400	3D Coordination
	03	Validate		SPACES	Design	Design	300	Part of Programing
04	**Communicate**			--See Below	-----	------	---	------
	01	Visualize		ALL	Design	Design	300	Design Review
				ALL	Construct	Construction	100	Phase Planning (4D Modeling)
	02	Transform		04) Services	Operate	Facility Use	500	Did not exist in BIM PxP
	03	Draw		ALL	Design	Design	300	Did not exist in BIM PxP Guide
05	**Realize**			---See Below	-----	-----	---	------
	01	Fabricate		02) Shell,	Construct	Construction	400	Digital Fabrication
				04) Services	Construct	Construction	400	Digital Fabrication
	02	Assemble		04) Services	Construct	Construction	400	Did not exist in BIM PxP Guide

6.4 SUMMARY

While only one example of an application of the BIM Use Ontology, a planning team can employ the BIM Use Ontology to assist in the selection of BIM Use Purposes and Characteristics. The selection is based on the overall BIM strategy for the organization or facility. The BIM Uses should be appropriate for the organization or facility. The selection of the proper BIM Uses sets the stage for the success of BIM implementation on a facility. This chapter has defined an approach to leverage the BIM Use Ontology in this planning process.

CHAPTER 7: SUMMARY AND CONCLUSIONS

By providing a common language (the BIM Use Ontology) for understanding the purposes for the implementation of BIM, the AECO Industry can begin to normalize the terminology and definitions related to the application of BIM. This standardization leads to a common understanding of the methods in which BIM can be implemented throughout all aspects of a facility including disciplines, phases, and elements. Facility information is gathered, generated, analyzed, communicated, and realized. Any activity implemented during the life of a facility should be implemented for a purpose. It is that purpose which this research strived to understand and document. Hopefully, this research will foster better communication throughout the silos of this Industry. When the BIM Use Ontology is adopted throughout the industry, it will change how this Industry plans, designs, constructs, and operates facilities by providing a better understanding of the implementation of BIM.

7.1 SUMMARY

A **BIM Use** is defined as "*a method of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives.*" A goal of this research was to understand and document the specific purposes of BIM. The BIM Use Ontology developed the standard terms, standard definitions, standard attribute types, standard classes, and a standard class hierarchy for the BIM Uses. These are the essential parts of an Ontology. The BIM Use Ontology presents these parts in the form of BIM Use Purposes and BIM Use Characteristics. Therefore, the BIM Use Ontology provides *a shared vocabulary which is utilized to model (or express) the BIM Uses, including the type of objects (or terms), and concepts, properties, and relationships that exist of the methods of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives.*

More specifically, this Ontology was developed to answer the following questions:

1. What are the specific BIM Uses?
    - BIM Uses specifically are a combination of the BIM Use Purpose (outlined in Chapter 4) and BIM Use Characteristics (outlined in Chapter 5).
2. What are the definitions of the BIM Uses?
    - Each BIM Use Purpose has an objective, which is considered to be the specific definition of a BIM Use.
3. What are the important attributes of each BIM Use?
    - The attributes of a BIM Use include the purpose, facility phase, facility element, facility discipline, level of development, process, information, infrastructure, references, and impact. These attributes are referred to as BIM Use Characteristics.
4. What are the classes of BIM Uses?
    - The classes of BIM Use Purposes include 5 superclasses and 18 subclasses as well as the classes of BIM Use Characteristics. The BIM Use Purposes classes are documented in Chapter 4 and BIM Use Characteristics classes are documented in Chapter 5.
5. What is the class hierarchy of the BIM Uses?
    - A BIM Use includes BIM Use Purposes and BIM Use Characteristics. The BIM Use Purpose is divided into five superclasses, each of which has three or four subclasses. The class hierarchy is documented in Figure 3-2 in Chapter 3 and in Table 4-1 in Chapter 4.
6. What is the relationship(s) of one BIM Use to another BIM Use?
    - Ideally, information moves from one BIM Use Purpose to another BIM Use Purpose. The BIM Use Characteristics build upon each other and add clarity to the specific information and context of the BIM Use Purpose.

7.2 CONTRIBUTIONS

The BIM Use Ontology provides the fundamental terminology and structure for the BIM Uses throughout the life-cycle of a facility. The primary contribution of the BIM Use Ontology can be applied to plan for the implementation of BIM. The BIM Use Ontology provides standard terms, definitions, descriptions, attributes, relationships, classes, and class hierarchies of the BIM Uses. The methods employed to document the BIM Uses to the BIM Use Ontology allows for additional BIM Uses to be mapped. The BIM Use Ontology accomplishes its definition by providing *a shared vocabulary applied to model the BIM Uses, including the type of objects and concepts that exist, and their properties and relations, of the methods of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives.*

The first contribution, the BIM Use Ontology, allows the Industry to share a common structure for the various applications of BIM. This reduces the confusion when communicating the differences of one BIM Use from another. The BIM Use Ontology allows for future expansion for the BIM Uses that have not yet been documented. Being available on a public website (bim.psu.edu) and having a creative commons license allows for wider and earlier adoption of the concepts within the BIM Use Ontology.

Secondly, the mapping of industry standard BIM Uses establishes a standard name, definition, and description of each BIM Use – along with a place for each BIM Use within the BIM Use Ontology. This reduces the confusion of organizations when defining what is meant by a specific application of BIM.

Lastly, a method for categorizing and documenting the BIM Uses will allow for the future BIM Uses to be properly categorized and defined as they are developed. The refined BIM Uses also reduce the confusion about each BIM Use. By revising the categorization of some of the BIM Uses, gaps within the BIM Uses and areas to potentially expand BIM implementation in the future were identified. Several possible areas of potential expansion include forecasting, validating, and assembling.

The BIM Use Ontology allows for better education of BIM users by providing common terms and definitions. A goal is that the website becomes the primary resource on the standard definition of each BIM Use and the BIM Use Ontology. In fact, the current website at bim.psu.edu has already become a standard industry resource and is referenced by various notable sources. Because of this wide application, there is a need to keep the website up-to-date and valid. This research helped to further that goal.

7.3 APPLICATION

The BIM Use Ontology provides the fundamental terminology and organizational structure for the strategies of implementing BIM throughout the life-cycle of a facility. This Ontology can be applied for many applications with the AECO Industry. One example of how the structure of BIM Uses can be applied is employing the BIM Use Ontology to structure the terminology within Model View Definitions and Information Delivery Manuals. A Model View Definition (MVD) *defines a subset of the IFC schema, that is needed to satisfy one or many Exchange Requirements* (Liebich 2011). An Information Delivery Manual (IDM) is "*the exchange definition written in non-technical prose for use by end-users. [It] describes the business process, stakeholders, exchange points, information requirements and business rules.*" (buildingSMART alliance 2007). Therefore, it is possible that all BIM Uses should have a corresponding information delivery manual (or multiple IDMs depending upon the organization of the information model). More extensively the BIM Use Ontology could be expanded to better understand the business practices of the AECO Industry as a whole and be expanded to incorporate most of the business practices of planning, designing, constructing, operating, and managing a capital facility. Overall, the BIM Use Ontology will improve the communication of fundamental processes within the domain of the BIM Uses.

7.4 RESEARCH LIMITATIONS

There are limitations to the BIM Use Ontology. These limitations include:

1. Expansion of BIM Uses
   Over the duration of the research, the list of BIM Uses may have become outdated as the implementation of BIM continues to expand within the Industry. However, because the BIM Use Ontology was developed to accept new BIM Uses and is not based on the technology employed to implement BIM, the changes in the implementation of BIM over the course of the research can be addressed through future expansions of the Ontology if necessary.
2. Limited Industry Implementation
   One additional method for validation would be to fully implement the Ontology on a project or within an organization. The scope of this study did not allow for the Ontology to be fully implemented on a facility. As project teams and organizations adopt the Ontology, there may be additional items identified which will require extension or revision to the Ontology.
3. Potential Bias
   While research steps were performed to help minimize the bias toward previously developed Penn State resources, biases may still exist within the BIM Use Ontology.
4. Lack of Performance Characteristics
   An element missing from the BIM Use Ontology are performance characteristics. Performance characteristics are items that act as metrics for success of the facility. Examples of performance characteristics include cost, time, energy, and acoustical performance. these characteristics were identified to be beneficial to be added to the Ontology, but the rigorous definition of the characteristics was deemed outside of the scope of this work.

7.5 FUTURE WORK

There are areas related to the BIM Use Ontology on which other researchers may want to consider conducting further research. These research areas include developing IDM and MVDs for BIM Use Purposes, mapping all information exchanges between BIM Use Purposes, identifying and organizing performance characteristics, developing a detailed implementation tool, conducting large-scale implementation of the BIM Use Ontology, and developing an ontology extension procedure.

7.5.1 INFORMATION DELIVERY MANUALS AND MODEL VIEW DEFINITIONS

Information Delivery Manuals (IDMs) and Model View Definitions (MVDs), as described in Chapter 2, are designed to identify the process and information needs to accomplish a purpose.

Currently, few MVDs and IDMs have been rigorously developed, and there is limited structured relationships between the existing IDMs and MVDs which have been documented. The BIM Use Ontology provides a potential framework for identifying the necessary IDMs and MVDs to understand the information flow through the life of a facility. Therefore, a next step is to document IDMs and MVDs for each BIM Use Purpose, or to at least consider the use of consistent terminology within the development of future IDMs and MVDs.

7.5.2 Information Exchanges

Currently, a large number of Information Exchanges (IEs) are being balloted for the U.S. National BIM Standard. These ballots include the Construction Operation Building Information Exchange (COBie), the HVAC Information Exchange, the Electrical Information Exchange, the Plumbing Information Exchange, the Life-cycle Information Exchange for Product Data, and the Building Programming Information Exchange. However, like the MVDs and IDMs, the information exchanges lack a clear structure to relate them to one another. Some information exchanges pertain to a particular facility system, as is the case with HVAC, electrical, and plumbing. While other information exchanges, such as COBie and Building Programming, are about life-cycle phases or, in the case of LCie, the entire life-cycle. These information exchanges are arbitrarily established with limited documentation regarding the structure relating them to one another.

The BIM Use Purposes could provide this structure, and therefore a next step in this area of research is to define the information exchanges between the BIM Use Purposes. For example, the information is passed from gathering to generating, generating to analysis, analysis to communicating, generating to communicating, or gathering to realizing. In actuality, there are ten information exchanges that need to be defined at the top BIM Use Purpose level. There are 153 information exchanges possible at lower levels within the BIM Use Ontology's BIM Use Purposes. Even more information exchanges are possible when considering the various BIM Use Characteristics. While not within the scope of this dissertation, these exchanges can now be thoroughly defined and documented.

7.5.3 Performance Characteristics

Performance characteristics are a critical element that has yet to be defined within the BIM Use Ontology. Performance characteristics act as metrics by which a facility can be measured. Common performance characteristics currently measured within a facility include: time, cost, energy, sustainability, functionality, and quality. These characteristics have yet to be standardized within a facility; much less in BIM. A BIM Use is often implemented to gather information about a particular performance characteristic. A next step within this area of research is to thoroughly document the performance characteristics of a facility within an ontology, which can then be tied to the BIM Use Ontology as a characteristic.

7.5.4 Implementation Tool

Currently, no practical tool exists to implement the BIM Use Ontology. The *BIM Project Execution Planning Guide* included a simple list to assist in the planning effort. However, due to the increased complexity of the BIM Use Ontology versus the list of BIM Uses, a simple list cannot adequately support selecting BIM Uses. A tool could be developed to assist in this process. The tool could help guide users through the BIM Planning procedures and help users determine which BIM Uses are appropriate based on the facility or organizational objectives. The tool could be based upon open standards, such as HTML5, and could be developed as an open source initiative to enable community contributions. The tool will be built upon a database that can quickly populate a BIM Plan or contract language based on the selected BIM Uses. The tool could also allow users to track the implementation of BIM over the life-cycle of the facility or organization and provide clear project performance metrics. In addition to tracking the metrics on a specific project, the tools could be developed to track trends across projects and facilities. This more developed BIM planning tool could assist planning teams to select the BIM Uses during the BIM planning process.

7.5.5 Large-Scale Implementation

While limited small-scale implementation of the BIM Use Ontology was accomplished as a proof of concept, no large-scale implementation of the BIM Use Ontology was attempted. This large-scale implementation should include both organizations and facilities.

7.5.6 Update the BIM Planning Guide

The BIM Use Ontology could be used to update both the *BIM Project Execution Planning Guide* and the *BIM Planning Guide for Facility Owners*. These guides are built upon BIM planning elements of which one is the BIM Uses. To align the BIM planning guides, the BIM Uses section could be replaced with the BIM Use Ontology. Another goal of this process could be to align all the guides into a singular resource which can form the structure for BIM Planning.

7.5.7 Ontology Extension Procedure

BIM and technology are always advancing. Due to this ongoing advancement, it is inevitable that the BIM Use Ontology will have to grow and expand. This expansion should happen within the parameters established within this research. However, prior to expanding the BIM Use Ontology, a criteria and procedure should be developed for how to add to the BIM Use Ontology. An extension procedure needs to be developed to determine location of new purposes and characteristics if they are developed. The administration of the BIM Use Ontology should be administered by a group. At the current time, this group is the Computer Integrated Construction Research Program, but it could potentially be transferred to NIBS or another entity. Within that group, a subcommittee should be developed for managing the BIM Use Ontology along with other BIM Planning resources. In addition to the subcommittee internal to the CIC Research Program, an advisory board of industry and academic members providing oversight of the group should be developed. Together, these groups could be responsible for ensuring that the BIM Use Ontology maintains its applicability to the industry and is still implementable.

