BUILDING INFORMATION MODELING (BIM) - TO PREPARE CURRENT CONSTRUCTION MANAGEMENT STUDENTS FOR TOMORROW'S CONSTRUCTION CAREERS

by

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I would like to dedicate this to my parents- Allan and Euleen Cory.

Immediate and extended family members also

Without them, I could not have gotten to where I am today!

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I would first like to thank my mother and father, Allan and Euleen Cory. They raised me to be inquisitive and to constantly ask what, why and how. I received so much encouragement from them to always to do the best I could. I would not be the man I am without them--- I owe them everything!

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I started off teaching a single class to help myself become a better public speaker, but ended up enjoying, helping, and watching students learn graphics they would use in their professional careers.

It is because of those past, current, and future students I do what I do!

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ABSTRACT

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Building Information Modeling, or BIM, is a process that is quickly changing the way Architectural, Engineering, and Construction companies manage construction projects. Being a company specific process, only parts of the process have been accepted as a standardized method across every company. Those components that are not standardized have become proprietary to each specific company. The goal of the research is to provide a rich and complete description of the use of BIM across multiple Architectural, Engineering and Construction (AEC) companies in order to inform and integrate BIM into construction graphics and management curricula in higher education. The literature review generated a thorough understanding of BIM standards currently identified. The methodology, a comparison of BIM theory to industrial practices, provided a broader picture of all aspects of BIM being utilized in current AEC companies. The results identified a comparison of all aspects of BIM to current AEC practices and paints a well-defined picture of what is being accomplished with BIM within company construction processes across AEC companies that are classified into several categories. BIM practices within each company indicate similarities and differences that give a rich BIM description across the entire AEC industry. The results suggest a high usage of BIM across more areas than just construction of the building branching out to all areas within a set of construction documents for project management.

CHAPTER 1. INTRODUCTION

This chapter provides an overview to my research study. The chapter establishes the significance of the problem within the canopy of construction management processes in the field as well as within the curricula in higher education. Important to the problem is laying the foundation and groundwork related to the definition of scope through purpose, research questions, assumptions, limitations and delimitations. Finally, the chapter concludes with a brief overview of the research project.

Background

I was a carpenter for 25 years when I first started teaching. By the time I started teaching, I had experienced everything possible about residential construction, or building houses for single-family living. I started cleaning around the jobsite and sweeping up sawdust at the end of the day for the houses built. I was in elementary school when I started helping my dad over the summers on construction sites. By the time I entered high school, I had moved up to be a reliable carpenter and had built over 2 dozen houses. I started out framing and then moved into exterior façade and eventually into finish carpentry where I excelled at putting on doors and hanging cabinets. I started getting into commercial construction or structures for public interaction like restaurants and stores as well as corporate headquarters and even university buildings later in my carpentry career. Commercial construction was a bit different from residential construction, but nothing that was not easily picked up. I then moved into a project manager's position where I dealt with others building the structure and I kept track of all material and schedules for project completion. I started teaching when I was 32 years of age when a former professor I had while in college called me up to help teach a lab for one of his classes. It was during this phase of my life when I actually witnessed firsthand how important the 2D drawings used to build structures from and construction management process were to the success of the construction project. I always thought there should/could be a better way to build from than the traditional 2D drawings used for hundreds of years.

When I entered into a teaching career, I was interested in creating a 3D computer model for the architecture, engineering and construction (AEC) to dispense necessary information to clientele needing specific information to help construct the building or project. Around my fifth year teaching, 3D computer modeling for the AEC industry became a reality. Now that I am in my eighteenth year, I am curious if what we are teaching is relevant to what is used currently in the AEC industry. Watching my colleagues around the world and locally as well as reviewing mountains of literature written on building information modeling as it relates to construction education, the approaches and methods for both the AEC industry and education are sometimes disconnected. Upon review of that literature and my teaching methods, it became clear that building information modeling (BIM) for the construction manager is becoming more prevalent in industry and less integrated into higher education.

Having a constant desire to help my students and a life-long learning attitude, I set out to learn as much as possible about creating 3D computer models and construction management curricula. From this personal experiences and research, I needed to formulate a qualitative research proposal that would contribute to the abundance of research that began decades ago when construction managers desired a better means of communication to help facilitate better construction techniques and procedures.

Significance

Many practitioners and researchers have acknowledged the limitations of current approaches to managing the information and knowledge relating to and arising from a construction project (Choi & Ibbs, 1995). According to Eastman et al. (2011, p. 2), “The AEC [architecture, engineering, and construction] facility delivery process remains fragmented and depends on paper-based modes of communication. Errors and omissions in paper documents often cause unanticipated field costs, delays, and eventual lawsuits between the various parties in a project team. These problems cause friction, financial expense, and delays.”

Rezgui and Miles (2011) identify the key reasons for the limitations related to such projects:

- Much construction knowledge, of necessity, resides in the minds of the individuals working within the domain.

- The intent behind decisions is often not recorded or documented. It requires complex processes to track and record the thousands of ad hoc messages, phone calls, memos, and conversations that comprise much project-related information.
- People responsible for collecting and archiving project data may not necessarily understand the specific needs of the actors who will use it, such as those involved in the maintenance of the building(s).
- The data is usually not managed while it is created but is instead captured and archived at the end of the construction stage. People who have knowledge about the project are likely to have left for another project by this time – their input is not captured.
- Lessons learned are not well organized and are buried in details. It is difficult to compile and disseminate useful knowledge to other projects.
- Many companies maintain historical reports of their projects. Since people always move from one company to another, it is difficult to reach the original report authors who understand the hidden meaning of historical project data. This historical data should include a rich representation of data context, so that it can be used with minimum (or no) consultation.
- New approaches to the management of knowledge within and between firms imply major changes in individual roles and organizational processes. While potential gains are desired, the necessary changes are resisted.

According to the Rezgui (2001, p. 242) "the lack of integration across partners is a major issue affecting the performance of the UK construction industry, and puts forward the use of IT to facilitate the sharing of information and knowledge as a major factor in securing improved performance in the future." (as cited in Latham, 1994) Azhar (2011) writes, "The architecture, engineering, and construction (AEC) industry has long sought techniques to decrease project cost, increase productivity and quality, and reduce project delivery time" (p. 241). All the factors listed above, in combination with the pace and progress of advanced technology, new materials and methods of construction, technological innovations, and information globalization, will inevitably force AEC businesses to adapt to new challenges.

It is only recently that a new approach of construction management has been introduced. Building Information Modeling (BIM) is one of the most promising developments in the architecture, engineering, and construction industries (Eastman et al., 2008). According to Azhar (2011), "With BIM technology, an accurate virtual model of a building is digitally constructed. This model, known as a building information model, can be used for planning, design, construction, and operation of the facility" (p. 241). Smith (2007) states:

> The concept of Building Information Modeling is to build a building virtually before the actual construction process to identify, analyze and solve potential problems and conflicts that can arise during construction as well as through the life cycle of the structure. BIM enables architects, engineers, designers, and construction managers to create a virtually realistic accurately detailed three-dimensional model of the building that takes the speculation out of design intent and construction process from the initial design stage throughout the construction process, and even into facility management. (p. 12)

Dealing with individual trades and people utilizing BIM, Smith (2007) defined BIM more specifically as "collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" (p. 12). Depending on the source, definitions and utilizations of the BIM process can vary dramatically.

Given these circumstances, a construction management (CM) professional must be capable of creating, editing, and managing a variety of information assets. Due to the ever-changing role of a construction manager in AEC, curricula in CM education must evolve. Determining how the BIM process is conducted in an industry setting would benefit virtually every CM curriculum by educating students on current management processes in industry. The purpose of the research is to provide a complete and thorough description of BIM usage within AEC companies, which could determine and help integrate BIM practices into future CM curricula.

The architecture, engineering, and construction (AEC) industry has evolved over centuries using trial and error in the methods and means of design and construction. Currently, the AEC industry is facing enormous technological and institutional transformations with their resultant difficulties and challenges. The industry is embracing new modes of information, sharing and adopting emerging and fast-growing concepts such as building information modeling (BIM), sustainability, collaboration, and related technologies (Becerik-Gerber, Gerber, & Ku, 2011). Most complex AEC projects involve multidisciplinary collaboration and the exchange of large building data sets (Singh, Gu, & Wang, 2011). These large data sets can include, but are not limited to, verbal, visual, written, and digital data. The traditional means of communication among the participants in the design-construct-own process is a combination of written specifications with symbolic diagrams contained on 2D drawings. Although there are some similarities in the symbolism used on the 2D drawings, there are substantial variations among industries, among countries, among regions within a country, among companies within a region, and among individuals within a company (Luth, 2011). The traditional information for a building is a package of such drawings on hundreds of pages of paper, which represent thousands, if not tens of thousands of parts, all of which seamlessly fit together to safely accommodate the inhabitants—whether on a small residential scale or a larger commercial one. This fundamental characteristic of an industry in which effective communication is the single most important contributor to success is the Achilles heel of the industry (Luth, 2011).

Construction projects do not always go together seamlessly. When those projects fail or lag behind in production, poor performance and inefficiencies are often caused by problems in communication, exacerbated by the traditionally fragmented nature of the construction industry. (Isikdag & Underwood, 2010). “Traditionally, the inter-disciplinary collaboration in the Architecture, Engineering, and Construction (AEC) industries has revolved around the exchange of 2D drawings and documents. Even though the separate design disciplines have been using 3D models and applications for visualization and design development, the collaboration practices have remained more or less 2D-based until recently” (Singh, Gu, & Wang, 2011, p. 134). Current and evolved methods of construction building and documentation that utilize 3D modeling for transfer of information are rapidly taking over the AEC industry. BIM is seen to offer solutions to many of the inefficiencies and systemic failures inherent in construction (Eastman et al., 2008). Another definition of BIM is more aligned with construction management: BIM is a set of interacting policies, processes, and technologies generating a “methodology to manage the essential building design and project data in digital format throughout the building's life-cycle” (Penttilä, 2006 p.

403). There are several definitions for both CM and BIM. The evolution of traditional construction management processes and the integration of Building Information Modeling has barely been researched.

The phenomenon of construction management processes using the skillsets of professionals whose experiences have developed in the AEC industries over time with current changes of technologies and processes like BIM can contribute to what it means within the AEC industry to develop lifelong learning skills. The use of BIM within those CM competencies and practices deepens the understanding of how current processes are changing what a construction manager does to control construction projects.

Statement of Purpose

The purpose of this study was first to identify, analyze, and compare how new technologies and processes such as BIM within the AEC industry influence daily activities from a construction manager's perspective, and then to report linkages and disconnects between real-world knowledge and what is being taught to current CM students with a goal of understanding all the aspects, components, and intricacies of BIM within the AEC industry. The ever-changing role of the construction manager in AEC creates the need to review and evolve higher-educational CM curricula into a multidisciplinary degree that includes construction methods and materials, project management, 3D spatial visualization, and, in some cases, computer programming, which would create a renaissance person capable of handling current industry needs.

Research Question

The questions central to this research:

1. How has Building Information Modeling influenced a construction manager's current position?
2. How has Building Information Modeling (BIM) influenced a construction manager's need for continuing education within the industry?

Assumptions

The following assumptions were inherent to the pursuit of this research:

1. There was a need to investigate building information modeling from the AEC industry professional's perspective to gain insight into the essence how BIM is utilized in industry.
2. Participants responded accurately and honestly during the interview process concerning their own experiences, knowledge and backgrounds within their companies BIM procedures.
3. Participants had the freedom to acknowledge they could not answer a question due to lack of knowledge or experience or legal obligations or if they were not cognisant of a particular component or feature of BIM utilized within their companies BIM process.
4. Participants were allowed to get release time from work to participate in 30-45 minute interviews.
5. The number of participants chosen for this study was sufficient for a case study examination of BIM process for their company.
6. Participants were sufficiently able to verbalize their knowledge and experience in the form of answers to the interview questions.

Limitations

The following have been identified as limitations for this study:

1. This study was limited by the number of participants and amount of cooperation of the participants and their abilities.
2. This study was limited by the amount of cooperation of the Computer Graphics Technology department administration in providing time for the researcher to complete the study.
3. This study was limited by researcher bias. After 50 years in construction and consulting, and 20 years of teaching and integrating BIM into curricula, I risked contaminating my study data with information from my own experiences.
4. This study was limited by time constraints for interviews. Interviews were

conducted during limited times to interfere as little as possible with company work functioning.

5. This study was limited by time constraints for site visits. Site interviews were conducted during limited times to interfere as little as possible with company functioning. Thus, participants contributed a portion of their daily activities dealing with BIM and construction management.

Definitions and Key Terms

Aggregation: the action of bringing together more than one model into a common environment (as defined by Bond Bryan Architects).

Analysis: the action or process of analyzing a model for various purposes, or a table or statement of the results of analysis of a model (based on *The Chambers English Dictionary*).

Architectural Model: a model made up solely of architectural building components (as defined by Bond Bryan Architects).

Archive: a component of the common data environment (as defined by PAS 1192-2:2013).

As-built: the record drawings and documentation defining deviation to the designed information occurring during construction at the end of the project (as defined by PAS 1192-2:2013).

As-constructed: the defect and deviation to the designed model occurring during construction. The "as-constructed" model and its appended documentation are continually updated through re-measurement as construction progresses (as defined by PAS 1192-2:2013).

Assembly: a composition or collection of components and/or modelled elements arranged to define part or all of a building, model, structure, or site (as defined by PAS 1192-2:2013).