The BIM Use Ontology maintenance group can ensure that consensus procedure is followed when extending the BIM Use Ontology to include additional BIM Use Purposes or BIM Use Characteristics. This procedure should include the following steps:

1. Identify new BIM term (BIM Use Purpose or BIM Use Characteristic) that needs to be added to the BIM Use Ontology
    - Could be balloted by an outside industry member or identified based on a periodic review of the BIM Use Ontology
2. Determine the attributes of the term including the term itself, definition, description, and synonyms
3. Map the term to the BIM Use Ontology based on its purpose or characteristic
4. Validate the term to ensure the term is not biased, does not overlap with other classes, is not a part of multiple classes, and aligns with the other classes
    - If the term passes the validation, determine if the overall BIM Use Ontology needs to be refined or if the new term is able to fit within the current structure.
5. After validation, a consensus within the BIM Use Ontology maintenance group needs to be reached to add the new term
6. After consensus is reached within the maintenance group, the new term and updated ontology should be released to the BIM Use Ontology advisory board. After a commenting period, a 2/3 approval of the advisory board will be used to adopted an updated BIM Use Ontology which includes new terms
7. Update ontology documentation to include new term and provide update into all the resources that employ the BIM Use Ontology

This extension procedure will ensure new terms are put through the same amount of rigor as those in the current BIM Use Ontology.

7.6 CONCLUDING THOUGHTS

From the onset of this research, I was hopeful that this research would make an impact on the AECO Industry. After concluding this research and developing the BIM Use Ontology, when the BIM Use Ontology is implemented within organizations and facilities, it should provide a structure to enable the industry to better understand how they utilize information through the life of the facility. While it will take time for the BIM Use Ontology to be widely adopted, the BIM Use Ontology will allow all members of the Industry to begin to communicate using a common language. Hopefully, this effort will foster communication between the many silos of the Industry. A common theme throughout the BIM Use Ontology is that BIM does not change the purpose, but only the means by which that purpose is achieved. The BIM Use Ontology is designed to allow everyone to be more precise in the communication of these purposes.

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APPENDICES

Appendix A. BIM USES (PURPOSES AND CHARACTERISTICS)

BIM Use Purpose			BIM Use Objective	Synonyms
01	**Gather**		**to collect or organize facility information**	administer, collect, manage, acquire
	01	Capture	to represent or preserve the current status of the facility and facility elements	collect
	02	Quantify	to express or measure the amount of a facility element	quantity take-off
	03	Monitor	to collect information regarding the performance of facility elements and systems	observe, measure
	04	Qualify	to characterize or identify facility elements' status	follow, track, identify
02	**Generate**		**to create or author information about the facility**	create, author, model
	01	Prescribe	to determine the need for and select specific facility elements	program, specify
	02	Arrange	to determine location and placement of facility elements	configure, lay out, locate, place
	03	Size	to determine the magnitude and scale of facility elements	scale, engineer
03	**Analyze**		**to examine elements of the facility to gain a better understanding of the elements**	examine, evaluate
	01	Coordinate	to ensure the efficiency and harmony of the relationship of facility elements	detect, avoid
	02	Forecast	to predict the future performance of the facility and facility elements	simulate, predict
	03	Validate	to check or prove accuracy of facility information and that is logical and reasonable	check, confirm
04	**Communicate**		**to present information about a facility in a method in which it can be shared or exchanged**	exchange
	01	Visualize	to form a realistic representation of a facility or facility elements	review
	02	Transform	to modify and translate information to be received by another process	translate
	03	Draw	to fashion a symbolic representation of the facility and facility elements	draft, annotate, detail
	04	Document	to create a record of facility information including the information necessary to precisely specify facility elements	specify, submit, schedule, report.
05	**Realize**		**to make or control a physical element using facility information**	implement, perform, execute,
	01	Fabricate	to manufacture the elements of a facility using facility information	manufacture
	02	Assemble	to bring together the separate elements of a facility using facility information	prefabricate
	03	Control	to physically manipulate the operation of executing equipment using facility information	manipulate
	04	Regulate	to inform the operation of a facility element using facility information	direct

Characteristic	Description
Facility Element	The system of the facility on which the BIM Use will be implemented.
Facility Phase	The point in the facility's life at which the BIM Use will be implemented.
Discipline	The party by whom the BIM Use will be implemented.
Level of Development	The degree of reliability to which a model element is developed.

Appendix B. BIM USE TERMS

The following is the list of BIM Use Terms that was analyzed to develop the initial BIM Use Ontology

3D trade coordination and digital fabrication	Digital fabrication	Plumbing pipe sizing
3D coordination	Digital project viewer	PM maintenance scheduling
“In the event” what happens	Digital technology integration	Point clouds
2D and 3D production management	Disaster planning	Populate a facility management database
2D conversions	Disaster recovery	Post occupancy management
2D detailing and annotation	Discipline analysis	Prefabrication
2D drafting and detailing	Dispatching of work order	Preliminary circulation and security assessment:
3D – virtual functionality viewing and testing of the design	Does what was built equal what was model?	Preliminary cost estimate
3D architectural modeling	Drainage analysis	Preliminary energy analysis:
3D architectural rendering	Drawing and document production	Present architectural Design
3D architectural visualization	Drawing generation	Present scheduling as 4D animation
3D clash detection and interference management	Drawing markup	Pro forma analysis
3D control and planning	Drawing production	Problem identification
3D coordination	Drive shop fabrication process	Product and technical information for manufacturers and distributors
3D coordination modeling	Duct and pipe sizing/pressure calculations	Program compliance
3D designs	Ductwork layout and sizing	Program validation
3D geometry building	Dynamic thermal simulation	programmatic requirements
3D laser scanning	Early design	Programming
3D model clash detection	Early energy analysis	Project communication and model review tools
3D model for wood structure	Early MEP design	Project controls
3D modeling	Economic analysis	Project management
3D parametric modeling	Egress from facilities	Property management
3D sketching	Electrical circuit manager	Public safety - evacuation routing
3D wire frame modeling	Electrical layout	Public safety - fire protection
4D clash detection and interference management	Elevator simulation	Public safety - hazardous materials storage

4D financial model	Elevators / escalators layout	Public safety - security
4D model	EMCS integration	Purchasing and materials tracking
4D modeling	Emergency alarm/control systems	QTO
4D phasing	Emergency evacuation or response simulations	Quality control (how do you check models that you receive, ensure data integrity)
4D scheduling	Emergency evacuation scenarios	Quantity take-offs
4D scheduling and sequencing	Emergency information	Quantity take off (for field production planning using Location Based Scheduling)
4D sequencing	Emergency management / security	Quantity take-off and cost estimating
4D simulation	Employee flow	Radiator sizing and number
4D snapshot	Energy	Rapid spatial analysis
5D – material take-offs & cost estimating	Energy (environmental) analysis	Real estate acquisition and/or disposal
5D estimation	Energy analysis	Real time operations overlay on the model
5D model	Energy analysis or management	Real-time configuration,
Accessibility assessment	Energy and environmental:	Real-time visualization or rendering tools
Acoustic analysis	Energy conservation and air quality	Record modeling
Acoustics	Energy consumption simulation and life-cycle cost analysis	Reduced entry time for data
Activity status	Energy demand control and energy management	Rendered walkthrough
After action review	Energy management - environmental contaminant analysis	Rendering
Air flow simulations	Energy management - real-time sensor display	Repair needs
Air quality	Energy modeling with BIM	Repeatable modular construction components to speed construction erection time
Airspace encroachments	Energy performance and operations	Report indifferences in 3D project models and tract project status
all "Information" rolling into FM (CMMS and CAFM)	Energy simulation	Reverberation time acoustic analysis

Analysis	Energy Simulation/Analysis	reviewing
Analysis of conformance to building code requirements and regulations	Engage neighbors or users in understanding construction process	Safety
Analysis of primary functions	Engineering analysis	Safety analysis of management
Appraisal	Enhance shop fabrication process	Scenario Exploration
Architectural and engineering planning and design	Enhance submittal / shop drawing review	Scenario planning (failure, disaster) and sequence of operations
Architectural model - spatial and material design models	Ensure model integrity	Schedule
Architecture – spatial and material design models	Economic/traffic planning	Schedule growth
Architecture design	Equipment requirement	Schedule management
As–built	Equipment simulation	Schedule progress tracking using the model
As-built conditions	Electability checks	Schedule simulation/4D
As-built documents	Erosion control analysis	Scheduling (model-based CPM and LBS
As-Built model creation	Estimates lifetime operating costs	Scheduling and quantity take-offs
As-built schedule and cost information	Estimating tools	Scheduling with BIM
As-builts	Evacuation routing	Scope
Asset management	Evaluating physical security & survivability	Scope clarification
Augmented/Immersive Reality	Exchange data with energy analysis	Security
Automate design	Existing As-built architectural/structural models	Security planning
Automated circuiting and labeling	Existing as-built MEP/data networks	Security sensors (sensors placed in real time, generate reporting of facility security breaches.)
Automated code checking	Existing conditions modeling	Sensor and control monitoring.
Automated design	Experimental design using a design ‘workbench’	Sensor data
Automated fabrication.	External building cleaning and maintenance	Sensor planning
Automated fixture arrangement	External lighting and signage	Sensor tracking and monitoring

Automated reinforcing layout and connections	Extract logic diagrams	Shadow analysis (solar potential)
Automated systems and controls	Fabrication/shop drawings	Shop drawing
Automatic connection design	Fabrication-level building systems	Sightline studies
Automatic duct sizing based on space demands	Facilities deliverables	Simulate facility operations
Backgrounds / equipment data for BMS	Facilities management	Simulate operations
BIM facility management	Facilities management work orders	Simulates natural ventilation and mixed-mode systems
BIM management	Facility and asset management tools	Simulating organizational performance within facilities
BIM model creation tools	Facility financial forecasting	simulating people flows
BIM virtual modeling/ mock up	Facility geo-location	Site analysis
BIM-based divestiture	Facility information model	Site circulation / parking / vehicle routing
Building commissioning	Facility management	Site conditions - existing conditions and new construction
Building evacuation	Facility management handover	Site logistics
Building functional analysis	Feed forward program	Site logistics model
Building maintenance scheduling	Feeder and branch circuiting	Site planning layout
Building management	FFE	Site planning, including parking, drainage, roadways
Building model generation	Field documentation	Site planning.
Building object models	Field verification	Site selection/ location planning
Building performance	Field verified as-builting	Site suitability/ alternatives analysis
Building product information	Financial and cash flow analyses	Site utilization planning
Building system analysis	Financial Asset Management	Smart (intelligent) tagging FF&E
Building system layouts	Forensic analysis	Soil Conditions
Building system models – structural, MEPF, and interiors	Full detail editing	Solar radiation analysis
Business support	Functional and economic viability	Source locations of building products (LEED analysis)
Call handling	Generative components	Space and asset management
Call systems	Generative design	Space layout

Capital cost estimates	GIS data integration	Space management / tracking
Capital improvement scheduling	GIS-based facilities management (maintain 3-D architectural/structural models)	Space management and validation
Capturing lessons learned	Grey water reuse	Space names for assessment
Change management	Have a dashboard to monitor buildings performance	Space object support
Check against program	Heat loss and gain	Space planning
Circulation and security validation	Heating and cooling loads	Space planning and program compliance
Clash and error detection	Height analysis	Space program validation:
Clash detection	Historical preservation	Space utilization
Clash detection and issues tracking for design coordination;	Hospital procedure simulation	Spaces and functions
Clash detection/coordination	HVAC and electrical system design	Spatial analysis.
CNC fabrication	HVAC plant simulation	Spatial area
COBie / commissioning	Identify communicate and manage changes	Specification writing
Code analysis	Import/ export "as maintained" data and model (ability to do as you want/need)	Specifications
Code compliance	Increase occupancy efficiency	Steel connection detailing
Code reviews	Integrating information, e.g., electronic specifications that are tied to the BIM	Steel detailing
Code validation	Interactive visualization	Steel fabrication detailing
Code/ scope checking	Interfaces for fabrication	Steel structural detailing
Collision detection / avoidance	Interfaces to multiple structural analysis tools	Structural
Combine designs into one model	Interference checking	Structural 3D model steel detailing
Combining and reviewing 3D modeling	Interior computational fluid dynamics application	Structural 3D modeling
Commissioning	Interior space analyses - areas (organizational, operations, leasing, etc.)	Structural analysis
Commissioning and asset management	Interior space analyses - elevation	Structural design and analysis
Commissioning docs	Interior space analyses - volumes	Structural design and analysis of reinforced concrete
Commissioning sign-offs.	Issue tracking	Structural drafting

Communication	Jobsite layout,	Structural engineering.
Communication of construction scheduling and sequencing – 4D	Landscaping tool	Structural layout
Compare as design to as operated energy analysis	Landscaping, fountains, and planting	Sub-trade coordination
Complex curved surface modeling:	Laser scanning	Sun shading
Conceptual Design	Laser scanning in-process	Supports automated fabrication
Conceptual design from a cost of construction	Lean construction	Supports automated fabrication
Conceptual design,	LEED documentation	Survey equipment
Conduit and cable tray modeling	LEED evaluation	Surveying
Configuration	Lighting	Sustainability
Configuration (retrofit)	Lighting analysis	Sustainability evaluation
Conflict, interference and collision detection	Lighting planning and automation	Sustainable design
Connection detailing	Lighting simulation	Sustainable documentation
Constructability modeling	Lighting simulator	Sustainability analysis
Constructability analysis	Lighting	Sustainability certification
Construction analysis and cost estimating	Logistics	Sustainment, restoration, and modernization modeling
Construction phase	Long-range and annual facility planning	Synchronized schedules
Construction scheduling	Maintaining as-built models	System models - structural and MEPF design
Construction sequencing	Manage project schedule	System routing
Construction sequencing planning/ phasing plans/	Management information	Systems analysis
Construction system design	Manufactured product information	Systems distribution routing and sizing
Construction systems layout	Manufacturer information	Systems layout
Construction timeline	Manufacturing components	Systems layout include temporary facilities
Content development	Marketing presentations	Take-off
Coordination	Marketing purposes	Target costing
Coordination clash detection	Master plan space scheduling and sequencing – 4D	Task and equipment scheduling for construction.
Coordination is above clash detection	Materials recycling	Telecommunications integration, security and general administrative services

Corrective action	Maximize the efficiency of the space	Temporal analysis existing
Cost	Mechanical & HVAC layout	Temporal analysis future
Cost and schedule control	Mechanical analysis	Temporal analysis historical
Cost engineer with BIM	Mechanical and air handling systems	Temporal and weather based event planning / maintenance
Cost estimating	Mechanical equipment simulation	Temporal events
Cost estimation or management	Mechanical inference modeling	Threat response planning (scenario planning)
Cost Growth	MEP analysis	Toilet fixture counts
Cost models	MEP/data network routing/ analysis	Tool requirements
Cost reliability and management	Model archiving	Total cost of ownership /Life-cycle Analysis
Costs	Model authoring	Training requirements
Creating an interactive virtual workspace for the design team to achieve integrated design goals	Model based layout	Trending your data into useable information
Creating and reviewing 3D models	Model based maintenance and repair	Trimble control and layout (OSHPD project actually building and validating install to the model, paper follows the model - is formality for OSHPD's sake)
Creation of 3D model to 2D	Model driven RFI and/or change order	Trip analyses
Crowd behavior	Model generation	Understanding equipment accessibility
Current working estimate divided by the programmed amount	Model validation, program, and code compliance	Value engineering
Curtain wall systems	Model viewing and review	Value engineering
Data exchange	Modular construction & off-site fabrication	Value engineering analysis
Decommissioning of facilities	Move management	Verification, guidance, and tracking of construction activities
Demographics	New construction and/or renovation	Version comparison
Design - construction integration	NexGen IT data handoff and data migration	Vertical and horizontal circulation
Design analyzing with BIM	O&M as-maintained modeling	View shed analysis

Design and analysis of all building systems	O&M data embedded within the model.	Virtual building
Design assessment	Occupancy analysis	Virtual mock-ups
Design authoring	Occupancy ergonomics and sensing	Virtual modeling
Design communication/ review	Offsite fabrication	Virtual testing and balancing
Design configuration/ scenario planning	Online design checks for circuit load, length, and number of devices	Virtual tours
Design coordination	Operating cost basis	Visual simulation
Design coordination (clash detection)	Operation simulation	Visualization
Design for fabrication.”	Operational training	Visualization - building skins
Design review	Options analysis	Visualization - textures
Design review and Visualization	Partial Trade Coordination	Walk-throughs and fly-through
Design validation	Performance for the user, understanding the space	Water planning
Design visualization	Performance reviews	Way finding
Design visualization for communication, functional analysis, & constructability	Permitting/zoning review	Way-finding - ADA compliant routes
Detailed framing	Personnel allocation	Way-finding - proximity/routing
Detailed framing and derivation of a cut lumber schedule,	Phase planning	Work packet coordination
Detailed modeling	Photographic 3D as-built in-process	Work specifications, installation and space management
Development of the building program	Pipework systems	Workflow scheduling
Diagnosis	Piping layout	

Appendix C. DESCRIBED BIM USE TERMS

Term	Description
Operational training	To use BIM to assist with education and training of operation personnel
Preliminary circulation and security assessment:	A courthouse has three circulation systems. One is for the public (public zone), another for the judges, jury, and court staff (restricted zone), and the third is for defendants and U.S. Marshals (secure zone). They are supposed to be disjoint, so the three groups served only mix in courtrooms and a few other designated spaces. Circulation
Security	For security there needs to be information on access control, alarm monitoring, fire monitoring, and incident reporting and tracking
Acoustic analysis	To forecast the acoustical performance of the facility
Acoustics	To forecast the acoustical performance of the facility
Air quality	To monitor the basic air quality within the facility
Solar radiation analysis	To forecast the solar radiation within the facility
Design analyzing with BIM	Review of models to better understand design intent
Forensic analysis	Building Information Model can easily be adapted to graphically illustrate potential failures, leaks, evacuation plans, etc.
Preliminary energy analysis	An early concept design has features that significantly determine energy use. These include the building orientation; the building shell's external materials and mass, the value of insulation; and the inclusion of atria, courtyards, and skylights. At this stage designers are interested in the building's heating and cooling loads over the year, and thus the demands of HVAC to maintain human comfort. The assessment purpose is to identify any impacts of these and other features that may significantly affect energy usage and to support design decisions to improve energy performance
Code reviews	fire departments and other officials may use these models for their review of building projects
Pro forma Analysis	A pro forma analysis is an analytical projection of the potential financial position of a company based on a review of historical information, operating metrics, and potential cost savings due to anticipated changes. Pro forma analysis is typically performed in conjunction with a financial review. A pro forma analysis is one of the main decision-making tools companies use when reviewing potential large-scale company changes, potential purchases, mergers or acquisitions (Acevado 2013).
Programming	• Efficient and accurate assessment of design performance in regard to spatial requirements by the owner
Space Management and Validation	• Identify and allocate space for appropriate building use • Assist in planning future space needs for the facility
Space program validation:	The space validation application checks GSA specific rules for area calculation for comparison and reconciliation with the congressionally

	authorized any court space program. It compares alternative layouts to the target space requirements of the space program. It also includes the efficiency and adequacy of parameters traditionally used by GSA to compare alternatives. The application generates seven different reports: summary of any court comparison against actual, area summaries by tenant agencies.
3D trade coordination and digital fabrication	• Reduce and eliminate field conflicts; which reduces RFI's significantly compared to other methods • Maximize off-site fabrication • Decrease Material Waste • Visualize construction • Increase productivity • Reduced construction cost; potentially less cost growth (i.e. less change orders) • Decrease construction time • Increase productivity on site • More accurate as built drawings • Enhanced Site Safety
3D coordination	• Coordinate building project through a modelo Reduce and eliminate field conflicts; which reduces RFI's significantly compared to other methods • Visualize construction • Increase productivity • Reduced construction cost; potentially less cost growth (i.e. less change orders) • Decrease construction time • Increase productivity on site o More accurate as built drawings
Conflict, interference and collision detection	Because BIM models are created, to scale, in 3D space, all major systems can be visually checked for interferences. This process can verify that piping does not intersect with steel beams, ducts or walls.
Building commissioning	Building commissioning provides documented confirmation that building systems function according to criteria set forth in the project documents to satisfy the owner’s operational needs
Facilities management	facilities management departments can use BIM for renovations, space planning, and maintenance operations
Building management	For building management, information needs to be available on environmental monitoring, HVAC, plant management, energy inventory, and reports and actions
Business support	For business support there should be data on finance and contract management.
Management information	Management information there should be information on publishing on the web, planning, benchmarking and performance measurement.
Property management	property management there needs to be information on property portfolio control, estate diary and real estate development

Space and asset management	For space and asset management there needs to be information available on design, costs and inventory, recharge, moves and changes and visualization of space usage. Can the system be used to place assets, and then list them and data points by space ID, floor, building and so forth? Can the CAFM system also contain scanned or typed contract information regarding buildings, floors or equipment? Can it be used to create zones for cleaning, security, occupancy, etc.?
Visualization	3D renderings can be easily generated in-house with little additional effort
Design review	• Eliminate costly and timely traditional construction mock-upso Different design options and alternatives are easy to model and change real-time during design review by end users or ownero Create shorter and more efficient design reviews • Resolve the conflicts that would arise in a mock-up and model the potential fixes in real-time along with tolerances revised and RFI’s answered • Preview space aesthetics and layout during design review in a virtual environment • Evaluate effectiveness of design in meeting building program criteria and owner's needs • Creates efficiencies in design process • Easily communicate the design to the owner, construction team and end users. Get instant feedback on meeting program requirements, owner’s needs and building or space aesthetics
Fabrication/shop drawings	It is easy to generate shop drawings for various building systems, for example, the sheet metal ductwork shop drawing can be quickly produced once the model is complete.
Design authoring	• Transparency of design for all stakeholders • Better control and quality control of design, cost and schedule • Powerful design visualization • True collaboration between project stakeholders and BIM users • Improved quality control and assurance
Detailed modeling	• Understanding of relationships between differing materials • Analysis of connection details • Consideration of material and construction tolerances • Communicate installation sequence between trades
Record modeling	• Aid in future modeling and 3D design coordination for renovation • Provide documentation of environment for future uses, e.g., renovation or historical documentation
Existing conditions modeling	Mechanical renovation design for government clients, so there is often limited (or very old) documentation that must be updated before we can design anything. People in my office claim that existing conditions in Revit take much longer than they would in traditional CAD although I would argue that it reduces errors and requires fewer site visits once the model is constructed.
Site Logistics Model	• Coordination of underground utilities

	• Site access, parking, and fencing • Material laydown and movement • Equipment location and movement • Site Safety
5D Model	"Term used to describe the linkage of estimating software to a model—element quantities are downloaded from the model database and imported directly into estimating software"
Cost estimating	BIM software(s) have built-in cost estimating features. Material quantities are automatically extracted and changed when any changes are made in the model
Preliminary cost estimate	Similar to energy analysis, the intention in preliminaryconcept design is to determine the effect of particular design features and to gain insight into the value of and potential cost of specific design concepts.This is done by means of a cost estimation module that uses minimal the information available from building models at this early stage of design to build preliminary cost estimates.
4D model	"Term used to describe the linkage of a schedule to a model—essentially turning on model elements in the order in which they are built"
4D scheduling	• Visualization of construction sequencing • Proper work sequencing • Conveying schedule to non-technical people • Reduction of "Trade Stacking" • Playing "What If?" scenarios
Construction sequencing	Building Information Model can be effectively used to create material ordering, fabrication, and delivery schedules for all building components
Call handling	For call handling the information must relate to the helpdesk, vendor tracking, maintenance procedures, purchasing and vendor invoicing
Energy analysis	• Automating analysis and saving time and cost • Analysis tools are less costly than BIM authoring tools, easier to learn and implement and less • disruptive to established workflow • Improve specialized expertise and services offered by the design firm • Achieve optimum, energy-efficient design solution by applying various rigorous analyses • Improve the quality and reduce the cycle time of the design analyses

Appendix D. COMPARISON OF BIM PXP TO BIM USE ONTOLOGY

The following is a mapping of the BIM Use Ontology BIM Use Purposes to the BIM Uses within the *BIM Project Execution Planning Guide* and vice-versa.

D.1. BIM PXP VS. BIM USE ONTOLOGY

BIM PxP Use	BIM Use Ontology
Existing Conditions Modeling	Gather\Capture
Cost Estimation	Gather\Quantify and Analyze\Forecast – Financial
Phase Planning (4D Modeling)	Communicate\Visualize – Schedule
Programming	Generate\Specify
Site Analysis	Generate\Arrange → Sitework
Design Review	Communicate\Visualize
Design Authoring	Generate
Structural Analysis	Generate\Size → Substructure and Shell
Lighting Analysis	Generate\Size → Service\Electrical\Lighting
Energy Analysis	Analyze\Forecast - Energy
Mechanical Analysis	Generate\Size → Services\HVAC
Engineering Analysis	Generate\Size → Services\
Sustainability / LEED Evaluation	Analyze\Validate - Compliance
Code Validation	Analyze\Validate - Compliance
3D Coordination	Analyze\Coordinate
Site Utilization Planning	Generate\Arrange → Construction Elements
Construction System Design	Generate → LoD 400
Digital Fabrication	Realize\Fabricate
3D Control and Planning	Realize\Control
Record Modeling	Generate → LoD 500
Building Maintenance Scheduling	Analyze\Forecast - Schedule
Building System Analysis	Realize\Regulate
Asset Management	Gather\Qualify
Space Management / Tracking	Gather\Qualify
Disaster Planning	Analyze\Forecast - Scenario

D.2. BIM USE ONTOLOGY VS. BIM PXP GUIDE

BIM Use Purpose				BIM Use Objective
01	**Gather**			(none)
	01	Capture		Existing Conditions Modeling
	02	Quantify		Cost Estimation (Part)
	03	Monitor		(none)
	04	Qualify		Space Management / Tracking Asset Management
02	**Generate**			Design Authoring Construction System Design Record Modeling
	01	Prescribe		Programming
	02	Arrange		Site Analysis Site Utilization Planning
	03	Size		Structural Analysis Lighting Analysis Mechanical Analysis Engineering Analysis
03	**Analyze**			(none)
	01	Coordinate		3D Coordination
	02	Forecast		Cost Estimation (Part) Disaster Planning Building Maintenance Scheduling Energy Analysis
	03	Validate		Code Validation Sustainability / LEED Evaluation
04	**Communicate**			(none)
	01	Visualize		Design Review Phase Planning (4D Modeling)
	02	Transform		(none)
	03	Draw		(none)
	04	Document		(none)
05	**Realize**			(none)
	01	Fabricate		Digital Fabrication
	02	Assemble		(none)
	03	Control		3D Control and Planning
	04	Regulate		Building System Analysis

Appendix E. COMPARISION OF INTERNATIONAL BIM USES TO BIM USE ONTOLOGY

In addition to U.S. standards for BIM, there are several other international BIM standards which include BIM Uses. Two of these international BIM Standards include buildingSMART Finland's Common BIM Requirements 2012 (buildingSMART Finland 2012a) and AEC (UK) BIM Protocols (AEC UK 2013).

E.1. COMMON BIM REQUIREMENTS

In 2012, buildingSMART Finland released an update to their Common BIM Requirements (COBIM). COBIM, like GSA, releases their standard is series. There are currently 13 series of these documents. These series include:

- Series 1: General part
- Series 2: Modeling of the starting situation
- Series 3: Architectural design
- Series 4: MEP design
- Series 5: Structural design
- Series 6: Quality assurance
- Series 7: Quantity take-off
- Series 8: Use of models for visualization
- Series 9: Use of models in MEP analyses
- Series 10: Energy analysis
- Series 11: Management of a BIM project
- Series 12: Use of models in facility management
- Series 13: Use of models in construction

In some of these series, such as quantity take-off, a series aligns directly to a BIM Use Purpose. While other series, such as Use of models in facility management, and Uses of models in construction, contain multiple BIM Uses for an entire discipline. Typically, an organization such as this has to do with who developed the standards. In the case of COBIM, it is apparent that the focus is much more towards the design of a facility rather than other phases and disciplines. In fact, the update of these requirements were funded by Senate Properties, which is a state-owned enterprise which manages the real estate of the Finish Government. This sponsorship moved attention towards facility management and construction. With attention shift resulted in series 10-13 being release in March 27th, 2012. To ensure the validity of the BIM Use Ontology, the COBIM guide series titles, Series 1: General part BIM Uses, and Series 13: Use of models in construction were mapped to the BIM Use Ontology.