Asset Information Management: the discipline of managing asset-related organizational data and information to a sufficient quality to support organizational objectives and outcomes (as defined by PAS 1192-3:2014).

Asset Information Model (AIM): a maintained information model used to manage, maintain, and operate the asset (as defined by PAS 1192-2:2013), OR data and information that relate to assets to a level required to support an organization's asset management system (as defined by PAS 1192-3:2014).

Asset Information Plan: the specific information plan for the Information Model used to manage, maintain and operate the asset (as defined by the CIC Outline Scope of Services for the Role of Information Management).

Asset Information Requirements (AIR): data and information requirements of the organization in relation to the asset(s) it is responsible for (as defined by PAS 1192-3:2014).

Attribute: a piece of data forming a partial description of an object or entity (as defined by PAS 1192-2:2013).

Building Information Model: a digital representation of the physical and functional characteristics of the project (as defined by AIA Document E202 - 2008 - 1.2.1).

Building Information Modelling: the process of designing, constructing, or operating a building or infrastructure asset using electronic object-oriented information (as defined by PAS 1192-2:2013) Building Information Modeling is the creation and use of coordinated, internally consistent, computable information about a building project in design and construction. In a BIM application, the graphics are derived from the information and are not the original information itself like in general CAD applications.

Building Information Modelling Execution Plan (BEP): a plan prepared by the suppliers to explain how the information modelling aspects of a project will be carried out (as defined by PAS 1192-2:2013).

Clash Detection: detecting possible collisions between elements in a building information model which would not otherwise be desired or buildable on site (as defined by Bond Bryan Architects).

Clash Rendition (CR): rendition of the native format model file to be used specifically for spatial coordination processes. To achieve clash avoidance or to be used for clash detection (as defined by PAS 1192-2:2013).

Classification: a systematic arrangement of headings and sub-headings for aspects of construction work including the nature of assets, construction elements, systems, and products (as defined by PAS 1192-2:2013).

Client: the individual or organization commissioning a built asset (as defined by PAS 1192-2:2013).

Code: a sequence of characters, often a mnemonic, having defined meaning when interpreted in the context of the field in which it is entered, used to concisely convey meta-data (as defined by BS1192:2007- 3.1).

Component: an individual building element that can be reused. Examples include doors, stair cores, furniture or internal room layouts, facade panels, etc. Components are typically inserted and moved/rotated into the required position (as defined by AEC (UK) BIM Standard v2, p. 7), OR a synonym for "occurrence" (as defined by PAS 1192-2:2013).

Component Grade: the level of detail that the individual building element has been modelled to (as defined by Bond Bryan Architects).

Computer Aided Design (CAD): is a geometric / symbol based computer drawing system that replicates hand drawing techniques (as defined by the Department of Veterans Affairs, USA).

Configuration: interrelated functional and physical characteristics of a product defined in product configuration information (as defined by PAS 1192-2:2013).

Consultant Model: a model that utilizes data imported from a design model or, if none, from a designer's construction documents; and contains the equivalent of shop drawings and other information useful to construction (as defined by Consensus DOCS 301 BIM Addendum, US).

Construction Information: information used to support one or more construction processes (as defined by ISO 12006-2:2001 - 2.20).

Construction Model: a model created to show how the building will be built in sequence. This type of model will often include cranes, scaffolding and other elements required to construct the final building (as defined by Bond Bryan Architects).

Construction Process: the process that transforms construction resources into construction results (as defined by ISO 12006-2:2001 - 2.11)

Construction Result: a construction object which is formed or changed in state as the result of one or more construction processes utilizing one or more construction resources (as defined by ISO 12006-2:2001 - 2.3).

Construction Sequencing: the process of adding a time line to a model. This can be incorporated into both design or construction models (as defined by Balfour Beatty Construction).

Contribution: the expression, design, data or information that a project participant creates or prepares and incorporates, distributes, transmits, communicates or otherwise shares with other project participant(s) for use in or in connection with a model for the project (based on definition by Consensus DOCS 301 BIM Addendum, US).

Conventional Cartesian Axis: a geometric convention using positive coordinates (X,Y,Z) ordered as (East, North, upwards), so that conventional plans use X,Y and Z is upwards (as defined by BS1192:2007- 3.3).

Co-ordinate: to combine or integrate harmoniously different elements within the model (based on *The Chambers English Dictionary*).

Data: information stored but not yet interpreted or analyzed (as defined by PAS 1192-2:2013), OR observations that in context yield information (as defined by PAS 1192-3:2014 / Skyrme & Amidon, Knowledge management, Institute of Management, Corby, 1997).

Data Capture: putting information into a form that can be fed directly into a computer (based on *The Chambers English Dictionary*).

Deliverables: the specific requirements for the project which may be generated directly from the model or from other sources. They may include the building information model, drawings, fly-through, images, data, schedules or reports (as defined by Bond Bryan Architects).

Design Model: a model of those aspects of the project that have reached the stage of completion that would customarily be expressed by an Architect/Engineer in two-dimensional construction documents. This shall not include models such as analytical evaluations, preliminary designs, studies, or renderings. A model prepared by an Architect/Engineer that has not reached the stage of completion specified is referred to as a model (as defined by Consensus DOCS 301 BIM Addendum, US).

Design Team: the architect(s), engineer(s) and technology specialists responsible for the conceptual design aspects of a building, structure or facility and their development into models, drawings, specifications and instructions required for construction and associated processes. The design team is part of the project team (based on the RICS definition).

Document: a container for persistent information that can be managed and interchanged as a unit (as defined by BS1192:2007 - 3.4), OR information for the use in the briefing, design, construction, operation, maintenance or decommissioning of a construction project, including but not limited to correspondence, drawings, schedules, specifications, calculations, spreadsheets (as defined by PAS 1192-2:2013).

Drawing: a document used to present graphic information (as defined by BS1192:2007 - 3.5), OR a static, printed, graphical representation of part or all of a project or asset (as defined by PAS 1192-2:2013).

Electronic Document Management System (EDMS): a system for storing, retrieving, sharing and otherwise managing electronic documents (as defined by PAS 1192-2:2013).

Element: a construction entity part which, in itself or in combination with other such parts, fulfils a predominating function of the construction entity (as defined by ISO 12006-2:2001 - 2.7).

Elevations: orthographic views taken directly from the model (as defined by Bond Bryan

Facility Management: management during the operational phase of a facility or building's life cycle, which normally extends over many decades. It represents a continuous process of service provision to support the client's core business and one where improvement is sought on a continuous basis (definition taken from Wikipedia).

Fabrication Model: a Building Information Model, which incorporates components that are suitable for fabrication. It is a development of the Full Design Model to include more detail (as defined by Bond Bryan Architects).

Federated Model: a model consisting of linked but distinct component models, drawings derived from the models, texts, and other data sources that do not lose their identity or integrity by being so linked, so that a change to one component model in a federated model does not create a change in another component model in that federated model (as defined by Consensus DOCS 301 BIM Addendum, US), OR a model consisting of connected but distinct individual models (CIC BIM Protocol, 1st ed., 2013).

File Extension: an added piece of information to the end of a file name to explain the format of the file. This is often in the form of .abc. Typically, file extensions are 3 or 4 characters long (as defined by Bond Bryan Architects).

Full Design Model: a model consisting of coordinated structural, architectural, MEP and other design models (based on definition by Consensus DOCS 301 BIM Addendum, US).

Graphical Data: data conveyed using shape and arrangement in space (as defined by PAS 1192-2:2013).

Graphical File: a file format designed specifically for representing graphical images (as defined by PAS 1192-2:2013).

Information: the representation of data in a formal manner suitable for communication, interpretation or processing by human beings or computer applications (as defined by PAS 1192-2:2013), OR data arranged and processed into meaningful patterns, put into context (as defined by DRAFT PAS 1192-3:2014 / Skyrme & Amidon, Knowledge management, Institute of Management, Corby, 1997).

Information Exchange: the structured collection of information at one of a number of pre-defined stages of a project with defined format and fidelity (as defined by PAS 1192-2:2013).

Information Management: measures that protect and defend information and information systems with respect to their availability, integrity, authentication, confidentiality, and nonrepudiation. These measures include providing for restoration of information systems by incorporating protection, detection, and reaction capabilities (as defined by Consensus DOCS 301 BIM Addendum, US), OR tasks and procedures applied to inputting, processing and generation activities to ensure accuracy and integrity of information (as defined by PAS 1192-2:2013).

Information Model: a model comprising documentation, non-graphical information and graphical information (as defined by PAS 1192-2:2013), OR all documentation, non-graphical information which the Project Team is required to provide into the Information Model by the Scope of Services for the Project Team and which is provided for the purpose of delivering Project Outputs (as defined by the CIC Outline Scope of Services for the Role of Information Management).

Information Modelling: the use of data to provide information through better understanding, by applying logic or mathematical functions to derive new data (as defined by PAS 1192-2:2013).

Instance: an occurrence of an entity at a particular location and orientation within a model (as defined by BS1192:2007 - 3.7).

Interoperability: the ability of two or more systems or components to exchange information and to then use the information that has been exchanged (as defined by IEEE on Wikipedia).

Integrated Project Delivery (IPD): a collaborative alliance of people, systems, business structures and practices into a process that harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction (as defined by AIA on Wikipedia).

Laser Scanning: controlled steering of laser beams followed by a distance measurement at every pointing direction used to rapidly capture shapes of objects, structures, buildings and landscapes (based on definition taken from Wikipedia).

Layer: a container comprising selected entities, typically used to group for purposes of selective display, printing and management operations (as defined by BS1192:2007 - 3.8), OR an attribute given to entities with CAD files enabling their visibility to be controlled. Further values may be assigned to the attribute to enable control whether it can be edited or deleted (as defined by PAS 1192-2:2013).

Lean: production focused on delivering value for the employer or client and eliminating all non-value-adding activities using an efficient workflow (as defined by PAS 1192-2:2013).

Lean Principles: understanding value from a client's perspective, identifying the value stream, and establishing a balanced flow of work in which the demand for product is pulled from the next customer, with a constant drive for continuous improvement and perfection (based on *Lean Thinking*, Womack & Jones, 2003 edition)

Level of Detail: the level of detail required for a Model (CIC BIM Protocol, 1st ed., 2013)

Lonely BIM: a non-collaborative 3D model produced by a single designer (phrase coined by Robert Klaschka of Studio Klaschka; definition by Bond Bryan Architects).

Main Contractor: the contractor responsible for the total construction and completion process of the building project. The term prime contractor is often used in central civil government and the defense sector to mean main contractor (as defined by the RICS).

Marked-up Drawing: a paper or electronic drawing that has been marked up with comments from other disciplines or the client (as defined by PAS 1192-2:2013).

Material: information in any electronic medium prepared by or on behalf of the Project Team Member comprised in: (a) the Specified Models; and (b) the Federated Models, to the extent that these comprise Specified Models or to the extent that the Project Team Member owns any additional rights in any Federated Model, excluding any material forming part thereof which is provided to the Project Team Member by or on behalf of the Employer (CIC BIM Protocol, 1st ed., 2013).

MEP Model: a model made up solely of mechanical, electrical and plumbing components (note: other information may exist within this model that is referenced from others but this is only used for reference purposes) (as defined by Bond Bryan Architects).

Model: a collection of containers organized to represent the physical parts of objects, for example a building or a mechanical device (as defined by BS1192:2007 - 3.10), OR a three-dimensional representation in electronic format of building elements representing solid objects with true-to-scale spatial relationships and dimensions. A model may include additional information or data (as defined by Consensus DOCS 301 BIM Addendum, US), OR a digital representation of part of the physical and/or functional characteristics of the Project (CIC BIM Protocol, 1st ed., 2013).

Model Element: a portion of the Building Information Model representing a component, system or assembly within a building or building site (as defined by AIA Document E202 - 2008 - 1.2.3).

Model File: a native, proprietary format, CAD file that can be a 2D or 3D model (as defined by PAS 1192-2:2013).

Model User: any individual or entity authorized to the use the model on the project, such as for analysis, estimating or scheduling (as defined by AIA Document E202 - 2008 - 1.2.5).

OpenBIM: a unique approach to collaborative design and realization of buildings allowing project members to participate regardless of the tools they use (as defined by Graphisoft).

Operator: an organization that uses an asset to create value but does not own the asset (as defined by PAS 1192-3:2014).

Origin: a setting out point for a project or program using co-ordinate geometry or related to the OS or geospatial reference (as defined by PAS 1192-2:2013).

Other Project Team Member: any person having responsibilities in relation to the production, delivery and/or use of Models and appointed by the Employer in relation to the Project, excluding the Project Team Member (CIC BIM Protocol, 1st ed., 2013).

Output File (see also **Views**): a generated rendition of graphical or non-graphical information (a plan, section, elevation, schedule, table or other view of a project) (as defined by AEC (UK) BIM Standard, v1, p. 7).

Owner: an organization that owns an asset and uses the asset either directly or indirectly to create value (as defined by PAS 1192-3:2014).

Point Cloud: a set of vertices in a three-dimensional coordinate system. These vertices are usually defined by X, Y and Z coordinates, and typically are intended to be representative of the external surface of an object. Point clouds are most often created by 3D scanners. These devices measure in an automatic way a large number of points on the surface of an object, and often output a point cloud as a data file. The point cloud represents the set of points that the device has measured (definition taken from Wikipedia).