E.1.1. COBIM vs. BIM Use Ontology

The following is a mapping of the Common BIM Requirements 2012 series titles from buildingSMART Finland to the BIM Uses Ontology.

Series	Title	BIM Use Ontology	Notes
1	General BIM Requirement	-	Contains Multiple BIM Uses
2	Modeling of the Starting Situation	Gather\Capture → Plan	Capture existing conditions
3	Architectural Design	Generate → Shell – Interiors	Generating only architectural elements
4	MEP Design	Generate → Services	Generate only service elements
5	Structural Design	Generate → Substructure and Shell	Generate only structure elements
6	Quality Assurance	Analyze\Validate	Validate for quality can include compliance
7	Quantity Take-off	Gather\Quantify	Exact match
8	Use of Models for Visualization	Communicate\Visualize	Exact match
9	Use of Models in MEP Analyses	Generate\Size → Services	Engineering of elements sizes
10	Energy Analysis	Analyze\Forecast - Energy	Forecast future energy use
11	Management of BIM Project	-	Provides a strategy for how manage a BIM project
12	Use of Models in Facility Management	- → Facility Use	This is a phase of a facility life in which BIM is implemented
13	Use of Models in Construction	- → Construction	This is a phase of a facility life in which BIM is implemented
14	Use of Models in Building Supervision (To be released)	- → Facility Use	This is a phase of a facility life in which BIM is implemented

E.1.2. COBIM – SERIES 1: GENERAL PART VS. BIM USE ONTOLOGY

The following are BIM Use terms taken from Common BIM Requirements Series 1: General part (buildingSMART Finland 2012b). Within section four on the COBIM General Requirements BIM Uses are organized by points in the facility life in which BIM is implemented. However, the points vary between milestones and phases.

Terms	BIM Use Ontology	Notes
Area and volume, main activities, site requirements in Needs and Objectives	Generate\Prescribe → Needs and Objectives → LOD 100	Also called Requirement BIM. Prescribing the overall general requirements of the facility during needs and objectives phase to LOD 100
Space program, total budget, selected site in Needs and Objectives	Generate\Prescribe → Spaces → Needs and Objectives	Prescribing spaces during the needs and objectives phase. Missing discipline and LOD
Identification of Spaces in Needs and Objectives	Generate\Prescribe → Spaces → Needs and Objectives	Prescribing spaces during the needs and objectives phase. Missing discipline and LOD
Laws, Regulations and Instructions in Needs and Objectives	Analyze\Validate – Compliance → Needs and Objectives	Compliance validating during the needs and objectives phase. Missing elements, discipline, and LOD
BIM of the Site and Existing Buildings in Design Alternatives	Gather\Capture → All → Design Alternatives	Capturing all elements during the design alternatives phase. Missing discipline and LOD
Alternative Spatial Group Models and Spatial Models in Design Alternatives	Generate → Spaces → Design Alternatives → LOD 100	Generate spaces during design alternatives phase to LOD 100. Missing discipline
Structural Design in Design Alternatives	Generate → Substructure/Superstructure → Design Alternatives → LOD 100	Generating Substructure/Superstructure elements during the design alternatives phase to LOD 100. Missing discipline
HVAC Design in Design Alternatives	Generate → HVAC → Design Alternatives → LOD 100	Generating HVAC elements during the design alternatives phase to LOD 100. Missing discipline
Cost Estimation based on Areas and Volumes in Design Alternatives	Analyze\Forecast→ Financial → Design Alternatives	Financial forecasting during the design alternatives phase. Missing elements, discipline, and LOD
Energy Consumption Simulation and Calculation	Analyze\Forecast→ Energy → Design Alternatives	Energy forecasting during design alternatives phase.

of Life-cycle Costs in Design Alternatives		Missing elements, discipline and LOD
Visualizations in Design Alternatives	Communicate\Visualize → Design Alternatives	Visualizing during design alternatives. Missing elements, discipline and LOD.
Comparison and Decisions in Design Alternatives	Communicate\Visualize → Design Alternatives	Visualizing during design alternatives. Missing elements, discipline and LOD.
Architectural Models in Early Design	Generate → Interiors → Early Design → LOD 200	Generating Interior elements during the early design phase to LOD 200. Missing discipline
Structural Models in Early Design	Generate → Substructure/Superstructure → Early Design → LOD 200	Generating Substructure/Superstructure elements during the early design phase to LOD 200. Missing discipline
HVAC Models in Early Design	Generate → HVAC → Early Design → LOD 200	Generating HVAC elements during the early design phase to LOD 200. Missing discipline
Electrical Models in Early Design	Generate → Electrical → Early Design → LOD 200	Generating electrical elements during the early design phase to LOD 200. Missing discipline
Model Merging and Checking in Early Design	Analyze\Validate → Early Design → LOD 200	Validating during early design phase to LOD 200. Missing
Early Design Cost Estimation in Early Design	Analyze\Forecast→ Financial → LOD 200	Forecasting cost during the early design phase to LOD 200. Missing element and discipline.
Energy Consumption Simulation and Calculation of Life-cycle Costs in Early Design	Analyze\Forecast→ Energy → Early Design → LOD 200	Generating interior elements during the early design phase to LOD 200. Missing discipline and element
BIM Coordinator in Early Design		Not a BIM Use. BIM Coordinator is a discipline or role
Impact of the BIM on Process and Decision-making in Detailed Design		Not a BIM Use. Impact is a characteristic of a BIM Use
Architectural Model in Detailed Design	Generate → Interiors → Detailed Design → LOD 300	Generating Interior elements during the detailed design phase to LOD 300. Missing discipline

Structural Models in Detailed Design	Generate → Substructure/Superstructure → Detailed Design → LOD 300	Generating Substructure/Superstructure elements during the detailed design phase to LOD 300. Missing discipline
HVAC Models in Detailed Design	Generate → HVAC → Detailed Design → LOD 300	Generating HVAC elements during the detailed design phase to LOD 300. Missing discipline
Electrical Models in Detailed Design	Generate → Electrical → Detailed Design → LOD 300	Generating electrical elements during the detailed design phase to LOD 300. Missing discipline
Visualizations in Detailed Design	Communicate\Visualize → Detailed Design → LOD 300	Visualize during the detailed design to LOD 300. Missing elements and discipline
Model Merging and Checking in Detailed Design	Analyze\Validate → Detailed Design → LOD 300	Validate during detailed design phase to LOD 300. Missing elements, and discipline.
Cost Estimation and Bills of Quantities in Detailed Design	Analyze\Forecast→ Financial → Detailed Design → LOD 300	Forecasting the life-cycle cost during detailed design phase to LOD 300. Missing elements and discipline
Energy Consumption Simulation and Calculation of Life-cycle Costs in Detailed Design	Analyze\Forecast→ Energy → Detailed Design → LOD 300	Forecasting future energy use during detailed design phase to LOD 300. Missing elements and discipline
BIM Coordinator in Detailed Design		Not a BIM Use. BIM Coordinator is a discipline
Analysis and Planning during contract tendering stage	Analyze	Analyzing during contract and tendering stage. Missing elements, disciplines,
Using BIM in Construction	Construct	Construction is only a phase in which BIM can be implemented. Missing Purpose, Elements, Discipline, and Level of Development.
Using BIMs in Maintenance in Commissioning	Operate	Maintenance is only a phase in which BIM can be implemented. Missing Purpose, Elements, Discipline, and Level of Development.
As-built Models in commissioning	Generate → Commissioning → LOD 500	Generating during the commissioning phase to LOD 300. Missing Elements and Discipline.

E.1.3. COBIM CONSTRUCTION VS. BIM USE ONTOLOGY

The following is a comparison of the Common BIM Requirements 2012 - Series 13: Use of models in construction (buildingSMART Finland 2013) to the BIM Use Ontology.

COBIM: Use of models in construction	BIM Use Ontology	Notes
Visualization and supervision of work with the help of Building Information Models	Communicate\Visualize → Construct	Visualize during construction phase. Missing elements, discipline and LOD
Quantity take-offs	Gather\Quantify → Construct	Quantify during construction phase. Missing elements, discipline and LOD
Procurement	Gather\Quantify → Construct	Use quantities to purchase facility elements. Missing elements, discipline and LOD
Construction Schedule in BIM	Communicate\Visualize → Schedule → Construct	Visualize the construction schedule. Missing elements, discipline and LOD
Presenting Construction Status Information in BIM	Gather\Qualify → Construct	Identify status of facility elements during construction phase. Missing elements, discipline and LOD
Construction Site Area Modeling (Site Layout Plan)	Generate → Sitework → Construct	Generate temporary sitework elements during construction phase. Missing discipline and LOD
Ensuring Safety at Construction Phase with help of BIM	Communicate\Visualize → Safety → Construct	Safety is a performance characteristic that is often part of visualization.
Production Data Delivery into As-Built BIM	Communicate\Transform → Construction	Transform construction phase data. Missing elements, discipline and LOD
Documentation of Earth Construction and Foundation Engineering as 3D Model	Generate → Substructure → Construct	Generate substructure elements during construction phase. Missing discipline and LOD
Change Orders/design changes during Construction		Not BIM Use rather an impact of BIM Use.
Concealed Installations	Communicate\Visualize → Construction	Visualize during construction phase. Missing elements, discipline, and LOD.
Product Data of Building Parts Chosen by Contractor	Communicate\Transform → Construction	Transform information during construction phase. Missing elements, discipline, and LOD
Data Handover into Facility Management	Communicate\Transform → Construction	Transform construction phase data. Missing elements, discipline, and LOD

E.2. AEC (UK) BIM PROTOCOL VS. BIM USE ONTOLOGY

Version 2.0 of the AEC (UK) BIM Protocol was released in September 2012 (AEC UK 2013). The standard contains:

- Main document,
- BIM execution plan,
- Model matrix,
- Revit standard and checklist
- Bentley standard and checklist
- ArchiCAD standard, template, and checklist

Within the protocol are two lists of BIM Uses. One list is within the main document and the other list is within the BIM Execution Plan.

E.2.1. AEC (UK) BIM PROTOCOL (MAIN DOCUMENT) VS. BIM USE ONTOLOGY

The main document of the AEC (UK) BIM Protocol lists seven BIM Uses (AEC UK 2012a). Of these BIM Uses two, Geometric coordination and clash detection and resolution, have the same BIM Use Purpose. The following is a comparison of the terms with the main document of the AEC (UK) BIM Protocol and the BIM Use Ontology.

Terms	BIM Use Ontology	Notes
Geometric coordination	Analyze\ Coordinate	Coordinate the facility. Missing elements, phase, discipline, and LOD. This BIM Use Purpose is the same as Geometric Coordination
Information & design development	Generate	Generate the facility. Missing elements, phase, discipline, and LOD.
Drawing Production	Communicate\ Draw	Draw the facility. Missing elements, phase, discipline, and LOD.
Data export through COBie or another method	Communicate\ Transform	Transform facility data to be understood by other processes. Missing elements, phase, discipline, and LOD.
Schedule production		Not a BIM Use. Many of the BIM Uses can provide inputs to the construction schedule however a schedule cannot be currently generated from the model. It can however be visualized using BIM
Clash detection and resolution	Analyze\ Coordinate	Coordinate the facility. Missing elements, phase, discipline, and LOD. This BIM Use Purpose is the same as Geometric Coordination
Procurement & performance specification	Communicate\ Document	Document the specifications of the facility. Missing elements, discipline, phase, and LOD

E.2.2. AEC (UK) BIM PROTOCOL (BIM EXECUTION PLAN) VS. BIM USE ONTOLOGY

Within the AEC (UK) BIM Protocol BIM Execution Plan, the AEC UK lists 27 various BIM Uses (AEC UK 2012b). While not cited, these BIM Uses are based on the BIM Project Execution Plan (Computer Integrated Construction Research Program 2010a). In general, these BIM Uses map well to the BIM Use Ontology.

Terms	BIM Use Ontology	Notes
Building Maintenance Scheduling	Analyze\Forecast - Schedule	Forecast schedule. Missing elements, phase, discipline, and LOD.
Building System Analysis (operational)	Realize\Regulate	Regulate operation of facility elements. Missing elements, phase, discipline, and LOD.
Asset Management	Gather\Qualify	Qualify status of facility elements. Missing elements, phase, discipline, and LOD.
Space Planning & Tracking	Gather\Qualify	Qualify status of spaces. Missing phase, discipline, and LOD.
Disaster Planning	Analyze\Forecast - Scenario	Forecast scenario. Missing elements, phase, discipline, and LOD.
Record Modelling	Generate → LoD 500	Generate to LOD 500. Missing elements, phase, and discipline
Existing Conditions Modelling	Gather\Capture	Capture facility. Missing elements, phase, discipline, and LOD.
Engineering Analysis	Generate\Size → Services\	Size service elements. Missing phase, discipline, and LOD. Duplicate of other engineering analysis
Energy Analysis	Analyze\Forecast - Energy	Forecast energy use. Missing elements, phase, discipline, and LOD.
Structural Analysis	Generate\Size → Substructure - Superstructure	Size substructure and superstructure elements. Missing phase, discipline, and LOD.
Lighting Analysis	Generate\Size → Service\Electrical\Lighting	Size lighting elements. Missing phase, discipline, and LOD.
Mechanical Analysis	Generate\Size → Services\HVAC	Size HVAC elements. Missing phase, discipline, and LOD.
Other Engineering Analysis	Generate\Size → Services\	Size service elements. Missing phase, discipline, and LOD. Duplicate of engineering analysis.

Sustainability (BREEAM) Evaluation	Analyze\Validate - Compliance	Validate compliance based on BREEAM criteria. Missing elements, phase, discipline, and LOD.
Code Validation	Analyze\Validate - Compliance	Validate compliance based on CODE criteria. Missing elements, phase, discipline, and LOD.
Programming	Generate\Specify → Space	Specifying spaces. Missing phase, discipline, and LOD.
Cost Estimation	Gather\Quantify and Analyze\Forecast – Financial	Financial Forecasting. Missing elements, phase, discipline, and LOD.
Digital Fabrication	Realize\Fabricate	Fabricate. Missing elements, phase, discipline, and LOD.
3D Control & Planning (Digital Layouts)	Realize\Control	Control. Missing elements, phase, discipline, and LOD.
Visualisation	Communicate\Visualize	Visualize. Missing elements, phase, discipline, and LOD. Same purpose as design reviews.
Design Authoring	Generate	Generate. Missing elements, phase, discipline, and LOD
Design Reviews	Communicate\Visualize	Visualize. Missing elements, phase, discipline, and LOD. Same purpose as visualization.
Phase Planning (4D Modelling)	Communicate\Visualize – Schedule	Visualize schedule. Missing elements, phase, discipline, and LOD.
3D Coordination	Analyze\Coordinate	Coordinate. Missing elements, phase, discipline, and LOD
Site Utilisation Planning	Generate\Arrange → Construction Elements	Arrange construction elements. Missing phase, discipline, and LOD
Site Analysis	Generate\Arrange → Sitework	Arrange sitework elements. Missing phase, discipline, and LOD
Construction Systems Design (Virtual Mock-up)	Generate → LoD 400	Generate to LOD 400. Missing elements, phase, and discipline.

Appendix F. APPEAL FOR BIM SERVICES

The following is the email that was sent as an appeal for BIM Services

> Group,
>
> I am in the process of updating the BIM Uses that are part of the BIM project execution planning guide and on the Penn State BIM website (bim.psu.edu). I am writing you to request a list of BIM Uses that your organization utilizes. A BIM Use is defined as a method of applying Building Information Modeling during a facility's life-cycle to achieve one or more specific objectives. Other words that are commonly used for BIM Use are BIM Use Case, BIM Application, BIM Service, BIM Strategy, and BIM Tool to name a few. If available please also include a brief definition of the BIM Uses in your list. Alternatively if your organization does not have a standard list of BIM Uses, please share any updates you would make to the current BIM Uses on the BIM Uses website (bim.psu.edu). Please email me any feedback at ralphkreider@gmail.com. Thank you in advance for your help in standardizing the Uses of Building Information Modeling.

Appendix G. INTERVIEW OVERVIEW

The following is the email that was sent to survey participants

As an expert in the field of Building Information Modeling I am seeking your assistance to validate the BIM Use Ontology that I have created as part of my PhD research. Over the last few years I have been working to create a constant language for the Uses of Building Information Modeling. As there is no common BIM language, the goal of this Ontology is to create a structured BIM vocabulary that provides a foundation for consistent terms and expressions throughout our industry. The BIM Use Ontology provides a shared vocabulary which is utilized to model (express) the Uses of BIM, including the types of objects (terms), and concepts, properties, and relationships that exist. The Ontology created provides that common language for the Uses of BIM.

This Ontology was created to be simple and easy to use by anyone within the industry. Over the last three years I have become very familiar with the organization of definitions and therefore need assistance from industry experts like you to validate this Ontology. In order to validate this Ontology, I would like to conduct a short interview with you to confirm the representativeness, the comprehensiveness, and the convenience of the BIM Use Ontology. The interview will include an overview of the problem, the goal, the process and the organization of the Ontology.

Additionally during the session, you will be asked to map BIM Uses familiar to you with the Ontology to verify the structure and make recommendations to improve the Ontology. After the session is completed, you will also be asked to complete a survey to provide additional feedback.

If you are interested in participating, please select one of my appointment times on my Google calendar. (http://goo.gl/Jwrmk.) If none of those times work, please feel free to send me another time that would work better for you.

I greatly appreciate you taking time from your busy schedule to assist in validating my research. I thank you for your commitment to the advancement of BIM throughout our industry.

Thanks,
Ralph

Ralph G. Kreider
Graduate Research Assistant
The Pennsylvania State University
bim.psu.edu

Appendix H. Focus Group Meeting Results

The Following are the updated ontologies based on the focus group meeting.

The following is the email that was sent to each participant:

> As a reminder to you, I will be validating the BIM Use Ontology that I have created over the past year through an online focus group meeting on Thursday and Friday.
>
> If you are willing to participate, please join at one of the following times:
>
> - Thursday 12/27/2012 at 9am-12pm Eastern
> - Thursday 12/27/2012 at 1pm-4pm Eastern
> - Friday 12/28/2012 at 9am-12pm Eastern
>
> Each session will be similar, so no need to attend them all. During the meeting we will overview the Ontology and then step through each of the BIM Uses and characteristics in a meticulous nature confirming their definitions. While the meeting itself is scheduled for three hours, however I do not anticipate it taking that long and understand if you cannot attend the whole meeting. Please feel free to participate as much as you are able.
>
> The meeting will be conducted using the following GoToMeeting Link.
> Computer link: https://www2.gotomeeting.com/join/937043370
> Phone: +1 (786) 358-5420
> Access Code: 937-043-370
> Audio PIN: Shown after joining the meeting
> Meeting ID: 937-043-370
>
> The following resources will be used during the meeting:
> Prezi (http://prezi.com/umpiscij7l8c/bim-use-ontology/)
> Google Site (https://sites.google.com/site/bimuses/)
> Ontology Spreadsheet
> (https://docs.google.com/spreadsheet/ccc?key=0AnDJ9Hhs3VzcdHVuVnFDcjU3VG1rc2JBNEFaLWNtOEE)
>
> After the meeting, please complete following survey:
> Survey Monkey (https://www.surveymonkey.com/s/BIM_Use_Focus_Group_Meeting)
>
> Thank you in advance for taking time from your busy schedule to assist in validating my research. I thank you for your commitment to the advancement of BIM throughout our industry.
>
> Thanks,
> Ralph
>
> Ralph G. Kreider
> Graduate Research Assistant
> The Pennsylvania State University
> bim.psu.edu

H.1. FOCUS GROUP ONE

The following is the result from the first focus group meeting:

BIM Use Purposes

01	**Generating**		**to create or author information about the facility**	create, author		acquisition
	01	Prescribing	to determine the need for and select specific facility elements	programming, specifying	include spaces and other examples in description	
	02	Arranging	to determine location and placement of facility elements	configuring, laying out, locating, placing		
	03	Sizing	to determine the magnitude and scale of facility elements	scaling, engineering		
02	**Analyzing**		**to methodically examine elements of the facility to gain a better understanding of it.**	Examining, evaluating		
	01	Coordinating	to ensure the efficiency and harmony of the relationship of facility elements	Clash detecting, Collision avoiding, etc.		
	02	Forecasting	to predict the future performance of the facility and facility elements	simulating, predicting	can forecast items such as financial, energy, flow, scenario, temporal	
	03	Validating	to check or prove accuracy of facility information and that is logical and reasonable	Checking, Confirming	can validate the prescription, functionality, and compliance	
03	**Communicating**		**to present information about a facility in a method in which it can be shared or exchanged**	Exchanging		
	01	Visualizing	to form a representation of a facility or facility elements	Reviewing	Create a visualization often for purposes such as reviewing the design, walkthroughs, rendering, 3D printing for reviewing, marketing, schedule visualization,	
	02	Modeling	to generate objects with intelligence to emulate the facility and facility elements	Parametric Modeling, representing		
	03	Drawing	to make a symbolic representation of the facility and facility elements	Drafting, Annotating, Detailing		

	04	Documenting	to create a record of facility information including the information necessary to precisely specify facility elements	Specifying, submittals, design schedules	to share the facility data of facility elements	
04	**Realizing**		**to make or control a physical element using facility information**	Implementing, performing, executing,		
		Controlling	to physically manipulate the operation of executing equipment using facility information			
	01	Regulating	to inform the operation of a facility element using facility information	directing		
	02	Assembling	to use facility information to fit together the separate elements of a facility	Prefabricating		
	03	Fabricating	to manufacture the elements of a facility using facility information	Manufacturing	3D manufacturing	
05	**Gathering**		**to collect or cull facility information**	Administering, collecting, managing, acquiring		Collecting, Tracking, monitoring
	01	Qualifying	to characterize, or identify facility elements	Following, tracking, identifying	static data, historical, is it there, asset management, asset based	qualitative
	02	Monitoring	to observe the performance of facility elements and systems	Observing	dynamic system data, real-time, what is it doing, activity based	
	03	Capturing	to represent, or preserve the current status of the facility and facility elements	Collecting		
	04	Quantifying	to express or measure the amount of a facility element	Quantity Take-off	often part of estimating or financial forecasting, how much	Quantitative

BIM Use Characteristics

Term			Definition	Synonyms	Description
A	**Defining**		**Characteristics of the BIM which state and describe exactly the nature, meaning of, and purpose of the BIM Use**		
	a	Term	A word or phrase used to describe a thing or to express a concept		
	b	Objective	The goal, aim or purpose for implementing a BIM Use		
	c	Description	An account of the BIM Use including all the relevant aspects, qualities, and properties		
	d	Synonyms	A word or phrase that means nearly the same as standardized BIM Use Term. It may have had the same meaning but has since been superseded.		
B	**Elaborating**		**Characteristic which add more detail concerning a BIM Use (including what, when, who, how much)**		
	a	Element	An Element is a major component, assembly, or "construction entity part which, in itself or in combination with other parts, fulfills a predominating function of the construction entity" (ISO 12006-2). Predominating functions include, but are not limited to, supporting, enclosing, servicing, and equipping a facility. Functional descriptions can also include a process or an activity.		Use OmniClass Table 21,Table 22 or Table 23
	b	Phase	A phase is a period of time in the duration of a construction project identified by the overall character of the construction processes which occur within it.		Use OmniClass Table 31 - Phases
	c	Discipline	Disciplines are the practice areas and specialties of the actors (participants) that carry out the processes and procedures that occur during the life-cycle of a construction entity		Use OmniClass Table 33 - Disciplines
	d	(Level of)Development	The level of completeness to which a model element is developed		
C	**Implementing**		**Characteristics that vary depending upon the method in which the BIM Use is implemented**		
	a	Process	The series of actions or steps take in order to achieve the objective of the BIM Use		
	b	Information	The data about the facility (including both geometric and attribute data such as model and serial number) necessary in order to achieve the objective of the BIM Use		
	c	Infrastructure	the elements necessary to implement a BIM Use		
	d	Maturity	the degree to which an organization excels performing a BIM Use		
	e	Benefits	The advantage gained by implementing a BIM Use		
	f	References	a source for addition information concerning the implementation of a BIM Use		

H.2. FOCUS GROUP TWO

The following is the result from the second focus group meeting:

BIM Use Purposes

01	**Authoring**		**to generate new information about the facility**	Generating		
	01	Prescribing	to determine the need for and select specific facility elements	programming, specifying		
	02	Configuring	to predict the location and arrangement of facility elements	arranging, laying out, locating		
	03	Sizing	to determine the magnitude and scale of facility elements	scaling, engineering		
02	**Analyzing**		**To methodically examine elements of the facility to gain a better understanding of it.**	Examining, evaluating		
	01	Coordinating	to ensure the efficiency of the interaction between facility elements	Clash detecting, Collision avoiding, etc.		
	02	Forecasting	to predict the future performance of the facility and facility elements	simulating, predicting	can forecast items such as financial, energy, flow, scenario, temporal	
	03	Validating	to check or prove accuracy of facility information and that is logical and reasonable	Checking, Confirming	can validate the prescription, functionality, and compliance	ground truth
03	**Communicating**		**to present information about a facility in a method in which it can be shared or exchanged**	Exchanging		
	01	Visualizing	to form an image of a facility or facility elements	Reviewing, Rendering	Create a visualization in a realistic manner often for purposes such as marketing or reviewing the design.	
	02	Modeling	to generate objects with intelligence to emulate the facility and facility elements	Parametric Modeling, representing		
	03	Drawing	to make a symbolic representation of the facility and facility elements including annotating and detailing	Annotating, Detailing		
	04	Documenting	to create a record of facility information including the information necessary to specify facility elements	Specifying, as-built	to share the facility data of facility elements	

	05	Scheduling	to plan an action to take place at a particular time	Logistics, 4D Modeling, Sequencing		
04	**Executing**		**to make and describe position of a physical element using facility information**	Implementing		
	01	Locating	to use facility information to describe the position of facility elements	Controlling		goes to codes or regulations
	02	Assembling	to use facility information to fit together the separate elements or components of a facility	build		
	03	Fabricating	to manufacture the elements of a facility using facility information	Manufacturing		
05	**Managing**		**to direct the use of facility information**	Administering, describing		
	01	Tracking	to follow and note changes in the facility elements	Following	static data	
	02	Monitoring	to observe the performance of facility elements and systems	Observing	dynamic system data	
	03	Capturing	to represent, or preserve the status of the facility and facility elements	Collecting, gathering, existing conditions,		
	04	Quantifying	to express or measure the amount of a facility element	Quantity Take-off	often part of estimating or financial forecasting	

BIM Use Characteristics

A	**Defining**		**Characteristics of the BIM Use which state and describe exactly the nature, meaning of, and purpose of the BIM Use**	
	a	Term	A word or phrase used to describe a thing or to express a concept	
	b	Objective	The goal, aim or purpose for implementing a BIM Use	
	c	Description	An account of the BIM Use including the relevant aspects, qualities, and properties	
	d	Synonyms	A word or phrase that means nearly the same as standardized BIM Use Term.	It may have had the same meaning but has since been superseded.
B	**Expanding**		**Characteristics which add more detail concerning a BIM Use (including what, when, who, how much)**	oh by the way if you don't like you can use your own
	a	Element	An Element is a major component, assembly, or "construction entity part which, in itself or in combination with other parts, fulfills a predominating function of the construction entity" (ISO 12006-2). Predominating functions include, but are not limited to, supporting, enclosing, servicing, and equipping a facility. Functional descriptions can also include a process or an activity.	Use OmniClass Table 21,Table 22 or Table 23
	b	Phase	A phase is a period of time in the duration of a construction project identified by the overall character of the construction processes which occur within it.	Use OmniClass Table 31 - Phases
	c	Discipline	Disciplines are the practice areas and specialties of the actors (participants) that carry out the processes and procedures that occur during the life-cycle of a construction entity	Use OmniClass Table 33 - Disciplines
	d	(Level of)Development	The level of completeness to which a model element is developed	Needs more definition then with E202. Need to describe. Author of the information, etc. placeholders
C	**Implementing**		**Characteristics that vary depending upon the method in which the BIM Use is implemented**	
	a	Process	The series of actions or steps take in order to achieve the objective of the BIM Use	
	b	Information	The data about the facility (including both geometric and attribute data such as model and serial number) necessary in order to achieve the objective of the BIM Use	
	c	Infrastructure	the tools (including software and hardware) necessary to implement a BIM Use	
	d	Maturity	the degree to which an organization excels performing a BIM Use	
	e	Benefits	The advantage gained by implementing a BIM Use	
	f	References	a source for addition information concerning the implementation of a BIM Use	