Project BIM Protocol: the Project Specific BIM Protocol setting out the obligations of the principal members of the Project Team in respect of the use of BIM on the Project (as defined by the CIC Outline Scope of Services for the Role of Information Management).

Project Delivery Team: either groups of organizations or individuals contracted directly or indirectly to deliver services or products to the project (as defined by PAS 1192-2:2013).

Project Information Model (PIM): the information model developed during the design and construction phase of a project, consisting of documentation, non-graphical information and graphical information defining the delivered project (as defined by PAS 1192-2:2013), OR the information model developed during the design and construction phase of a project [PAS 1192-2:2013] (as defined by DRAFT PAS 1192-3:2014).

Project Information Plan: the plan for the structure and management and exchange of information from the Project Team in the Information Model and the related processes and procedures (as defined by the CIC Outline Scope of Services for the Role of Information Management).

Project Team: comprising the Project Team Members (as defined by the CIC Outline Scope of Services for the Role of Information Management).

Project Team Member: the person appointed by the Employer pursuant to the Agreement (CIC BIM Protocol, 1st ed., 2013), OR any person having responsibilities in relation to the production, delivery and/or use of the content of the Information Model and appointed by the Employer in relation to the Project (as defined by the CIC Outline Scope of Services for the Role of Information Management).

Published: information refers to documents and other data from Shared information. OR a component of the CDE for drawing renditions that have been approved as suitable for a specific purpose—for example, suitable for construction (as defined by PAS 1192-2:2013).

Record Model: the final version of the digital model used by the construction team to construct the building (as defined by Bond Bryan Architects).

Reference File: a CAD model file associated or linked with another CAD model file. Also referred to as an "X-ref" (as defined by PAS 1192-2:2013).

Requirements: the documented expectations of facility owners/commissioners for sharable structured information. These are also referred to as the Employers Information Requirements (EIR) (alternatively, the Clients Information Requirements) (as defined by PAS 1192-2:2013).

Revision: used to identify revisions of documents, drawing and model files (as defined by PAS 1192-2:2013).

Shared: information that has been checked and approved and is made available across the project team, such as information for data exchange between BIM software, like gbXML, CIS/2 and IFC files (reference BS1192:2007) (as defined by AEC (UK) BIM Standard v2, p. 8), OR component of the CDE. The shared section of the CDE is where information can be made available to others in a "safe" environment. The early release of information assists in the rapid development of the design solution. To allow this to be achieved, the concept of information "status/suitability" has been adopted (as defined by PAS 1192-2:2013).

Space: three-dimensional, material construction result contained within, or otherwise associated with, a building or other construction entity (as defined by ISO 12006-2:2001 - 2.10).

Specified Models: the model or models which the project team member is to produce and deliver as specified in the model production and delivery table (as defined by CIC BIM Protocol, 1st ed., 2013).

Standard Method and Procedure: a set of standard methods and procedures covering the way information is named, expressed, and referenced (as defined by PAS 1192-2:2013).

Status: the "suitability" of information in a model, drawing, or document. Not to be confused with the status in architectural documentation as "new build," "retain," or "demolish" (as defined by PAS 1192-2:2013).

Structural Analysis: the action or process of analyzing a model from a structural point of view or a table or statement of the results of analysis of the model (based on *The Chambers English Dictionary*).

Structural Model: A model made up solely of structural components (as defined by Bond Bryan Architects).

Subcontractor: a contractor employed by the main contractor to undertake specific work within the building project; also known as specialist, works, trade, work package, and labor-only contractors (as defined by the RICS).

User: an individual using a built asset for its designed purpose (as defined by PAS 1192-2:2013).

Version: sub-indexing to revision, as used in the common data environment to show the development of information and information models—e.g., if a version is named P1.1, P1 is the revision number and the .1 is the version to that revision (as defined by PAS 1192-2:2013).

View (see also **Output File**): a generated rendition of graphical or non-graphical information, such as a plan, section, elevation, schedule, or other view of a project (as defined by AEC (UK) BIM Standard v2, p. 8).

Virtual Construction Model: the subsequent version of the project information model developed from the design intent model by the construction supplier and their supply chain (as defined by PAS 1192-2:2013).

Work In Progress (WIP): Each individual company or discipline's own work. This is information that has not been approved or verified as fit to share across the project team (reference BS1192:2007) (as defined by AEC (UK) BIM Protocol v2, pp. 7–8).

Overview of Study

While the AEC industry is going through tremendous changes in construction processes, higher education teaching lags significantly behind. Despite the existence of hundreds, if not thousands, of scholarly articles about BIM and its benefits to industry, students, and clients, how many educators really know what goes on in industry to accomplish BIM processes within a company? Without a clear understanding of BIM in a functional AEC company, no educator could cover the components necessary for students to function adequately in real-world situations. In order to educate current university construction management and graphics students for current practices within the AEC industry, an understanding of those practices in the field or industry is essential.

The first step of any research project is to define a problem, and after 20 years of teaching, I did not know what any AEC company was doing to accomplish the BIM process I claim to be an expert at. In order to transform BIM curricula, I needed to determine what is being done in terms of BIM within AEC. The first step, then, leads to helping focus current and future courses using BIM in not just virtual design and construction, but also construction management degrees.

The research started with four purposefully selected AEC companies who utilize BIM in their everyday management process of building structures or components within structures. The next step was to identify individuals within the company with five years of BIM experience for interviews about the company BIM process. A secondary component was a formal site visit of one of the company's jobsites. This allowed me to witness first-hand how BIM was interjected into everyday projects. Once the company interview and site visit were finished, follow-up emails were sent to clarify information. Once all four companies' interviews and BIM processes were analyzed, a comparative analysis of each answer for all four companies was done. This allowed me to determine similarities and differences in those company processes as compared to each other and the components and definitions of BIM.

Finally, industry changes in regard to the process of managing construction projects were compared to current construction management curricula identified by the American Council for Construction Education (ACCE), the accrediting body for all construction management education.

Given the growth of BIM within the industry, it is conceivable that BIM processes will become standard practices in all curricula for future construction professions. It is anticipated that the lived experiences of this case study of those using BIM can help future generations understand the importance of each component within BIM to their careers.

CHAPTER 2. LITERATURE REVIEW

For thousands of years, graphic representations have been one of the main forms of communication (Luzadder & Duff, 1989). From the earliest prehistoric drawings to current drafting standards, graphical illustrations are a natural means for communicating ideas, concepts or actions (Shantz, 1989). The construction industry has relied on those two dimensional (2D) drawings as the main method to construct buildings. The building industry is the largest industry in the world (Department of Commerce, 2007), with distinguishing characteristics such as highly fragmented organizations, unique projects, relatively short period of production, outdoor and unstructured working conditions, and labor-intensive activities (Becerik-Gerber & Rice, 2010). The construction management process according to Luck (1996) "is fragmented as individuals from different organizations which are geographically and temporarily dispersed are involved in the construction process" (p. 1). This disjointed effort leads to redoing work, which is commonplace amid all contractors. Similar to construction, "the architecture, engineering, and construction (AEC) industry has long sought techniques to decrease project cost, increase productivity and quality, and reduce project delivery time" (Azhar, 2011, p. 241). As in any process or method, the way the AEC industry creates 2D documentation is changing to a more efficient method. Building Information Modeling/Management (BIM) offers AEC professionals a means to accomplish aforementioned objectives (Azhar, 2011).

Concepts of Building Information Modeling can be traced back to the early 1970's when 3D solid modeling software packages began to emerge. The development of the ArchiCAD software program in 1982 in Hungary is viewed by many as the real beginning of BIM, and the development of the Revit software program in 2000 saw a real shift toward effective BIM implementation (Quirk, 2012). What exactly is BIM? Charles Eastman is a Professor in Architecture at Georgia Tech University and was the first to identify what a 3D computer model of the building could futuristically be to an AEC professional. Eastman, Teicholz, Sacks, and Liston (2008) stated that

> BIM simulates the construction project in a virtual computer environment. With BIM technology, an accurate virtual model of a building, known as a building information model, is digitally constructed. When completed, the building information model contains

precise geometry and relevant data needed to support the design, procurement, fabrication, and construction activities required to realize the building. (p.1)

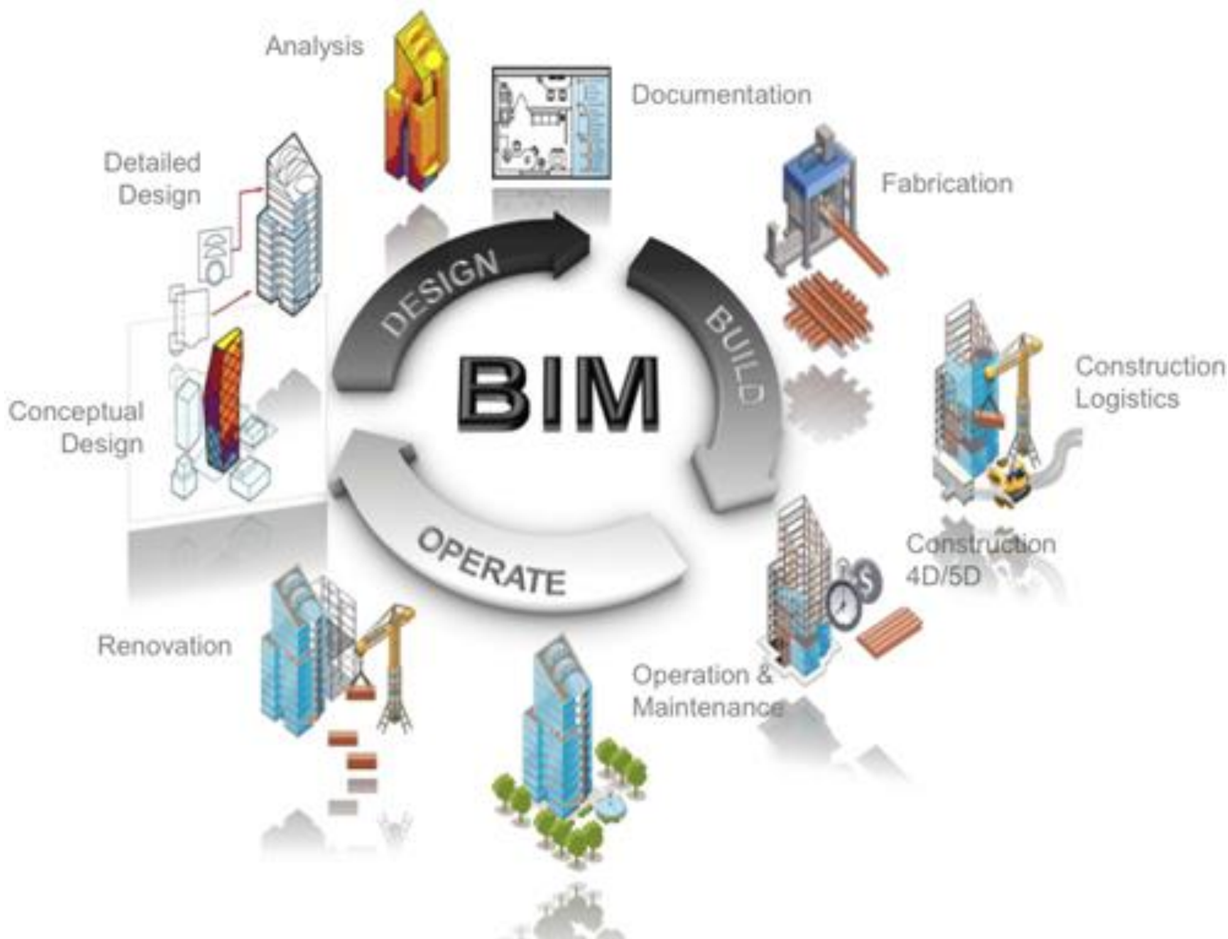

Figure 1: BIM- Autodesk defined visually. Syncronia (2012). Retrieved from http://blog.syncronia.com/en/autodesk-bim-conference-2011

"BIM has evolved into something more than just a 3D model. BIM is a process, which is composed of several components utilized in construction and management of the building, and like any process is subject to inconsistent ways to utilize that process depending on each company's needs or management style" (Cory & Jenkins, 2008, pp. 1-2). According to LaFevre (2007), "BIM isn't something you can order off the shelf like hardware or software—it is a process" (p. 14). The process does, however, include current technologies like hardware and software tools, but it is not limited to those items. According to the Autodesk website (2016),

> Building information modeling covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example manufacturers' details). BIM can be used to demonstrate the entire building life cycle,

> including the processes of construction and facility operation. Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility or group of facilities.

It is up to each AEC company to determine how BIM is implemented into their management processes. Historically, the 2D drawings communicate the design intent, but sometimes contain missing, inconsistent, or erroneous information (Cory & Jenkins, 2008). It is estimated that nearly 45% of all quality problems which occur on construction sites are due to unclear project information (Snook, 1995). Cory and Jenkins (2008) write, "Unlike the traditional 2D drawings, which are just lines and shapes on a screen, 3D objects in BIM are 'intelligent' and are backed by a database of information about their physical and functional characteristics" (p. 7). Autodesk produces AutoCAD software and purchased Revit in 2009. According to Brown (2016), "Autodesk continues to lead the BIM market today as iterations and revisions power continued improvements within the space. Autodesk sees more than $2 billion in revenue from the products it sells today and remains the market leader in the category." With the leadership in multiple software packages worldwide, Autodesk (2016) has a definition that has become a standard in the AEC industry: Building Information Modeling (BIM) is an intelligent 3D model-based process that equips architecture, engineering, and construction professionals with the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure. The official definition comes from the National Building Information Modeling Standards (NBIMS, 2017):

> Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. (p. 21)

Anyone that has ever seen, dealt, or even watched a building being built should understand the organization and management needed to build a building. Thousands of components need to be constructed in an organized fashion to culminate in the finished functional and safe building. According to Smith (2007),

> The concept of Building Information Modeling is to build a building virtually before the actual construction process to identify, analyze and solve potential problems and conflicts that can arise during construction as well as through the life cycle of the structure. The heart of Building Information Modeling is an authoritative building information model (p. 12).