H.3. FOUCS GROUP THREE

The following is the result from the third focus group meeting:

BIM Use Purposes

Term			Objective	Synonyms	Description	notes
01	**Authoring**		**to generate new information about the facility**	Generating		
	01	Prescribing	to determine the need for and select specific facility elements including spaces	programming, specifying		
	02	Configuring	to determine location and arrangement of facility elements including spaces	arranging, laying out, locating		
	03	Sizing	to determine the size and scale of facility elements	scaling, engineering		
02	**Analyzing**		**To methodically examine elements of the facility to gain a better understanding of it.**	Examining, evaluating		
	01	Coordinating	to ensure the efficiency and harmony of the relationship of facility elements		including clash detection, collision avoiding, visual inspection	
	02	Forecasting	to predict the future performance of the facility and facility elements	simulating, predicting	can forecast items such as financial, energy, flow, scenario, temporal	
	03	Validating	to check or prove accuracy of facility information and that is logical and reasonable	Checking, Confirming	can validate the prescription, functionality, and compliance	
03	**Communicating**		**to present information about a facility in a method in which it can be shared or exchanged**	Exchanging		
	01	Visualizing	to form an image of a facility or facility elements	Reviewing, Rendering	Create a visualization in a realistic manner often for purposes such as marketing or reviewing the design., include schedule visualization	
	02	Modeling	to generate objects with intelligence to emulate the facility and facility elements	Parametric Modeling, representing		
	03	Drawing	to make a symbolic representation of the facility and facility elements	Annotating, Detailing		

			including proper annotation and detailing			
	04	Documenting	to create a record of facility information including the information necessary to precisely specify facility elements	Specifying	to share the facility data of facility elements	
04	**Executing**		**to make a physical element or perform a physical take using facility information**	Implementing		lends itself to Construction
	01	Regulating	to use facility information to control the operation of a facility element or executing equipment	Controlling		
	02	Assembling	to use facility information to fit together the separate elements of a facility	Prefabricating		really close to fabricating
	03	Fabricating	to manufacture the elements of a facility using facility information	Manufacturing		
05	**Administering**		**to handle or direct the use of facility information**	Managing		lends itself to O&M
	01	Tracking	to follow and note the facility elements including spaces	Following	static data	
	02	Monitoring	to observe the performance of facility elements and systems	Observing	dynamic system data	
	03	Capturing	to represent, or preserve the current status of the facility and facility elements	Collecting		
	04	Quantifying	to express or measure the amount of a facility element	Quantity Take-off	often part of estimating or financial forecasting	
						FMs entire life is scheduling

BIM Use Characteristics

Term			Definition	Synonyms	Description
A	**Defining**		**Characteristics of the BIM which state and describe exactly the nature, meaning of, and purpose of the BIM Use**		
	a	Term	A word or phrase used to describe a thing or to express a concept		
	b	Objective	The goal, aim or purpose for implementing a BIM Use		
	c	Description	An account of the BIM Use including all the relevant aspects, qualities, and properties		
	d	Synonyms	A word or phrase that means nearly the same as standardized BIM Use Term. It may have had the same meaning but has since been superseded.		
B	**Elaborating**		**Characteristic which add more detail concerning a BIM Use (including what, when, who, how much)**		
	a	Element	An Element is a major component, assembly, or "construction entity part which, in itself or in combination with other parts, fulfills a predominating function of the construction entity" (ISO 12006-2). Predominating functions include, but are not limited to, supporting, enclosing, servicing, and equipping a facility. Functional descriptions can also include a process or an activity.		Use OmniClass Table 21,Table 22 or Table 23
	b	Phase	A phase is a period of time in the duration of a construction project identified by the overall character of the construction processes which occur within it.		Use OmniClass Table 31 - Phases
	c	Discipline	Disciplines are the practice areas and specialties of the actors (participants) that carry out the processes and procedures that occur during the life-cycle of a construction entity		Use OmniClass Table 33 - Disciplines
	d	(Level of)Development	The level of completeness to which a model element is developed		
C	**Implementing**		**Characteristics that vary depending upon the method in which the BIM Use is implemented**		
	a	Process	The series of actions or steps take in order to achieve the objective of the BIM Use		
	b	Information	The data about the facility (including both geometric and attribute data such as model and serial number) necessary in order to achieve the objective of the BIM Use		
	c	Infrastructure	the elements necessary to implement a BIM Use		
	d	Maturity	the degree to which an organization excels performing a BIM Use		
	e	Benefits	The advantage gained by implementing a BIM Use		
	f	References	a source for addition information concerning the implementation of a BIM Use		

Appendix I. Survey Questions and Results

A survey was sent to the interview and focus Group Participants. The following are the questions and responses.

1. Please Enter Your Contact Information

Name:

Company:

Address:

Address 2:

City/Town:

State: -- select state --

ZIP:

Country:

Email Address:

Phone Number:

Please Enter Your Contact Information

Answered: 10 Skipped: 0

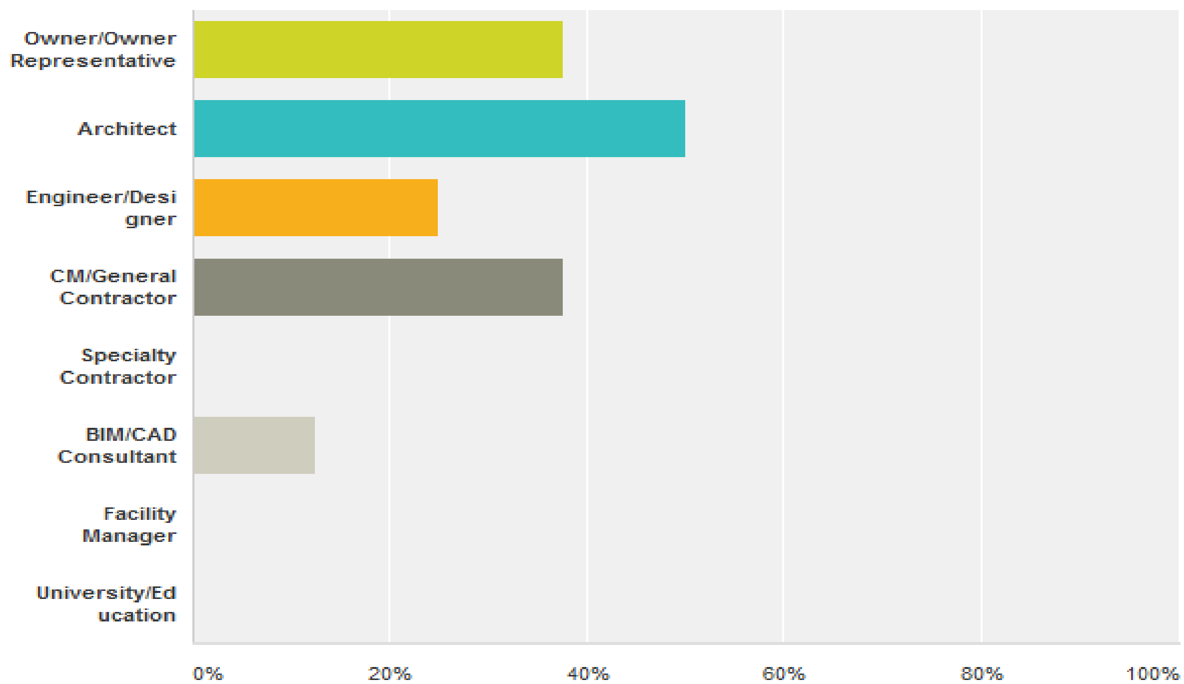
Answer Choices		Responses	
Name:	Responses	100%	10
Company:	Responses	100%	10
Address:	Responses	90%	9
Address 2:	Responses	40%	4
City/Town:	Responses	90%	9
State:	Responses	90%	9
ZIP:	Responses	90%	9
Country:	Responses	90%	9
Email Address:	Responses	100%	10
Phone Number:	Responses	90%	9

2. Please select the most appropriate discipline(s) based on your organization's role

- [ ] Owner/Owner Representative
- [ ] Architect
- [ ] Engineer/Designer
- [ ] CM/General Contractor
- [ ] Specialty Contractor
- [ ] BIM/CAD Consultant
- [ ] Facility Manager
- [ ] University/Education

Other (please specify)

Answered: 8 Skipped: 2



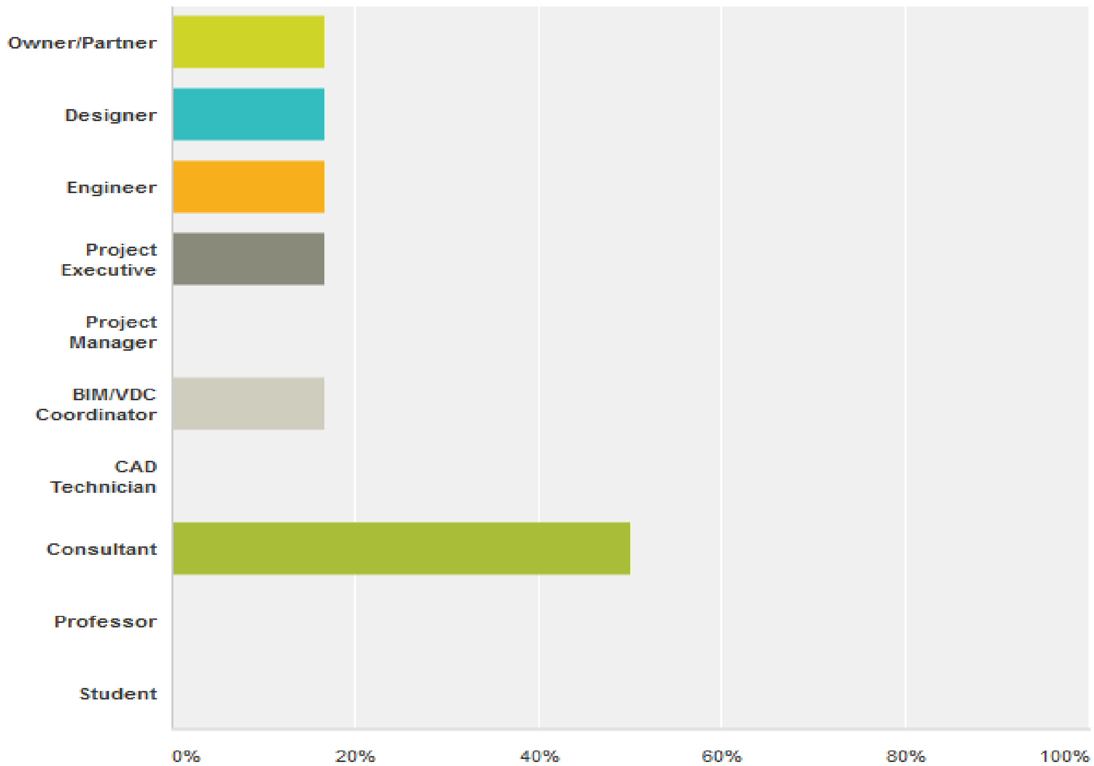
Answer Choices	Responses	
Owner/Owner Representative	37.50%	3
Architect	50%	4
Engineer/Designer	25%	2
CM/General Contractor	37.50%	3
Specialty Contractor	0%	0
BIM/CAD Consultant	12.50%	1
Facility Manager	0%	0
University/Education	0%	0
Total Respondents: 8		

3. Please describe your role within your organization:

- ☐ Owner/Partner
- ☐ Designer
- ☐ Engineer
- ☐ Project Executive
- ☐ Project Manager
- ☐ BIM/VDC Coordinator
- ☐ CAD Technician
- ☐ Consultant
- ☐ Professor
- ☐ Student

Other (please specify)