With BIM, cross-functional project teams share intelligent models to better plan, design, build, and manage building and infrastructure projects (Autodesk, 2016). The traditional method of construction graphic and management education has to change, evolve and adapt to meet current spatial visualization and building information modeling construction standards. Determining how BIM is done in an industry setting and comparing it to current education curricula would benefit virtually every construction management educational program across the nation and even internationally.

Functions of BIM

The AEC industry has currently identified several functions that building information models perform in construction projects. Kreider, Messner, and Dubler (2010) identified four areas and 25 BIM uses within the areas currently implemented in the AEC industry. Their research was to identify specifically the "potential benefit of individual uses of BIM on a project along with identifying which uses are most frequently implemented on projects" (Kreider et al., 2010, p. 3).

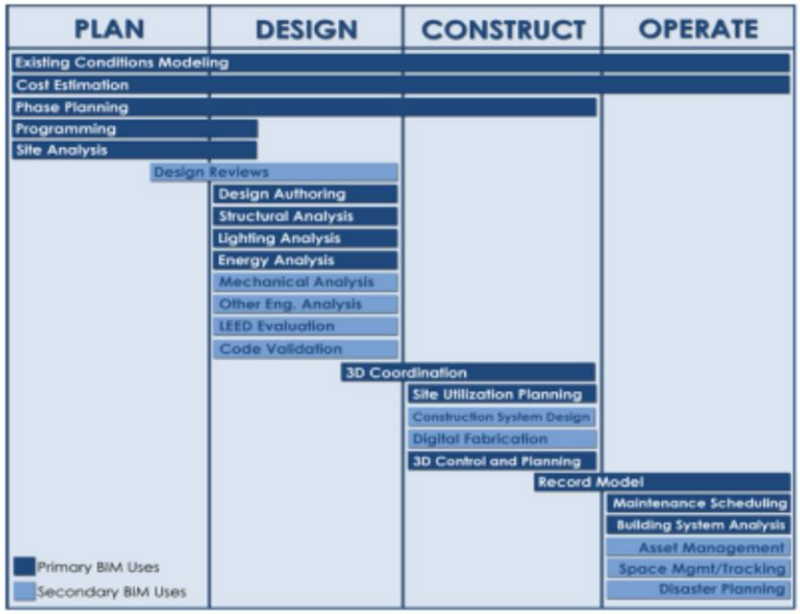

Figure 2: Four areas of BIM identified (Messner et al., 2011)

Of the four areas listed in Figure 2 by Messner (2011), there were 25 components or uses of BIM identified in the Kreider report. Figure 3, taken from Kreider (2010, p. 9), identifies the top ranked utilized BIM uses within the study in order of frequency used as well as benefit to the project.

Architects, engineers, contractors, fabricators and building product manufacturers were target focus group for the research. 3D coordination is used with 60% frequency, according to the table above. General contractors' use of BIM is 42%, fabricators' use is 40% and MEP engineers' use is 34% (SmartMarket Report, 2009) which would make sense that each of these participants would need to 3D coordinate their portion of the building with each other. Having so many possible BIM uses as defined (SmartMarket Report, 2009), it might be easier for an AEC professional to introduce very specific components of the BIM process into their company because they know exactly how the company functions and what would benefit the company most. How does higher education select which components of the entire BIM process to include in a curriculum without knowing the process AEC industry professionals utilize?

Table of BIM Use Frequency and Benefit with Rank Out of Twenty-Five Uses (Kreider et al. 2010)

BIM USE	Frequency	Rank	Benefit	Rank
	%	1 to 25	-2 to +2	1 to 25
3D Coordination	60%	1	1.60	1
Design Reviews	54%	2	1.37	2
Design Authoring	42%	3	1.03	7
Construction System Design	37%	4	1.09	6
Existing Conditions Modeling	35%	5	1.16	3
3D Control and Planning	34%	6	1.10	5
Programming	31%	7	0.97	9
Phase Planning (4D Modeling)	30%	8	1.15	4
Record Modeling	28%	9	0.89	14
Site Utilization Planning	28%	10	0.99	8
Site Analysis	28%	11	0.85	17
Structural Analysis	27%	12	0.92	13
Energy Analysis	25%	13	0.92	11
Cost Estimation	25%	14	0.92	12
Sustainability LEED Evaluation	23%	15	0.93	10
Building System Analysis	22%	16	0.86	16
Space Management / Tracking	21%	17	0.78	18
Mechanical Analysis	21%	18	0.67	21
Code Validation	19%	19	0.77	19
Lighting Analysis	17%	20	0.73	20
Other Eng. Analysis	15%	21	0.59	22
Digital Fabrication	14%	22	0.89	15
Asset Management	10%	23	0.47	23
Building Maint. Scheduling	5%	24	0.42	24
Disaster Planning	4%	25	0.26	25

Figure 3: Uses of BIM (Kreider, 2010)

Today, information in the Building Information Model is used for a variety of functions within the AEC industry. To name a few, Kreider (2010, p 5) identified and defined:

- **Design Visualization**: 3D view helps clarify the design intent.
- **Scope Clarification**: Design can be dissected for each subcontractor to reveal his or her portion of the work.
- **3D Collision Detection/Avoidance**: Digital plans can be merged to illustrate areas where installed materials interfere spatially.
- **Construction Sequencing Planning/Phasing Plans/Logistics**: The element of "time" can be added to the model to create a visual construction sequence plans and aid in the development of Site Logistics plans.
- **Options Analysis:** Different options of materials for "what-if" scenarios. Evaluation of aesthetics, functionality, performance…etc.
- **Walk and Fly-through**: BIM operator can take a virtual walk (or flight) through the 3D model.

- **Marketing Presentations**: Imagine the impact when you explain the 3D model (showing the sequence of construction during different stages, walk-throughs/fly-through…etc.) to a potential client for a project yet to be built!

While several contractors utilize BIM in the four areas of plan, design, construct and operate; others consider BIM by what is called the D's of construction documentation.

D's of BIM

BIM started out as utilization of the 3D model to extract 2D documentation in hopes of better management of information of the construction of the structure. It soon evolved into what is called the D's of BIM.

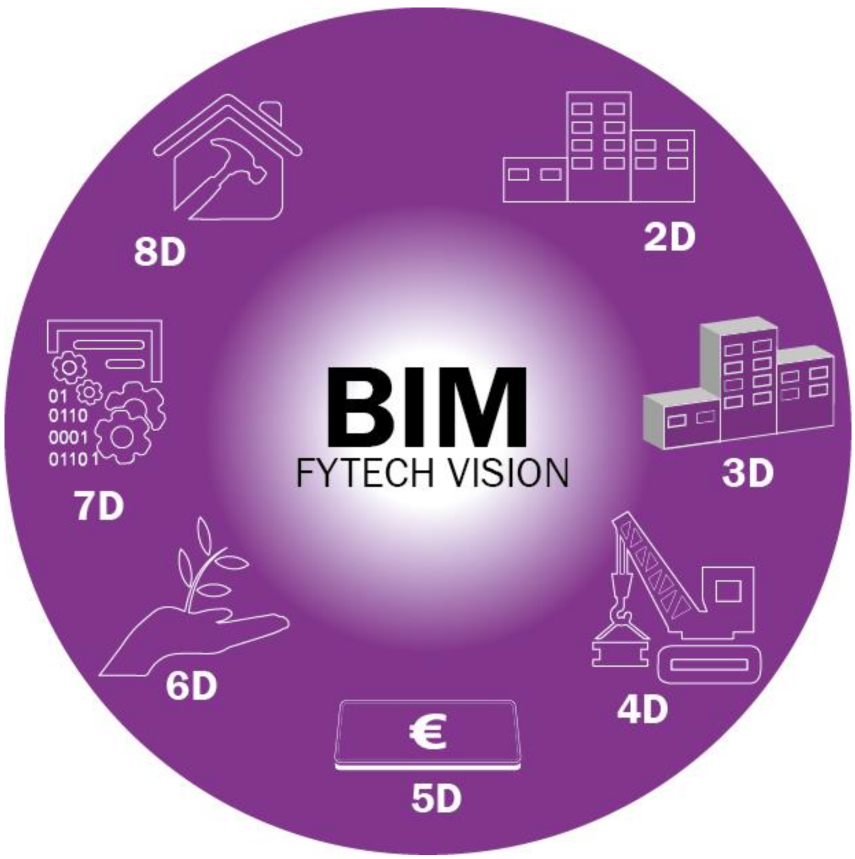

Figure 4: The D's of BIM. FYTECH (2012). Retrieved from http://fytech.fr/modelisation

The exact meaning of the D's is a topic of discussion among AEC professionals and scholars. While some professionals and scholars are fed up with the extreme aspects of the countless extension of the D's in BIM, others embrace them and utilize them regularly in the company management process.

2D

AEC professionals identify BIM in terms of what it is used within or extracted from the model as commonly stated- the D's of BIM. It starts with 2D which is a byproduct of the 3D model. 2D documentation has been utilized for centuries and still is used to construct. Graphical standards for 2D documents came into effect around the beginning of the 20th century (Schantz, 1989). The written language through which the design ideas of engineers and architects are transmitted to mechanics and builders is a graphical code called "multiview orthographic" (Belofsky, 1991). Standardized multiview drawing became common industrial practice, which had its benefits and drawbacks according to Luzadder (1977, p. 70).

The benefits to standardizing drawings in 2D Multiview include:

- Easy to construct
- Only concerned with 2 dimensions in individual views
- Gives true size and shape for features
- Most accurate and descriptive type of engineering graphic
- Parts were made exactly the same
- Parts could be used in any one of a thousand objects it was built for—not just one item!

Some of the disadvantages include:

- Difficult to visualize
- Required interpretation
- Limited usage

Multiview drawings were commonplace in the industrial world, but it usually took several years of training for individuals to understand and interpret the new visual language (Cory, 2001). With multiview drawings comprising a majority of drawings used in the manufacturing and construction industry, over 100 years of procedures and processes to build objects could not be changed overnight. Established procedures and productivity of workers were the driving forces for resistance to change from traditional 2D working drawings to utilizing 3D models. (Cory, 2001). The manufacturing industry was the first to take the leap into model utilization, but the AEC industry has shown promise over the last couple of years with companies embracing technology, utilizing the 3D model to generate all construction working documentation for projects in Figures 5 and 6 below.

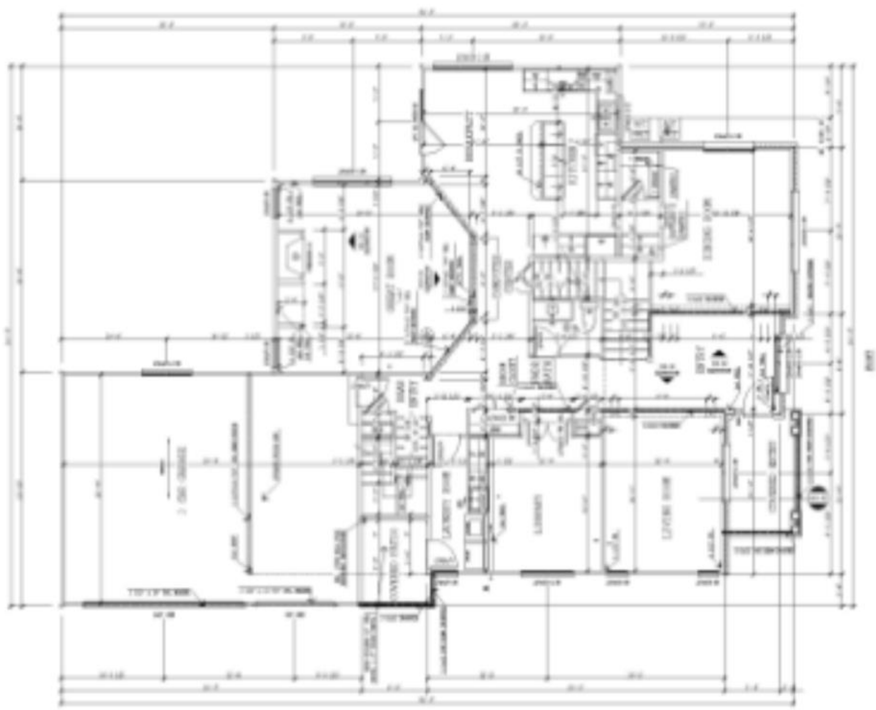

Figure 5: 2D floor plan from 3D model

Figure 6: 2D elevations extracted from 3D model

3D

Figure 7: 3D information model of building (Cory & Jenkins, 2008)

Even though 2D construction documents are still used to build every AEC project, the 3D model can extract those same documents with less human error (see Figure 7). The collaboration of creating the model allows for checks and balances between designers of different trades. The implementation and utilization of 3D models, especially architectural, had become significantly easier and more efficient to construct (Giambruno, 2002). It has only been recently that software companies are creating the 3D Model in the form an Architect or Engineer understands- the traditional from traditional 2D drafting (Cory, 2001). This one statement is the driving force behind the utilization of 3D computer models in AEC projects.

It was originally financially impossible to utilize models in construction projects due to the fact that individuals were not educated in model creation, and the software was not efficient or easy to understand. Software packages to date were drawing Architectural documentation by creating the documents in a traditional 2D fashion but adding the height to create a 3D model. This in itself was somewhat helpful to allow better visualization. Other packages take the model a step further- designers can “construct” the entire building inside the computer by selecting specific wall systems, floor systems, door and window types with all included materials respectively. You design and build the structure the same way you build the building in the real world. Building the structure inside the computer can have huge benefits as well as tremendous complications for the user. When working correctly, 3D modeling software can efficiently generate all the working drawings for an entire structure. Griffis, Hogan, and Li (1995, p. 997) defined several benefits for utilizing 3D modeling within AEC:

Most common usage:

- Checking clearances and access
- Visualizing details from non-standard viewpoints
- Using the model as a reference during project meetings
- Performing constructability reviews

Greatest perceived impediments to the use of 3D in construction:

- Undetermined economic impacts
- Inertia
- Lack of trained people
- Cost (perceived as an impediment by non-users)

Perceived benefits by users:

- Reducing interference problems
- Assisting in visualization
- Reducing rework
- Improving engineering accuracy
- Improving jobsite communication

As more and more professionals are educated and utilize 3D modeling for construction documentation, the model in construction inevitably should and will become the driving force in the design and construction of all AEC projects. According to the SmartMarket report (2009, p. 18), BIM users and non-users agree strongly is the future importance of BIM to their success. Users that rate BIM high or very high doubled from the current level of 39% to 74% in five years. And even though no non-users attribute high or very high importance to BIM today, half of them agree that it will reach that level of criticality within five years. More and more industrial professionals are starting to realize the benefits within construction documentation, but while others are just implementing 3D models, other more progressive firms are experimenting with and using the model in advanced processes like 4D BIM in their construction management of projects.

4D

According to Rapp and Benhart (2014), "A construction project is a group of individual work activities that are started and completed in a specified sequence in order to finish the project. The construction schedule communicates this sequence by setting the start and finish dates for each of the individual actives based on the types of resources (crews, tools, equipment, etc.)" (p. 283). Traditionally done using Gantt charts by hand or on computer, a new method of scheduling has branched off utilizing the 3D model within the AEC industry: 4D BIM. What exactly is 4D? To date, 4D CAD appears to be focused on integrating the technical design information respectively within the design and construction phases (Griffis & Sturts, 2000). More simply put, 4D BIM utilizes project geometry in the 3D model and then adds the dimension of time for the construction project scheduling. The schedule is a timeline as stated above by Rapp and Benhart (2014), there is a start and finish date when components will be utilized or even looked at during the construction phase of the building. The timeline can be in all stages of the project: pre-construction, construction and post-construction for the life of the building.

There are benefits and drawbacks to using 4D BIM in industry. Koo and Fischer (2000) identified three distinct benefits to using 4D BIM in construction:

1. *Visualization tool*. Koo and Fisher (2000) define this visualizing tool as "Visualizing and interpreting construction sequence" This visual identification of where and when components are put together in the overall building makes the information clearer for the participants involved.
2. *Integration tool*. The traditional building process and the medium through which information is exchanged restricts collaboration among the designers and builders of the AEC industry (Koo & Fischer, 2000). A better and clearer understanding and perception of components within the schedule will improve collaboration between trade members and make it even more likely that potential problems of components

interfering with one another are detected prior to assembly or construction. This allows a more fluid assembly of all components of the building.

3. *Analysis tool.* When thousands of components come together to create a building, space allocation is critical to determine and identify where components will end up being installed. 4D allows spatial interactions to be analyzed to determine which components will move to avoid collisions. The analysis of said components has become an integral part of most job determining interferences weeks before installation (p. 257).

There are issues associated with 4D BIM as well, as Koo and Fischer (2000) describe:

1. Consistency in level of detail modeled. The level of accuracy modeled can vary between trades. While some may end up just putting in representative lines to identify conduit, other trades model the conduit specifically and take it to extremes specifying material and manufacturer within the model. The level is usually determined by each company or the general contractor. If one or two trades decide the level of detail just representative while other trades go to level three detail—the schedule and analysis can be thrown out due to inability for components to interact with one another.
2. Omission of materials or components. The most evident issue would be lack of information included in the model. In years past, an architect or design was only concerned about lines on paper—spatial visualization of information was not even considered but assumed to be within the construction manager's abilities.
   a. With today's technology—a designer has to do so much more than just model walls. They essentially have to understand how the entire building goes together and be knowledgeable about each component of the building.
   b. Individuals have spent entire lifetimes just learning their single trade and now a designer/modeler has to know them all. It is a huge undertaking and parts might end up being missed within the model.
3. Omission of activities. It is critical for construction planners to create a schedule so that all components of the project have related activities. However, confirming that all associations exist can be a time consuming process because of the sheer number of

components and related activities in a project. Along with actually missing, a modeled component is missing an entire activity in the schedule.

4. Logic in scheduling. If there weren't enough items to be cognizant of, construction managers have to ensure the sequence of assembly is in an order that allows all components to be installed logically! An example, one would never put in the ceiling tile before all mechanical components were installed properly and the mechanical installers were out of the way of the ceiling trades. The logic behind who assembles their components first has evolved over thousands of years of practice- one senior manager passing on his knowledge to newer managers. This has to be passed on to designers now, because they are the ones creating the 4D model and schedule how the building is to be assembled. 4D is in the infancy stage of construction and problems will occur until everyone is up to speed of how to do things.
5. Time-space conflicts. Along with managing horizontal timelines for each group of parts in complete assembly, construction managers must also be mindful of the amount of space needed to install the component as well as space needed in setup around the assembly for installers. Multiple crews working in the same area will inevitably cause workflow issues of the assembled construction job for both trade teams (p. 254-256).

Professionals make entire careers just doing scheduling for construction companies as do other tradespeople. 4D BIM is another process that could be implemented and utilized in conjunction with the 3D model within AEC companies that utilize BIM. The number of companies using 4D BIM according to Kreider (2010), in Figure 3, is a little less than 30%. While this is not used as much as 3D coordination, 4D scheduling is making groundbreaking steps to have its place in AEC projects.

5D

Rapp and Benhart (2014) identify traditional estimation as the "control of construction costs takes place during every phase of the construction project" (p. 315). The estimate for a project is generated during the preconstruction phase and after the design phase. According to Rapp and Benhart (2014), "The estimate is the yardstick by which cost performance is measure. The resources used in the estimation of construction projects are labor, materials, equipment and subcontractors" (p. 317).

Traditional means of estimation involved a single person or group of people counting each item using the 2D blueprints. This method was tried and true for hundreds of years, but was riddled with problems and errors. The human factor of missing components always came into account. No matter how good the individual was, there were always omissions and even excess amounts of material on the jobsite. Quantity take-off or estimation attached to the 3D model has been identified as 5D. Utilizing 5D BIM is the integration of quantities with a monetary cost associated into the 3D model that generates the entire building preliminary material cost. From experience in construction, I can say that normal waste factors during traditional estimation was between 15 and 30% more material was needed due to issues like cutting, damage, or just over purchasing to ensure there would be enough to finish construction. 5D BIM allows for more accurate takeoffs as long as the model has included all of the objects necessary for the building and therefore can reduce the amount of waste in future projects:

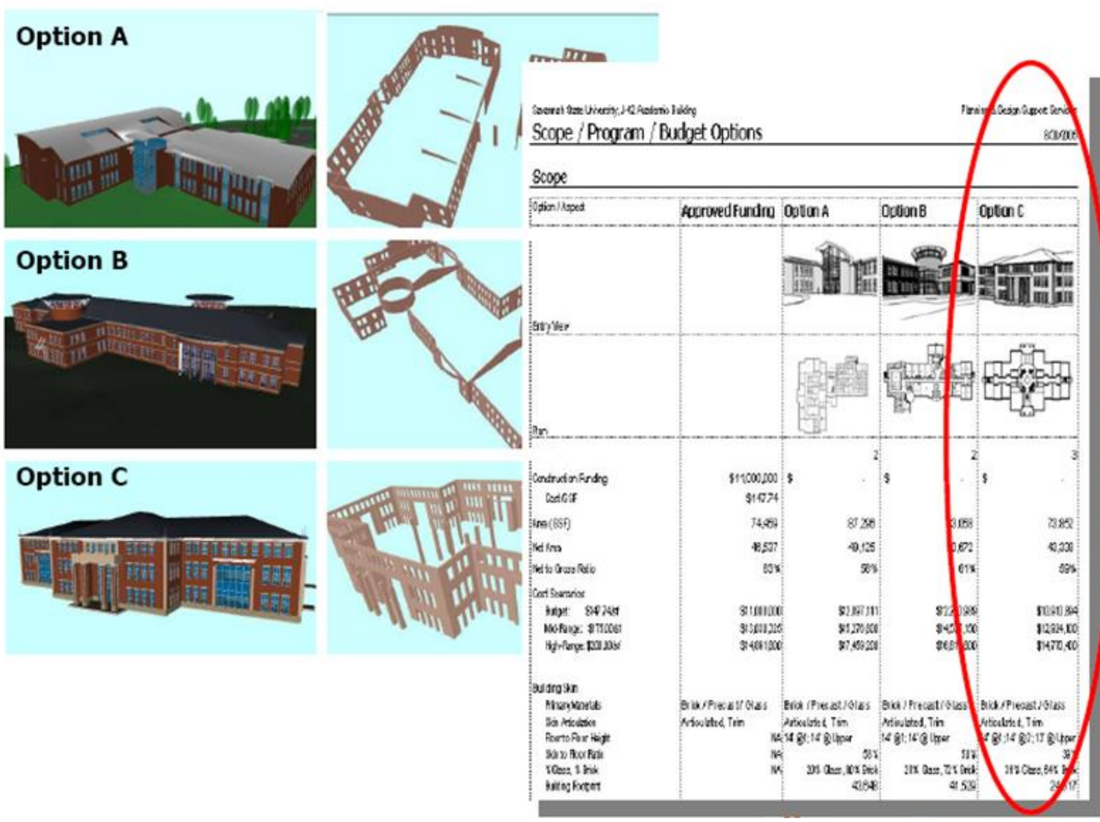

Figure 8: 5D BIM estimation of material and costs (Cory & Jenkins, 2008)

Material now is only purchased when needed and in most cases delivered a day or two before it is to be installed. This would indicate a cleaner jobsite where material was stacked early in the construction process and possibly not used for months, the new just in time delivery means material does not stay outdoors much and is completely used within days or a week of being delivered. Waste factors have reached an all-time low for construction and schedules for installation are becoming shorter. (Cory & Jenkins, 2006)

5D BIM is just in its infancy stage and not many companies are utilizing it in their day to day processes. Those who do use it are sold on it completely and will never go back to traditional ways. One could say there are tremendous benefits to 5D BIM, but there are also huge issues too.

Being in the infancy stage of use within construction, there is limited research available for 5D BIM. One such research paper though, was by Thurairajah and Goucher (2013), who identified a number of benefits when a company uses 5D BIM. According to their research, "The analysis of the findings, it can be seen that BIM has several key advantages to offer cost consultants during the cost estimating stage. These include the potential time improvements through automatic processes and the possibility to access additional information, which will be useful in improving the reliability of documentation" (p. 6). A quantitative study found that even when detailed estimates are produced by relatively inexperienced estimators, 5D was more effective than that of the traditional 2D estimating methods, especially with a reduction in errors and time taken (Shen & Issa, 2010). 5D BIM is able to process vast amounts of data relatively quickly and has the potential to make work easier (Samphaongoen, 2010). There are also some drawbacks to using 5D BIM, as suggested in Stanley and Thurnell's (2014, p. 111) research in table 3 of their paper:

1. Lack of software compatibility
2. Cultural resistance
3. Setup costs- i.e. hardware and software costs, training
4. Lack of protocols for coding objects.

While all these items are valid points, it is no different than when the AEC industry went through the major change giving up their pencils in lieu of computers to create construction documentation a few years ago. People are reluctant to jump on new technology early so that all the kinks can get figured out. Letting someone else find the problems and others benefiting from their experiences is how most of the manufacturing and construction industry operates. Being relatively new to construction, 5D BIM is structured to only increase in use. It would be up to each company to determine when and what to utilize within the D's of BIM.

Other D's

As stated above, we have discussed 2D, 3D, 4D and 5D. Once you get past 5D BIM, there is an abundance of deliberations about which number D describes what in the construction process. The sample of 6, 7, 8 and X below is from a BIM construction outsourcing company.

- 6D- Lifecycle or Facility Management
- 7D Location Base Systems (GPS)
- 8D Disaster Management Systems
- XD anything above 5D- still a work in progress by most companies utilizing BIM. (Sutech Solutions, 2016)

Other BIM dimensions exclusive of geometry, time, or cost; includes components like facility management, structural analysis, energy analysis, spatial planning, LEEN information, and any other information that can be extracted from or embedded into the model.