Answered: 6 Skipped: 4

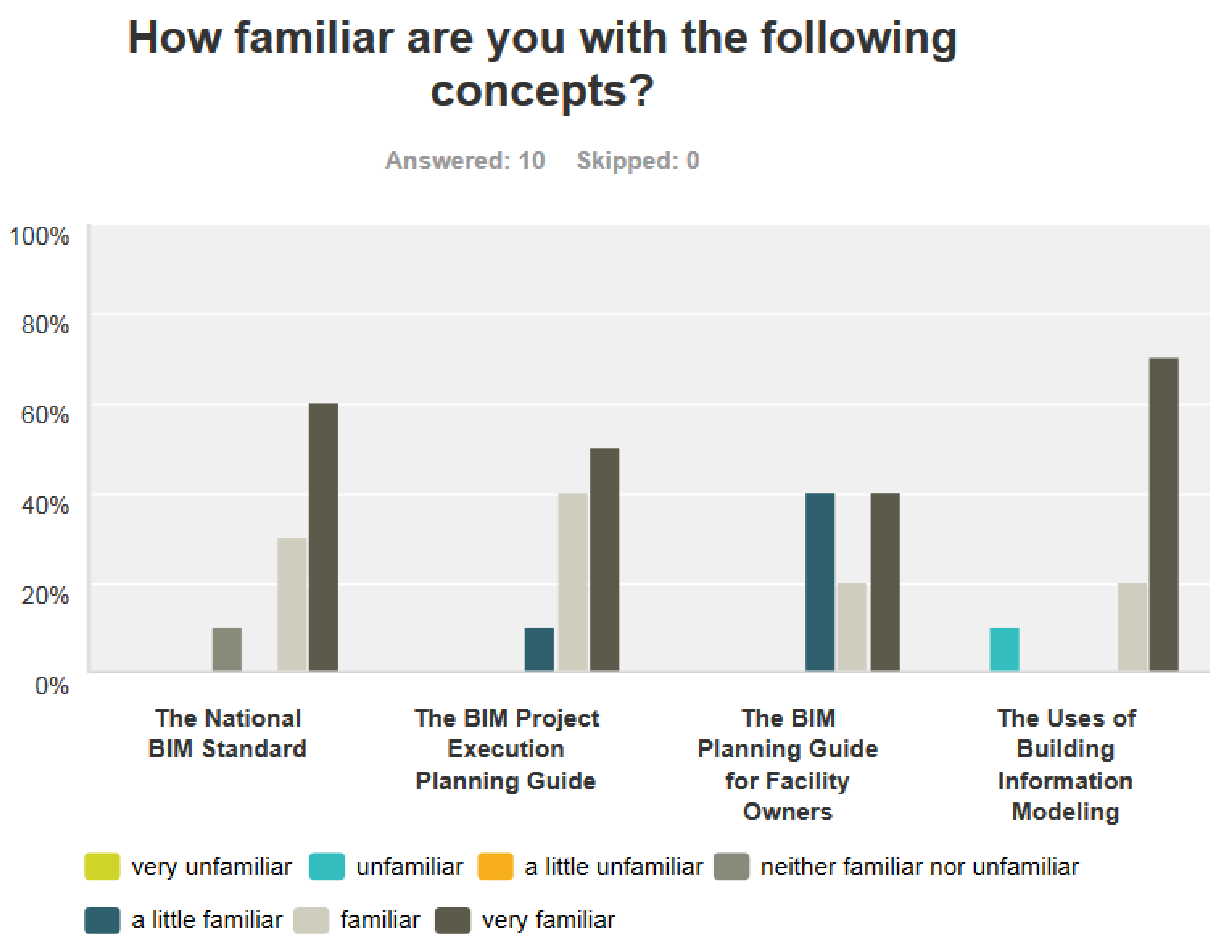


Answer Choices	Responses	
Owner/Partner	16.67%	1
Designer	16.67%	1
Engineer	16.67%	1
Project Executive	16.67%	1
Project Manager	0%	0
BIM/VDC Coordinator	16.67%	1
CAD Technician	0%	0
Consultant	50%	3
Professor	0%	0
Student	0%	0
Total Respondents: 6		

Comments (5)

4. How familiar are you with the following concepts?

	very unfamiliar	unfamiliar	a little unfamiliar	neither familiar nor unfamiliar	a little familiar	familiar	very familiar
The National BIM Standard							
The BIM Planning Guide for Facility Owners							
The Uses of Building Information Modeling							
The BIM Project Execution Planning Guide							



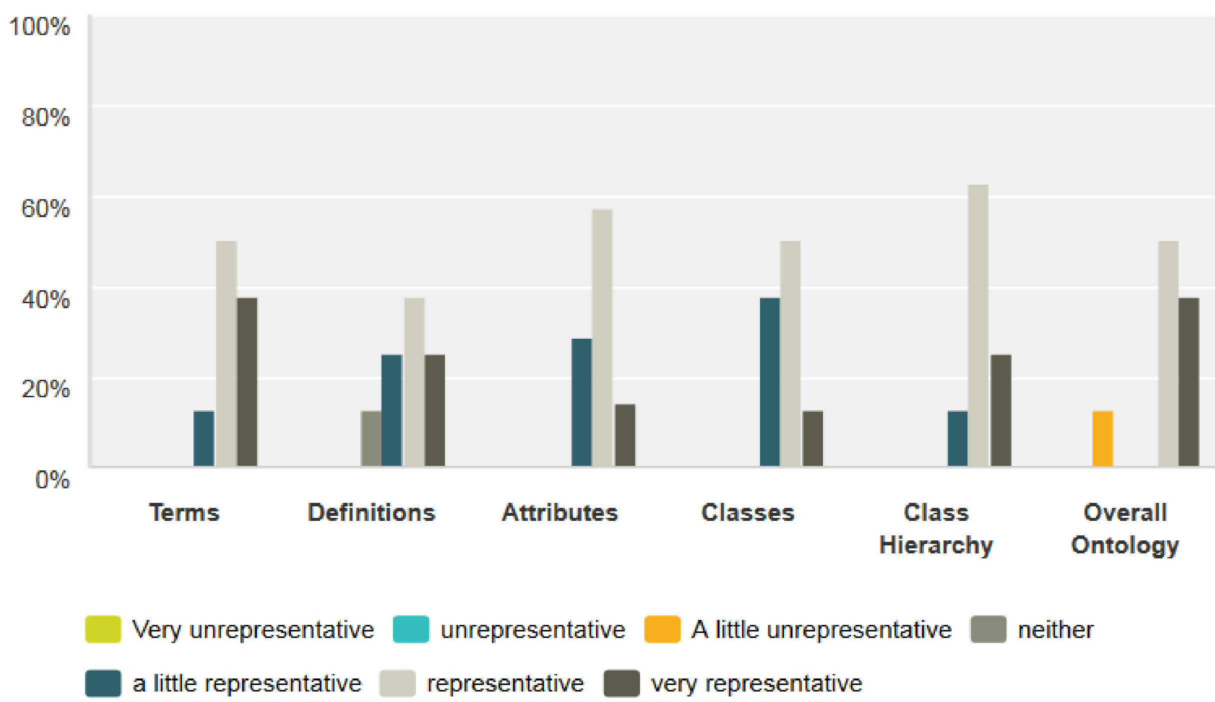
	very unfamiliar	unfamiliar	a little unfamiliar	neither familiar nor unfamiliar	a little familiar	familiar	very familiar	Total
The National BIM Standard	0% 0	0% 0	0% 0	10% 1	0% 0	30% 3	60% 6	10
The BIM Project Execution Planning Guide	0% 0	0% 0	0% 0	0% 0	10% 1	40% 4	50% 5	10
The BIM Planning Guide for Facility Owners	0% 0	0% 0	0% 0	0% 0	40% 4	20% 2	40% 4	10
The Uses of Building Information Modeling	0% 0	10% 1	0% 0	0% 0	0% 0	20% 2	70% 7	10

5. Please rate the representative (or typicality) the ontology is of the BIM Uses within industry

	Very unrepresentative	unrepresentative	A little unrepresentative	neither	a little representative	representative	very representative
Terms							
Definitions							
Attributes							
Classes							
Class Hierarchy							
Overall Ontology							

Please rate the representative (or typicality) the ontology is of the BIM Uses within industry

Answered: 8   Skipped: 2



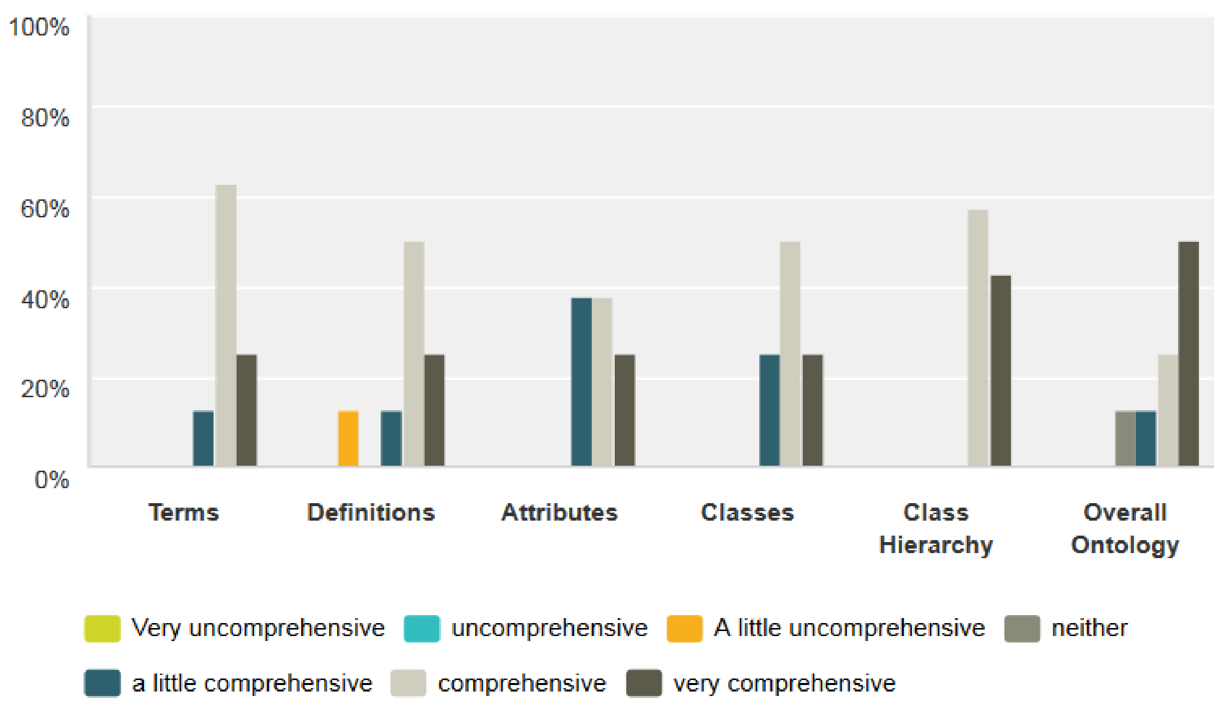
	Very unrepresentative	unrepresentative	A little unrepresentative	neither	a little representative	representative	very representative	Total
Terms	0% 0	0% 0	0% 0	0% 0	12.50% 1	50% 4	37.50% 3	8
Definitions	0% 0	0% 0	0% 0	12.50% 1	25% 2	37.50% 3	25% 2	8
Attributes	0% 0	0% 0	0% 0	0% 0	28.57% 2	57.14% 4	14.29% 1	7
Classes	0% 0	0% 0	0% 0	0% 0	37.50% 3	50% 4	12.50% 1	8
Class Hierarchy	0% 0	0% 0	0% 0	0% 0	12.50% 1	62.50% 5	25% 2	8
Overall Ontology	0% 0	0% 0	12.50% 1	0% 0	0% 0	50% 4	37.50% 3	8

6. Please rate the comprehensiveness (or completeness) of the main elements of the BIM Use Ontology

	Very uncomprehensive	uncomprehensive	A little uncomprehensive	neither	a little comprehensive	comprehensive	very comprehensive
Terms	○	○	○	○	○	○	○
Definitions	○	○	○	○	○	○	○
Attributes	○	○	○	○	○	○	○
Classes	○	○	○	○	○	○	○
Class Hierarchy	○	○	○	○	○	○	○
Overall Ontology	○	○	○	○	○	○	○

Please rate the comprehensiveness (or completeness) of the main elements of the BIM Use Ontology

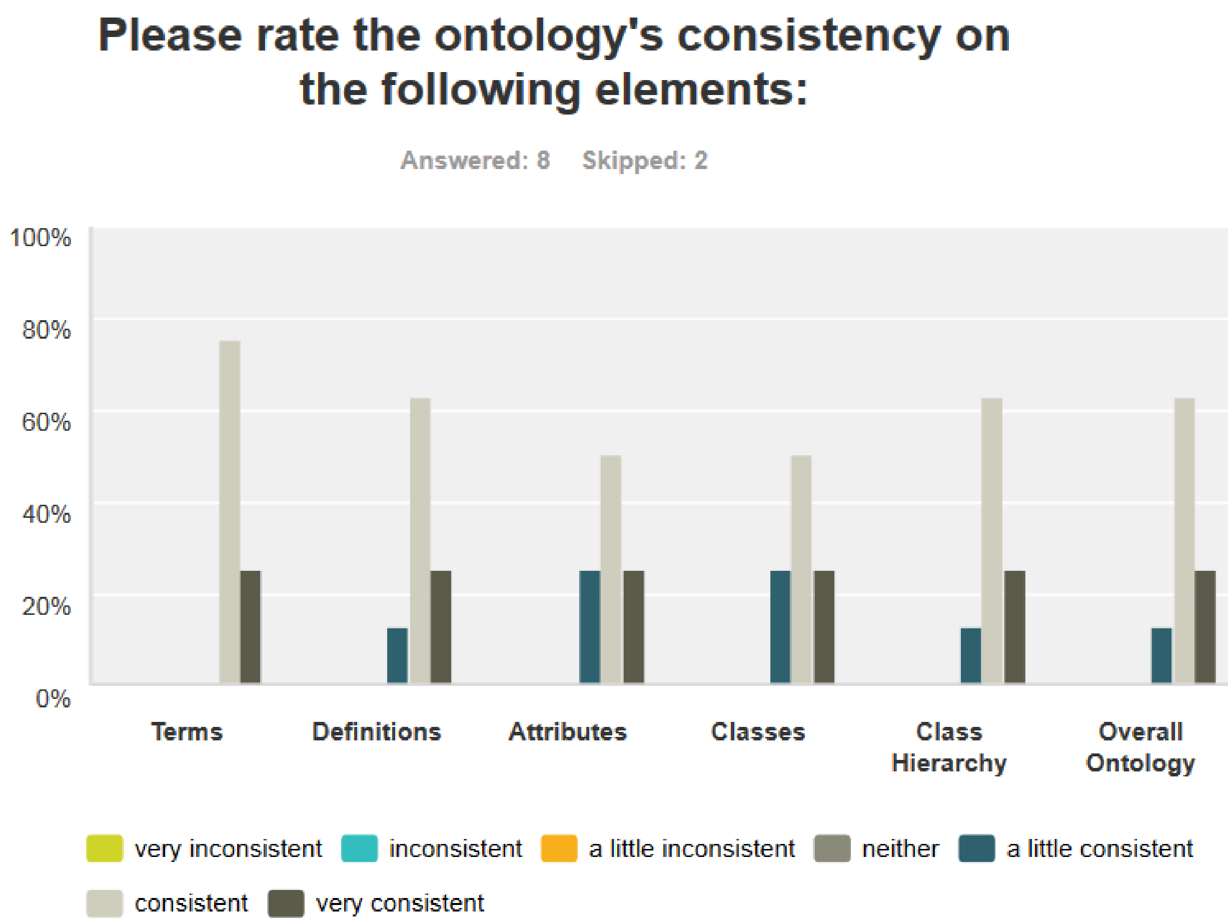
Answered: 8 Skipped: 2



	Very uncomprehensive	uncomprehensive	A little uncomprehensive	neither	a little comprehensive	comprehensive	very comprehensive	Total
Terms	0% 0	0% 0	0% 0	0% 0	12.50% 1	62.50% 5	25% 2	8
Definitions	0% 0	0% 0	12.50% 1	0% 0	12.50% 1	50% 4	25% 2	8
Attributes	0% 0	0% 0	0% 0	0% 0	37.50% 3	37.50% 3	25% 2	8
Classes	0% 0	0% 0	0% 0	0% 0	25% 2	50% 4	25% 2	8
Class Hierarchy	0% 0	0% 0	0% 0	0% 0	0% 0	57.14% 4	42.86% 3	7
Overall Ontology	0% 0	0% 0	0% 0	12.50% 1	12.50% 1	25% 2	50% 4	8