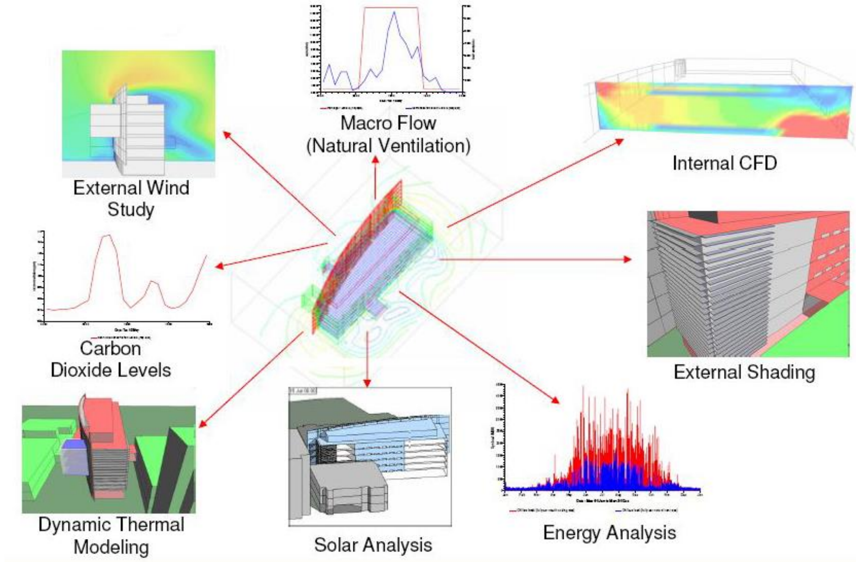

Figure 9: XD BIM: Environmental analysis (Cory & Jenkins, 2008)

Figure 9 identifies other D's of BIM at least when it comes to building environmental analyses. There are more and more D's of BIM are being developed every day. The AEC industry is embracing the building model to analyze and determine multiple aspects of the structure before the construction even breaks ground. With more and more information given to project managers as well as now to designers, all parties involved can make informed decisions that not only save the company money and time, but also the clients get a better building on or under budget well ahead of schedule.

Benefits of BIM

Most AEC professionals identify different benefits while utilizing BIM. Mike Le Fevre (2007) of Holder Construction came up with illustration that elegantly and simply identifies what the "good stuff" is when utilizing BIM in relation to utilized business practices. While Le Fevre (2007) identifies measureable benefits from a company's perspective, Neil Calvert (2013) also identifies project benefits similar to Le Fevre (2007) for owners in Figure 10 below.

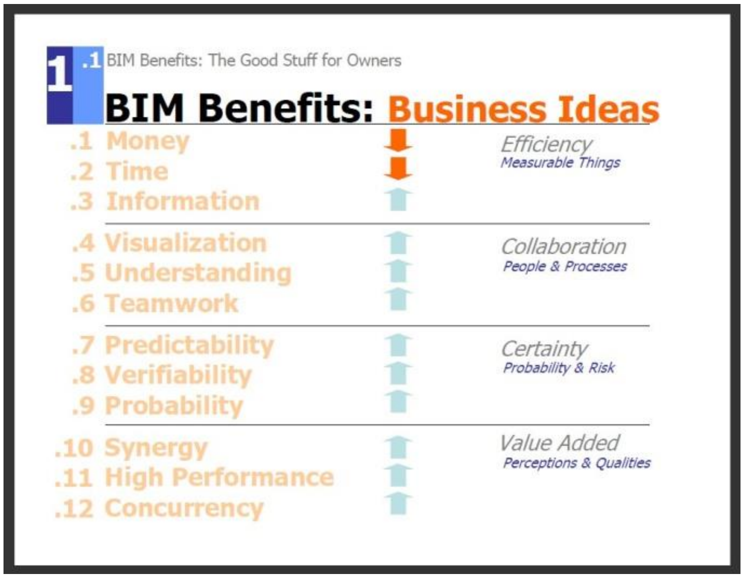

Figure 10: Benefits of BIM to AEC companies (Le Fevre, 2007)

Along with Calvert's illustration of project management benefits, he also gives some amazing statistics when BIM is used on projects. Calvert (2013) identifies the savings below:

- 20% reduction in build costs (buy 4, get one free!)
- 33% reduction in costs over the lifetime of the building
- 47% to 65% reduction in conflicts and re-work during construction
- 44% to 59% increase in the overall project quality
- 35% to 43% reduction in risk, better predictability of outcomes
- 34% to 40% better performing completed infrastructure
- 32% to 38% improvement in review and approval cycles.

And while these graphics give a breakdown of benefits to business and projects, there are still benefits associated with each group of stakeholders.

The benefits to individual parties involved within construction process of a given project from Cory and Jenkins (2008) identified within the BIM 101 course for AGC are as follows:

Benefits for Project Owners:

- Options Analysis:
  - Digital decision-making tool for different options (finishes, equipment, layouts). They can be analyzed "quickly" through the model.
- Energy Design & Analysis:
  - Accurate projections for building's energy operating costs.
- Better Design & More Efficient Construction:
  - Design documents are more complete and understandable. Conflicts are resolved "virtually" rather than being first discovered on the jobsite.
  - Enhances odds that project will be delivered on-time and on-budget
    - BIM eliminates the "unknown" by solving problems ahead of time. Therefore, accurate durations and costs can be calculated.
- Higher quality construction:
  - Collaboration between trades results in less rework. Material is installed in its assigned position the first time, instead of having to be moved around to avoid conflicts with other material.
- Intelligent "As-Built" Drawings:
  - The model used to build the project now becomes the model to operated and maintain the project.
- Reduction in Requests-for-Information (RFIs)
  - Since conflicts between materials/assemblies/equipment are eliminated…fewer RFIs will be generated.

Benefits for Architects/Engineers:

- Seamless Transfer of Design into CDs:
  - Errors in construction documents are expensive, damaging client relationships and exposing architects to potential liability. BIM eliminates defects caused by uncoordinated drawings and allows for improved collaboration between project team members. Thus, contract documents are more complete and understandable.
- Options Analysis:
  - Digital decision-making tool for different options (finishes, equipment, layouts). They can be analyzed "quickly" through the model.

- Sustainability/Energy Efficiency:
  - A "what-if" analysis evaluates the environmental impact of various materials.
- Sight Lines:
  - Model allows for better visualization and analysis…it's a model of what exactly is going to be built!

Benefits for Contractors:

- Higher Reliability of Expected Field Conditions/Fewer Errors/Less Rework:
  - Fewer errors and omissions on the project plans require fewer corrections in-field. Therefore, downtime is reduced allowing workers to be productive (no standing around).
- Fabrication Off-Site:
  - Since product data information in the model is keep up-to-date, the data can be sent directly to the fabricator!
- "What-if" Analysis:
  - Ability to conduct different sequencing options for the flow of construction. Can also be used to quickly evaluate and visualize different options for Value Engineering.
- Ease of visualization using the model
  - Views can be rotated, zoomed-in; objects can be sorted and filtered. One can virtually "walk" or "fly" through the building. The contractor is no longer limited by the number of cut-sections through the building….now it's an infinite number!
- Construction Planning and Scheduling involves sequencing activities in regards to space and time. While the traditional methods of bar chart or critical path schedules are used to communicate the planned sequence of construction, they may not accurately capture the spatial links/conflicts between activities.
  - With BIM, the construction sequence is coordinated with the expected time and space flow of all the trades on the site via the different objects located in the model.
  - The building can now be virtually-built right before your eyes. Any sequence conflicts can be modified right on the spot…before it even takes place on the actual construction project!

Quantity Take-Off

- Since there is data for each object in the model, quantities (count, area, linear feet, square feet…etc.) and costs can be retrieved.
- BIM tools offers features for extracting and quantifying BIM components. Some BIM tools are capable of linking directly into a third-party estimating package.

Geometry-based Clash Detection

- BIM-based clash detection tools can selectively check clashes between specified systems (i.e. Ductwork vs. Structural). The clash detection can be run at any level of detail and across any number of building systems and trades. Note that a detailed clash detection analysis is only possible with well-defined and structured building models. (p. 1-54-1G: 1-63-1G)

Even though all project members benefit in their own ways, the largest benefit to all is early collaboration and communication. It is no longer an "I" or "they" way of doing business, but more like "we" collaborative way of working. When everyone shares information early and often, everybody benefits.

BIM for Higher Education

While the literature review focused on industry, there are benefits for future higher education curricula of construction management and visualization. According to Rezgui, Wilson, Olphert, and Damodaran (2007), "Several factors, including the pace of technological innovation and the globalization of the economy, have forced business and industry to adapt to new challenges triggered by an ever-sophisticated society characterized by an increasing demand for customized and high quality services and products in various segments of industry" (p. 187). The popularity of Building Information Modelling (BIM) in the commercial construction industry is increasing every day (Sullivan, 2007). The educational and industrial programs that focus on construction management or graphics are at the forefront of this need. Companies are recruiting students with construction and computer graphics skills into BIM positions because of the 3D modeling knowledge and 3D spatial visualization skills. Most construction companies are slowly redefining their efforts to incorporate BIM technology and methods. The contractors are using BIM processes to identify interferences, estimate quantities of materials, link data to schedules and produce 4D animations of the construction process that inevitably help discover dynamic interferences of construction activities. It only makes sense that higher education utilizes those same BIM benefits to educate tomorrow's managers. These companies are looking for individuals straight out of college that are knowledgeable about construction management, BIM and have good spatial visualization skillsets to become successful within the AEC industry.

Current Construction Management Curricula Requirements

Building Information Modelling is sweeping the AEC industry as a new method of construction management and production. Why? Reddy states, "BIM represents a migration in the architectural design field from two dimensions to three dimensions by creating intelligent, multi-dimensional building models" (as cited in Sabongi & Arch, 2009, p. 2). Building information modeling shows a building at every aspect of its development and illustrates construction, design, and materials in detail. Through building information modeling, designers can enhance the computer designs that project into buildings, and the construction methods that incorporate the actual materials. Proponents claim that BIM enables architects and engineers to create detailed three-dimensional models that take the guesswork out of design intent and construction. Project owners like building information modeling because it enables them to better visualize the completed project and provides a 3D blueprint for continued building operation and maintenance (Erger, 2009, para 1). The embedding capacities of building information modeling make it a dynamic platform and allow multiple groups in different locations to work on projects (Thomson & Miner, 2007, p. 61).

As well as the AEC industry trying to figure out what BIM is and how to educate company administrators, employees, and even clients, higher education is experiencing a trend toward introducing components of building information modeling into curriculum. This is extremely difficult if educators have no personal experience with BIM, and even more so if they have no alliance with industry professionals. Despite obstacles, both AEC professionals and higher educators are introducing what they think is beneficial to either their company or their students.

In higher education curriculum, keeping current with methods and processes in industry is a never-ending effort. The inclusion of BIM in undergraduate curriculum is slowly making headway, but is significantly slower than its integration into current AEC industry projects. Clevenger et al.

(2010) report that "until recently, architecture programs have led in the implementation of building information modeling into curriculum with engineering and construction programs lagging significantly behind" (p. 3). Sabongi and Arch (2009) from Minnesota State University conducted an exploratory study of members of the Associated Schools of Construction. Of the 119 universities and colleges polled, 45 responded. Only 9% of respondents currently addressed BIM in their coursework. Less than 1% were teaching BIM as a stand-alone class. Reported problems of implementation included no room in the current curriculum for additional classes (82%), the impossibility of adding additional required or elective classes and still graduating in eight semesters (66.7%), problems with faculty having the time or resources to develop a new curriculum (86.7%), and a lack of availability of BIM-specific materials and textbooks (53.3%) (Sabongi & Arch, 2009, p. 3).

Limited research regarding building information modeling in construction management education suggests that changes are needed as current efforts struggle to meet industry or academic outlooks. Several university studies have found dissatisfaction among students and educators with the advancement of technology-based curriculum development, especially building information modeling (Sylvester & Dietrich, 2010; Sabongi & Arch, 2009). To this end, and to address the current state of change at Purdue University in the Building Construction Management and Computer Graphic Technology departments, a pilot study of industry professionals will test a strategy for widespread change and adoption of building information modeling integrated into current curriculum and determine whether the construction management area is in need of a complete overhaul of curriculum, as well as assess the possibility of adding a bachelor's degree in BIM modeling to current options for undergraduate students.

Across the nation, the current construction management curricula of accredited schools are pretty much consistently the same. According to the American Council for Construction Education (ACCE), "the total curriculum shall support the goals and objectives of the construction education unit and meet content requirements within the 5 major subject categories":

	Curriculum Categories	Minimum Academic Credit
1)	General Education ……………….	15 semester (22 quarter) hours
2)	Mathematics and Science ………..	15 semester (22 quarter) hours
3)	Business and Management ………	18 semester (27 quarter) hours
4)	Construction Science*……………	20 semester (30 quarter) hours
5)	Construction* ..…………………..	20 semester (30 quarter) hours
	Total Combined Construction Science and Construction*	50 semester (75 quarter) hours
	Subtotal: Prescribed Category Credits	98 semester (146 quarter) hours
6)	Other Credit Hours (As needed to complete 120 hour threshold or to meet additional institutional and program requirements)	22 semester (34 quarter) hours
	Total ACCE Accreditation Requirement	**120 semester (180 quarter) hours****

* Construction Science and Construction are separate subject categories. The minimum aggregate of both Construction Science and Construction combined requirement is 50 semester (75 quarter) hours of academic credit.