7. Please rate the ontology's consistency on the following elements:

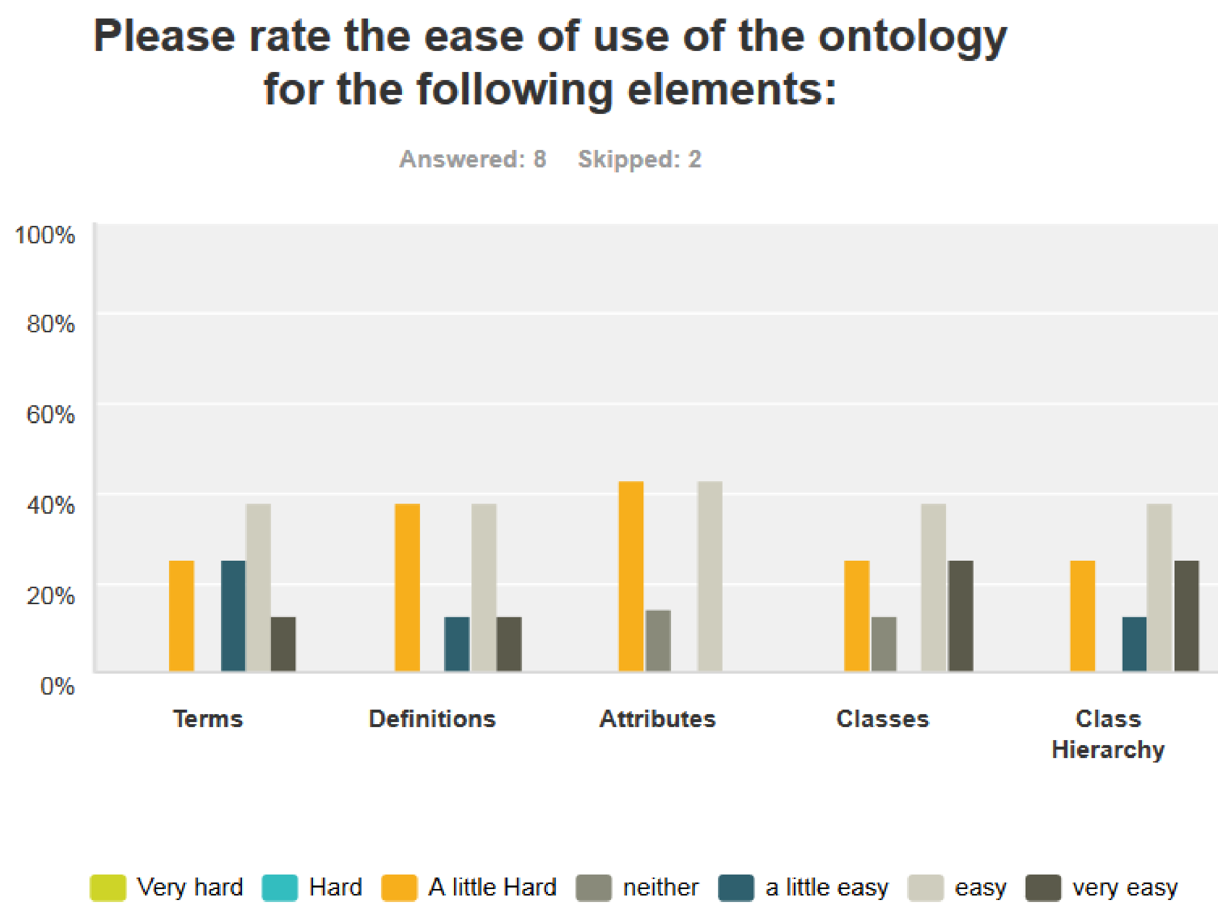
	very inconsistent	inconsistent	a little inconsistent	neither	a little consistent	consistent	very consistent
Terms	○	○	○	○	○	○	○
Definitions	○	○	○	○	○	○	○
Attributes	○	○	○	○	○	○	○
Classes	○	○	○	○	○	○	○
Class Hierarchy	○	○	○	○	○	○	○
Overall Ontology	○	○	○	○	○	○	○



	very inconsistent	inconsistent	a little inconsistent	neither	a little consistent	consistent	very consistent	Total
Terms	**0%** 0	**0%** 0	**0%** 0	**0%** 0	**0%** 0	**75%** 6	**25%** 2	8
Definitions	**0%** 0	**0%** 0	**0%** 0	**0%** 0	**12.50%** 1	**62.50%** 5	**25%** 2	8
Attributes	**0%** 0	**0%** 0	**0%** 0	**0%** 0	**25%** 2	**50%** 4	**25%** 2	8
Classes	**0%** 0	**0%** 0	**0%** 0	**0%** 0	**25%** 2	**50%** 4	**25%** 2	8
Class Hierarchy	**0%** 0	**0%** 0	**0%** 0	**0%** 0	**12.50%** 1	**62.50%** 5	**25%** 2	8
Overall Ontology	**0%** 0	**0%** 0	**0%** 0	**0%** 0	**12.50%** 1	**62.50%** 5	**25%** 2	8

8. Please rate the ease of use of the ontology for the following elements:

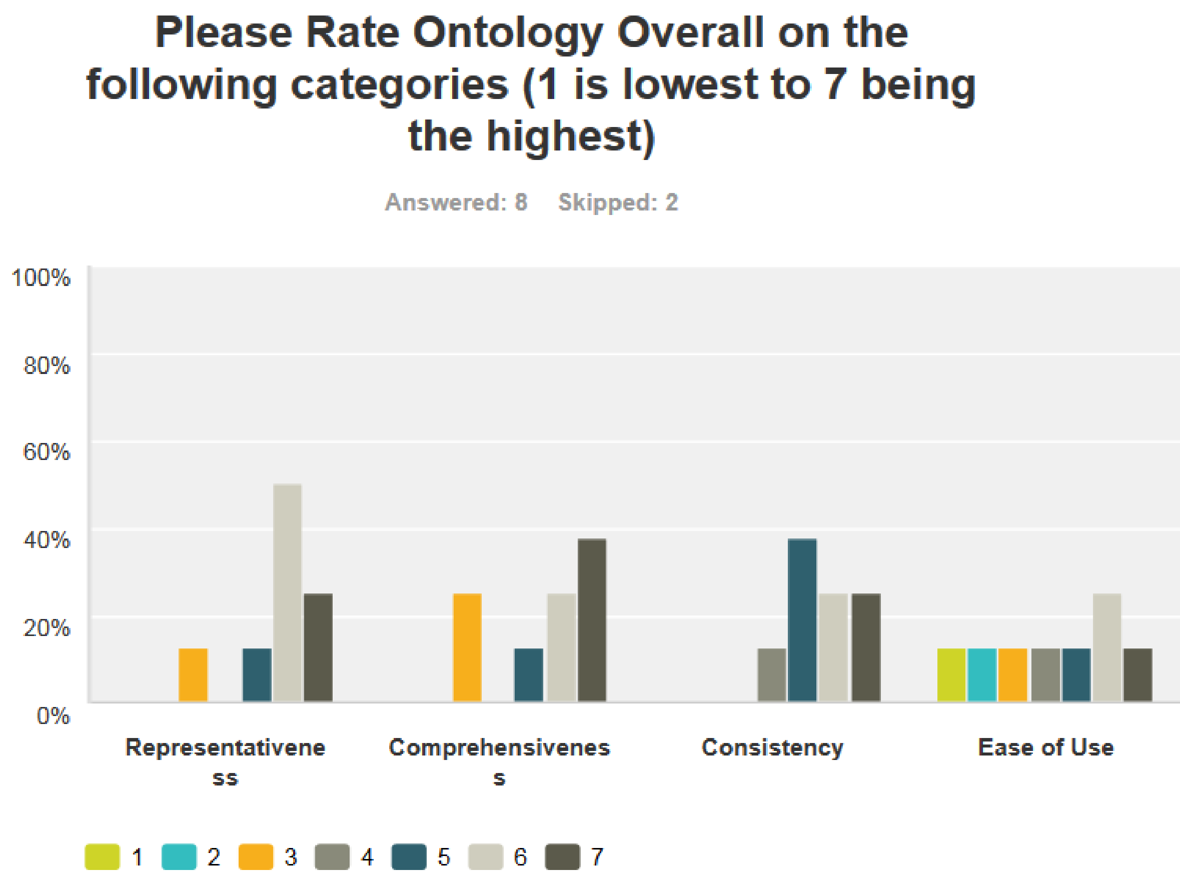
	Very hard	Hard	A little Hard	neither	a little easy	easy	very easy
Terms							
Definitions							
Attributes							
Classes							
Class Hierarchy							



	Very hard	Hard	A little Hard	neither	a little easy	easy	very easy	Total
Terms	0% 0	0% 0	25% 2	0% 0	25% 2	37.50% 3	12.50% 1	8
Definitions	0% 0	0% 0	37.50% 3	0% 0	12.50% 1	37.50% 3	12.50% 1	8
Attributes	0% 0	0% 0	42.86% 3	14.29% 1	0% 0	42.86% 3	0% 0	7
Classes	0% 0	0% 0	25% 2	12.50% 1	0% 0	37.50% 3	25% 2	8
Class Hierarchy	0% 0	0% 0	25% 2	0% 0	12.50% 1	37.50% 3	25% 2	8

9. Please Rate Ontology Overall on the following categories (1 is lowest to 7 being the highest)

	1	2	3	4	5	6	7
Representativeness							
Comprehensiveness							
Consistency							
Ease of Use							



	1	2	3	4	5	6	7	Total
Representativeness	0% 0	0% 0	12.50% 1	0% 0	12.50% 1	50% 4	25% 2	8
Comprehensiveness	0% 0	0% 0	25% 2	0% 0	12.50% 1	25% 2	37.50% 3	8
Consistency	0% 0	0% 0	0% 0	12.50% 1	37.50% 3	25% 2	25% 2	8
Ease of Use	12.50% 1	12.50% 1	12.50% 1	12.50% 1	12.50% 1	25% 2	12.50% 1	8

10. Please provide additional comments to improve the ontology

This is a promising start for a contract language, but I'm not sold on it's adoption for daily use. The nice thing about implementing contract language is that it can be legally mandated. Daily practice is a different story. BIM uses are typically discussed through a combination of process (tools, methods), context (when, where, who), and objective. Placing so much primacy on the objective for identification isn't immediately intuitive. I understand theoretically why this ontology prioritizes objectives; starting with global objectives and then drilling down into process and context works for contracts. However, the objective terms and definitions seem over broad, even vague. In practice, I imagine most people will skip such a high-level, nebulous vocabulary (e.g. prescribing, configuring, coordinating) and go straight to a more specific, traditional one (e.g. programming, model authoring, clash detection). Dealing with this split vocabulary is a challenge, dealing with it across A,E,C,O and M is probably impossible. The ontology occasionally appropriates industry terms when they are convenient to the system (e.g. authoring, coordinating) and invents the rest. On first hearing them, most of the invented terms fail to resonate with meaning separate from their definitions - this might change with more exposure. It might be more effective to approach the split vocabulary issue with super imposition rather than appropriate and invent. Instead of avoiding industry terms, use and classify the most common. The classes are the most intuitive part of the ontology.

It's rather difficult to give ratings as I don't believe I got to see the full BIM ontology. Even if what was shown me was the full ontology, I don't think I got to spend enough time with any of these elements to properly judge their ease of use, consistency, comprehensiveness, etc. Sorry I couldn't be more helpful on this.

To be honest, the layers of 'terms, definitions, attributes, classes, and class hierarchy' are a little difficult to wrap my head around in terms of completing a survey on whether each one is typical, complete, or comprehensive. Can you provide an example at the top of this survey page as a reminder, like 'Term = ______, Definition = ________, Attribute = _________' and so on? Otherwise, good work...and good luck!

Additional definitions are helpful in relating the ontology to practical use. Examples would probably go a long way. Nice job Ralph!

I think it is a little hard to use because it is a more detailed way of thinking. You have to be precise in how you explain a term verses the purpose you really mean. Getting clarity across the industry will be good for communication and contracts.

Appendix J. IRB

This research was cover under the research study titled "BIM Execution Planning for Projects and Owners (IRB#: 33511)." On October 31, 2011 that research study was determined by the Office for Research Protection to be exempt from initial and ongoing IRB review.

VITA

Ralph Kreider is currently a Doctor of Philosophy Candidate in Architectural Engineering at the Pennsylvania State University where he is a member of the Computer Integrated Construction (CIC) Research Program. As a member of the CIC Research Program, Ralph has been a major contributor on the buildingSMART Alliance™ project on the *BIM Project Execution Planning Guide* and the *BIM Planning Guide for Facility Owners*. As a contributor to these efforts, Ralph spent time working with the United States Army Corps of Engineers in the development of a USACE specific BIM Project Execution Plan Template. He also developed a survey to help determine the frequency of use and perceived benefit of different applications of Building Information Modeling which was published as part of the Sixth International Conference on Innovation in Architecture, Engineering and Construction. The *BIM Project Execution Planning Guide*, which has been accepted as part of the U.S. National BIM Standard and The *BIM Planning Guide for Facility Owners*. His dissertation focuses on defining and classifying the various BIM Uses. As he finalizes his dissertation, Ralph Kreider is the BIM Program Manager for MBP in Columbia, MD. At MBP, Ralph. Kreider is responsible for providing leadership and oversight of the integration of BIM into new and existing service offerings.