* One semester hour equals 15 instructional hours; one quarter hour equals 10 instructional hours

Figure 11: Curriculum: baccalaureate program ACCE accreditation requirements (ACCE, 2014, p. 10)

I found that all 74 ACCE schools follow this curriculum, with minor changes here and there within each university. One school required a couple more classes in management, and another required two courses in surveying rather than the minimum of one, but all met the listed requirements or exceeded them. I also found it interesting that the very first sentence in the ACCE (2014) document states, "The purpose of the curriculum is to provide an education that will lead to a leadership role in construction and to prepare the student to become a responsible member of society. The curriculum should be responsive to social, economic, and technical developments and should reflect the application of evolving knowledge in construction and in the behavioral and quantitative sciences" (p. 7). It then goes on to state, "The ACCE encourages accredited programs to regularly evaluate current curricula and develop new curricula that reflect changing construction technologies and management trends" (p. 7).

Current State of BIM in AEC Curricula

A large number of schools are integrating BIM into curricula within different disciplines and in different ways. The construction management discipline is an example of one that utilizes BIM within the Architecture, Engineering and Construction (AEC) industry. Other disciplines incorporating BIM include architecture, civil engineering, construction management engineering, interior design, and even architectural technology. Barison and Santos (2010) did the most complete study using the Content Analysis process (Krippendorf, 2004) to examine a set of papers and syllabi that document experiences in schools, mainly those schools that today are identified as leaders in BIM education, as listed in figure 12.

Table 1: Universities, programs and *BIM courses* included in the review.

	UNIVERSITY	AUTHOR(S)	PROGRAM	*BIM COURSE*
Introductory	U. of North Carolina	Nelson	Architecture	Building Information Modeling
	Montana State University	Berwald	Architecture	Digital Graphics and Design
	U. of Wisconsin-Milwaukee	U. of Wisconsin-Milwakee	Architecture	Computers in Architecture (Arch 382)
	Israel Institute of Technology	Sacks and Barak	Civil Engineering	Communicating Engineering Information
	Auburn University	Taylor, Liu & Hein	Construction Management (CM)	Constr. Info. Tech. , Digital Constr. Graphics
	California State University	Kymmell	Construction Management	Building Information Modeling I, II
Intermediary	Texas Tech University	Rex and Park	Architecture	Digital Media II
	USC	Becerik-Gerber	Engineering and CM	Building Information Management
	University of Utah	Scheer	Architecture	Building Information Modeling, Design Studio
	Queensland U. of Tech.	Nielsen et al.	Architecture	BIM Unit (Architectural Tech. and Science VI)
	NJ Institute of Technology	NJ School of Architecture	Architecture	Design Studio
	Texas State University	Mulva and Tisdel	Architectural Engineering	Design Studio I and II
	George Mason University	George Mason University	Civil, Environ., Infrastructure Eng.	Building Information Modeling (CEIE499/690)
	University of Washington	University of Washington	Construction Management	Advanced Project Management Concepts
	California State University	Kymmell	Construction Management	Building Information Modeling III
	Purdue University	Schmelter and Cory	Computer Graphic Technology	Commercial Construction *BIM Course*
	Norwegian U. of Sc. & Tech.	Hjelseth	Structural Engineering	Design of Buildings and Infrastructure
	Cal Poly	Korman and Simonian	CM and Civil Engineering	MEP Coordination Studio-Laboratory
Advanced	Cal Poly	Dong	Architecture, CE and CM	Int. Design Studio and Int. Bldg. Envelopes
	Virginia Tech	Ku	CM, Building Construction, Arch.	Several *BIM courses*
	Texas A&M University	Texas A&M University	Architecture, CM	Integrated Design Studio
	Penn State University	Poerschke at al.	Architecture, Civil Engineering	Integrated Design Studio (ARCH 497A)
	GeorgiaTech	GeorgiaTech	Graduate curses	Building Information Modeling: Case Studies
	California State University	Kymmell	Construction Management	Building Information Modeling IV
	University of North Texas	Arnold	Construction Engineering Tech.	Senior Design Class

Figure 12: Universities, programs, and BIM courses included in the review (Barison & Santos, 2010)

One can see, however, that every discipline as well as degrees offering courses is included in the report, not just construction management.

Sacks and Pikas (2013) next did a study of BIM included in universities' curricula. Their approach was similar to Barison and Santos (2010) in that they reviewed journal articles about BIM within undergraduate degrees, but differed in that they only focused on construction management programs. In addition, their scope was limited to what BIM included in curricula they could find online. This excluded multiple universities' construction management programs, as well as other areas of focus whose curricula include BIM around the nation and the world. Figure 13 below shows that they only reported BIM courses for three universities, based on interviews with educators. Sacks and Pikas (2013), however, went into depth with the educators from these universities to identify the BIM education needed within the curricula. The table excerpt at the top of Figure 13 shows the courses focused on and at which university, followed by different categories of reported BIM education.

Table 6. Six Courses Selected for In-Depth Analysis

Course identification	Course name and number	University	Level and program
A	CEE 110/210: Building Information Modelling	Stanford	Introductory
B	AE 597G: Building Information Modeling Execution Planning	Pennsylvania State University	Advanced
C	CE 470: BIM and Integrated Practices	University of Southern California	Intermediate
D	CE 570: BIM for Collaborative Construction Management	University of Southern California	Advanced
E	014008: Graphic Engineering Information	Technion	Introductory
F	019627: Advanced BIM	Technion	Advanced

Table 7. BIM Education at Three Universities Based on Interviews with Educators

Category	Stanford University	University of Southern California	Technion—Israel Institute of Technology
Motivation for teaching BIM	Industry needs engineers with BIM education	Academia's responsibility for developing next-generation architects and engineers	Provide foundational skills for engineering communication (first degree); educate industry leaders in BIM (graduate level)
BIM content offered	Two elective "standalone" BIM courses: CEE 110/210: Building Information Modeling and CEE241: Managing Fabrication and Construction; several design and management courses have integrated BIM for teaching purposes	Elective courses CE 470: Building Information Modeling and Integrated Practices and CE 570: Building Information Modeling for Collaborative Construction Management; integration of BIM content to other courses by other lecturers.	Compulsory first year 014008: Graphical Engineering Communication; elective graduate course 019627: Advanced Building Information Modeling"
Conception of BIM	"BIM is not a drafting skill but a technology that enables communication between AEC industry professionals (like any other language)"	"BIM is a concept that requires process change—a collaborative platform for various project parties for effective communication. At universities fundamentals must retain but BIM must be taught as an integrator between a diversity of fields"	"BIM is an activity that uses parametric, object-oriented and geometric modeling to support design, representation, engineering analysis and performance simulation, construction planning and design communication for building construction"
Approach to BIM education	BIM cannot take place in isolation because it requires construction knowledge; on the other hand, BIM can be used to teach students how buildings are constructed; approach depends on context of course	BIM basics must be taught to enable students to progress individually and it must be integrated into real-life processes to show its applicability for continuous communication (information exchange)	Provide basics of BIM education in first year, incorporate exercises that require its use in following years of first degree, and offer advanced skills only in graduate courses
Teaching methods	Video materials, lectures, classes, self-learning, and involvement of students in research	Self-learning, classes, video materials, and involvement of students in research	Lectures, tutorials, modeling assignments, term project (first degree); multidisciplinary team projects at graduate level
BIM integration in existing courses and lecturers' capability to teach BIM	Faculty need not know all technical aspects of using BIM technologies; rather they should motivate and guide students to right tools and learning facilities	Once students have the basics given through standalone courses, students are expected to be able to self-teach and take BIM knowledge to other courses	Limited to small number of construction management and structural engineering courses

Figure 13: BIM Education for Construction Management I (Sacks & Pikas, 2013)

Lee and Hollar (2013) also reported on BIM included in curricula. Their table below, shown in Figure 14, gives an overall summary of their findings.

Table 1. Summary of BIM Implementation Efforts in CEM Undergraduate Curricula

Strategy Employed for BIM Implementation	***Course***	***Reference***	***Learning Outcomes and Technological Limitations***
Stand-Alone Course	Residential and Commercial Design	Woo (2007)	• Better understanding of 1) design, construction, and engineering information and 2) the architect's role in the design and construction process • Limitations in using BIM software in creating various models
	Engineering Elective	Dupuis et al. (2008)	
	Architectural Engineering Graphics	Weber & Hedges (2008)	
	Digital Construction Graphics	Taylor et al. (2008)	
Integrated Teaching Modules	Construction Documents	Livingston (2008)	• Enhanced student's ability to understand 1) building structures & components; 2) complex construction systems; 3) construction plans & specifications; and 4) construction means & methods • Improved accuracy of student's quantity takeoffs • Positive perceived impact on students' learning and student's willingness to use BIM • Effective course content delivery for the active learning
	Building Envelopes	Dong (2009)	
	Residential Construction	Meadati & Irizarry (2010)	
	Structural Design	Barham et al. (2011)	
	Materials & Methods	Glick et al. (2011)	
	Engineering Graphics	Sacks & Barak (2010)	
	Formwork	Meadati et al. (2011)	
	Mechanical and Electrical	Korman & Simonian (2010)	
	Scheduling	Hyatt (2011)	
	Estimating	Sylvester & Dietrich	
Cross-Curriculum Teaching Modules	Construction Management and Structural Engineering	Richards & Clevenger (2011)	• Better understanding of 1) roles and responsibilities of other disciplines; 2) the complexity and variety of information between different disciplines; and 3) collaborative work environment for the construction process
	Integrated Studio	Sharag-Eldin & Nawari (2010)	
	Architectural Design Studio	Hedges & Denzer (2008)	
Capstone Project	Capstone Course	Azhar et al. (2010)	• Students' strong interest in learning BIM • Difficulty in using BIM tools for a capstone project

Many of the cases presented in Table 1 were "pilot projects" where BIM was deployed in a course for the first time and the impacts on student learning evaluated. These efforts within the CEM curriculum show great potential for successful BIM implementation in an undergraduate curriculum.

Figure 14: Summary of BIM implementation efforts in CEM undergraduate curricula (Lee & Hollar, 2013)

Looking at the table and information within their paper, most cases were what is referred to as pilot projects, in which BIM was introduced into a course for the first time. Lee and Hollar, however, put a twist on their study to include AEC industry perceptions, trends, and practices as they related to construction management education.

While several other authors cited in these papers wrote individual papers about unique courses they offer at their universities, there was no real survey, report, or journal done to include BIM within construction management (CM) courses across the nation or internationally. The three papers above were the ones most cited by others as the expert opinions on and most accurate reflection of the current state of BIM within CM.

Impact of BIM on Construction Management

From preliminary design through facility management when the building is occupied, each phase of the construction process and management of that process is impacted by building information modeling. Higher educators without BIM knowledge or experience cannot fully identify changes in curricula that would be beneficial to future construction managers. Limited research regarding building information modeling in construction management education suggests changes are needed changes, while current efforts struggle to meet industry outlooks. Results of several university studies demonstrate dissatisfaction among students and educators with the advancement of technology-based curriculum development, especially building information modeling (Sylvester & Dietrich, 2010; Sabongi & Arch, 2009). It is this dissatisfaction and the need for a complete curriculum change that helped defined this research.

Barison and Santos (2010) state, “It is widely expected that Building Information Modeling (BIM) will lead to changes in the performance of professionals in the Architecture, Engineering, and Construction (AEC) sector; particularly with regard to architects and civil engineers” (p. 1). I would further include within this statement “internationally expected.”

CHAPTER 3. METHODS

The purpose of this study was to identify, analyze, and interpret how Building Information Modeling (BIM) within the AEC industry influences daily activities from a construction manager's perspective and then report similarities and disconnects between real-world knowledge and what is being taught to current construction management students in higher education. According to the literature review, BIM is a multifaceted process if which each company either adopts or rejects certain components. Due to the nature of the questions posed, a multi case study approach provided the best mechanism for conducting this research.

This chapter outlines the case study methodology and the procedures for selection of companies, selection of participants within each company, data collection, and analysis. The chapter concludes with a discussion of trustworthiness and triangulation of data sources relative to the study.

Theoretical Framework

In order to determine the theoretical framework, I first had to look at the research. When researching and discussing the construction management processes within a company, key questions come to mind, such as "How does the company utilize BIM in daily managerial processes? What components do they use and why?" McQueen (2002) states, "Interpretivist researchers seek methods that enable them to understand in depth the relationship of human beings to their environment and the part those people play in creating the social fabric of which they are a part" (p. 17). According to McQueen, "Interpretivist view the world through a 'series of individual eyes' and choose participants who have their own interpretations of reality to 'encompass the worldview'" (p. 16). This view through the eyes of individuals led me to Bill Succar's idea for and generation of the BIM framework. Succar (2009) identifies the need for a "systematic investigation of BIM's divergent fields" with "knowledge components [that] must be defined and expanding boundaries delineated which explores some of the publicly available international guidelines and introduces a BIM framework—a research and delivery foundation for industry stakeholders" (p. 357).

The BIM framework is multi-dimensional, similar to how BIM is utilized in industry. Succar's BIM framework can be represented by a triaxial knowledge model comprising:

- BIM fields of activity identifying domain "players" and their "deliverables". These fields are represented on the x-axis.
- BIM stages delineating implementation maturity levels (y-axis)
- BIM lenses providing the depth and breadth of enquiry necessary to identify, assess and qualify BIM Fields and BIM Stages (z-axis) (Succar, 2009, p. 359).

BIM Fields represent three interlocking activities: technology, process, and policy (TPP). Each field has two subfields that include players and deliverables. Technology within the BIM framework includes "a group of players who specializes in developing software, hardware, equipment and net-working systems necessary to increase efficiency, productivity and profitability of AECO sectors. These include organizations which generate software solutions and equipment of direct and indirect applicability to the design, construction and operation of facilities" (Succar, 2009, p. 359).

Succar (2009) identifies ***BIM Stages*** as representing maturity of "BIM use within organizations, projects, and industry as a series which stakeholders need to implement gradually and consecutively" (p. 362), and he divides stages into three components:

1. Object-based modeling
2. Model-based collaboration
3. Network-based integration.

According to Succar, "BIM Lenses are distinctive layers of analysis (Fig. 18) applied to Fields and Stages to generate 'Knowledge views'. Lenses allow the domain researcher to selectively focus on any aspect of the AECO industry and generate knowledge views that either (a) highlight observables which meet the research criteria or (b) filter out those that do not. In essence, all knowledge views are abstractions derived from the application of one or more lenses and/or filters" (p. 367).

Succar describes the BIM framework as "[aiming] to investigate and represent a host of concepts and relations. To reduce complexity, enable knowledge acquisition and validation of Framework's topics, a specialized 'conceptual' BIM Ontology has been developed" (p. 367). Succar identifies BIM ontology as four high-level knowledge objects: concepts, attributes, relations, and knowledge views (p. 368). Partnering BIM ontology with visual knowledge modeling, the BIM framework is a benefit to both AEC and academia with its ability to generate knowledge modules, templates, and tools that assist in implementing and teaching BIM processes. Being a mostly visual process, Succar's (2009) BIM framework visual model is shown below in Figure 15.

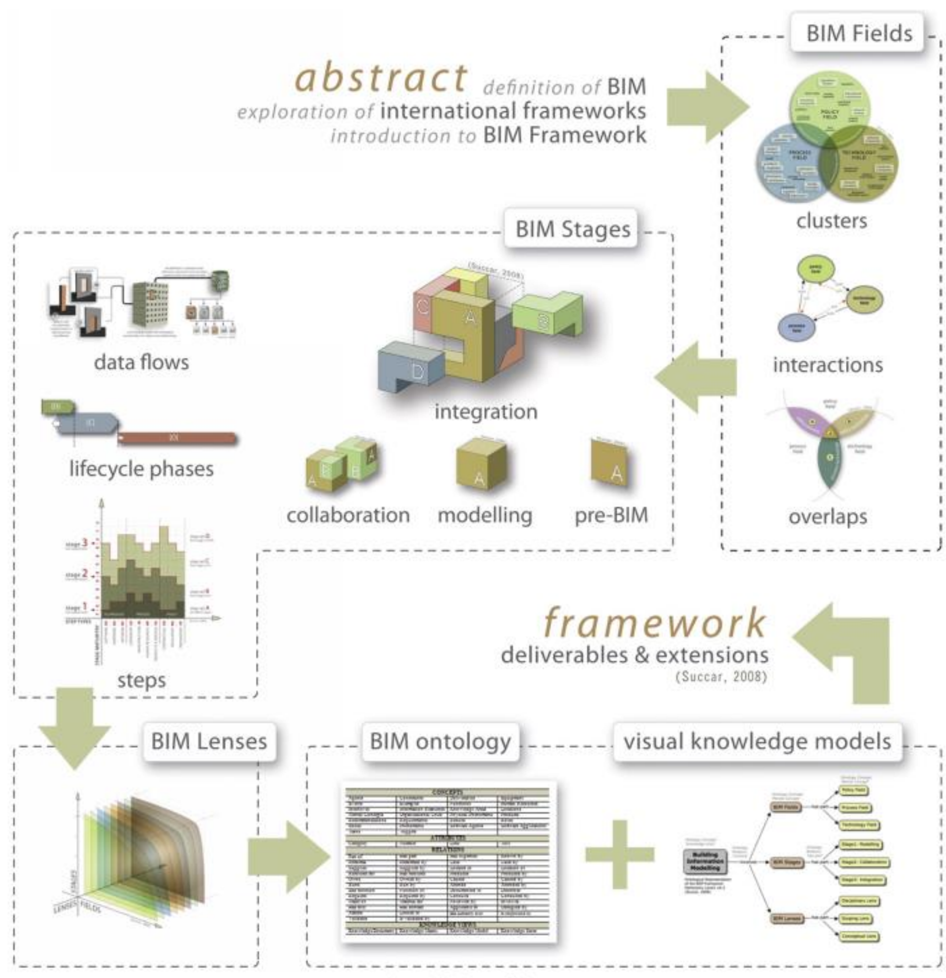

Figure 15: Visual representation of BIM framework (Succar, 2009)

Positionality

I grew up in a construction family. My father was a carpenter, as were his father and his father before him. I have now been in the construction industry for approximately 50 years. I have been everything from clean-up boy all the way up to superintendent and eventually owner of a design/building company. Several of these years, however, were during a time when houses were drawn using a pencil and paper with T-square and triangles. I have been fortunate enough to see the creation of construction documents transition from pencil and paper onto the computer.

During the last 20 years of my construction experience, I have been extremely fortunate to have the opportunity to teach courses at Purdue University. I have been teaching construction graphics within the Computer Graphics Technology department. During my teaching, I have also been consulting with several AEC companies, giving personal workshops and answering email questions, as well as asking questions of each company. While I can create most AEC models on the computer, I have yet to experience a construction project that incorporates BIM entirely into the management process. I continually read about BIM processes, but witnessing it firsthand with an unbiased opinion would add validity to this research.

Because I have been in the construction industry for many years, my first inclination would be to include my personal experiences; however, I did not want that to affect this project's overall portrayal of a BIM process within AEC companies. I also came to the realization that despite my years of construction experience, I have no real connection to BIM processes within companies currently utilizing the process for management of projects. I am not in the trenches every day using BIM in AEC projects, and thus, although the decision was extremely difficult, I came to the conclusion my research should function as described by Daniels (2013): "The research looked at things in such a way that we see only what stands before our eyes, only what we can describe and define" (Epoche' para. 13).

Background

BIM is different from company to company. Examining only one company's BIM process would not give enough information and would be biased against aspects of BIM that were not performed within that company. Taking a look into the BIM process of two or more companies and comparing these would give a broader and more complete picture. To give this project an even broader approach, I compared the BIM process of four construction companies in completely different categories of building. This approach allowed me to better understand the intricacies of BIM. Given this, case study was selected as a methodology; as Yin (2009) explains, "The more that your questions seek to explain some present circumstance (the 'how' and 'why' some social phenomenon works), the more that a case study method will be relevant" (p. 4).

From the literature review in Chapter 2, BIM was identified as a multifaceted process within the construction of a project, which occurs specifically around construction managers' daily activities. According to Rapp & Benhart (2014), "Competencies needed by construction managers include being capable of creating, editing, and managing a variety of construction-based media assets, estimation of material, construction methods and procedures, scheduling, safety, and has values while being personally aware of everything around them and construction site" (p. 230). Additionally, those competencies continue to evolve (e.g., the addition of internet/intranet information systems and computer 3D modeling for project management). This current expansion of competencies leads to a need to review and evolve higher educational construction management curricula. Therefore, the competencies examined here are the process of BIM within daily construction managers' activities.

Research Design

Ultimately, the goal for answering the research question would be a method of learning about the daily activities of another person—by listening to their descriptions of what their subjective world is like for them, together with an attempt to understand this in their own terms as fully as possible, uninhibited by preconceptions and interferences. To answer these questions, I used a multiple case study comparing four AEC companies utilizing BIM within CM processes to obtain a global picture of the impact BIM has had on a traditional construction management (CM) position. Researching specific companies' actions or construction management procedures utilizing BIM and gathering data from professionals would inevitably resolve the research questions. Specifically, the research questions were:

1. How has Building Information Modeling influenced a construction manager's current position?
2. How has Building Information Modeling (BIM) influenced a construction manager's need for continuing education within the industry?

From the initial research questions and extensive literature review, it was determined to use case study methodology in this research. According to Yin (2009), "Case studies are the preferred method of research when (a) "how" or "why" questions are being posed, (b) the investigator has little control over events, and (c) the focus is on a contemporary phenomenon within a real-life context" (p. 2). When the case study procedures are followed, "the richness of the phenomenon and the extensiveness of the real-life context require case study investigators to cope with a technically distinctive situation: there will be many more variables of interest than data points" (Yin, 2009, p. 2). A case study would allow me to gain valuable insight into the BIM process of different companies. In this study, a multiple case study design was used to produce detailed descriptions of the BIM phenomenon. Yin (2009) emphasizes that multiple cases are strengthened when you have the possibility of direct replication, which will be more powerful than information coming from a single case. As an outside researcher who knows BIM theory and technology, I am separated from AEC procedures by years of teaching BIM to determine what BIM is capable of within the construction industry.

Defining the Case

Yin (2009) explains defining the case and bounding the case (e.g., all individuals at one company are a single case). There was still the decision of which cases to focus on within the research. I decided to break a case into two categories. The first decision was based on which companies were utilizing BIM in their day-to-day construction management process. The second was to identify people within the companies who utilized and interacted with the BIM process daily and had intimate knowledge of their company's complete BIM managerial process.

Selection of Company Units

The first part of the research was the selection of companies. Data gathering is crucial in research, as the data are meant to contribute to a better understanding of a theoretical framework (Bernard, 2002). I used purposive sampling to select the companies. Tongco (2007) explains, "The purposive sampling technique, also called judgment sampling, is the deliberate choice of an informant due to the qualities the informant possesses" (p. 147). Each company selected utilizes BIM in daily activities and is considered a BIM expert within the AEC industry. The entire construction industry consists of thousands of companies, and each has a very specific type of construction they focus their efforts to build. However, companies in any category can implement BIM. I at first thought the differences in each company's focus would cause discrepancies in the results, but then realized that a different perspective of BIM within differing categories of construction companies would give a broader and richer picture of the "how" in Yin's (2009) definition of case studies. My teaching, work experience, and consulting provided me with several AEC contacts, which in turn allowed me to determine which companies to select that utilized BIM.

During my 20 years of collaboration with AEC companies and more than 50 years working in positions ranging from general laborer to project manager, I have learned and recognized that projects can fall into one of five distinct types of AEC companies, which align with definitions given by the Construction Recruiters Network (CRN). CRN (2016) identifies five distinct types of construction companies:

- General Contractor
    - Hired by clients, usually architects, to oversee a construction site and manage trade with vendors, employ general contractors. They usually work with companies and landowners. They evaluate plans, draw up estimates and manage the execution of projects.
- Design/Build
    - Design-builders not only oversee construction but also design and engineer structural components. They work alone by combining the design and construction phase of a project, the opposite of the design-bid-build process.
- Package Builders
    - This area is not being used in the research because it is extremely close to Design/Build. Additionally, package contractors break the project down into segments or packages of the whole project—like quartering a pie and only focusing on ¼ of that pie. These segments can be all done at once or build one segment and then not focus on the project for a month or even a year later. I am looking at BIM in an entire project process (start to finish) and not just individual segments of a whole project.

- Architectural/Engineering
  - A combination of Design/Build and trade contractors. This construction company area does it all, from designing buildings in house to construction and then designing all mechanicals for the structure. Most if not all work is done within the company.
- Trade Contractors/Mechanicals
  - Trade contractors are subcontractors who specialize in a field of work like plumbing, painting, masonry, fire protection, etc. They work for prime contractors and property owners. (CRN, 2016)

Of the five types of construction companies, this research focuses on one company from each of the overall areas of General Contractor, Design/Build, Architecture/Engineering, and Trade Contractors. I wanted to give a complete overview of BIM over the entire AEC industry, so I purposefully selected one company from each of the four areas for this research.

The next step was to determine which companies would be selected across the nation. The first factor was that the companies needed to utilize BIM in daily functions. The next factor was that the companies would need to be reputable. This question was not so easy to determine. Reputable can mean many different components to different people. According to Nelson (2016), "It is important to know that a reputable construction firm delivers excellent building works that follow the required standards and norms." The qualities that each reputable company possesses can be identified in Nelson's list below:

- Expertise: You need to check its expertise through awards, publications, new technologies, and certifications. A reputable firm should proof its expertise through previous projects.
- Experience: Choose a company based on the previous projects they have completed over the years. Moreover, you can check the number of years they have been operating in the industry.
- Reputation and goodwill: You can determine this by checking the firm through analysis and market research. This can be based on company's revenue and sales volume.

- Rich portfolios: A reputable construction firm ought to have an excellent portfolio. Before engaging in any services, you need to explore their ongoing and completed projects. This can be of help in determining the quality of work they perform.
- Management team: You should seek services of a company with the reputed management team. This means that decisions are not just made by a single person, but rather a great panel of professionals. This team ought to include architects, engineers, builders, and many others (para. 1-5).

The seven criteria in Table 1, below, were used to determine the selection of AEC companies and narrow the selection to one company within each area of construction:

Table 1: Criteria utilized to determine AEC company BIM research participation

	Category	Subcategory
1	**Use BIM in over 50% of their projects**	All companies were at 80% or better for using BIM on jobs—and three used it 100%, for every job.
2	**Experienced contractor in their respective areas**	Each company selected was in the *Engineering News-Record*'s (ENR) "Top 400 Contractors 2016" list. More specifically, three made the top 70 on the list, and two were in the top 20. This ENR rating does not include trade contractors. The mechanical contractor was 27th on the top 100 MEP contractors list.
3	**Competitive in bid proposals—keep costs down using BIM**	To make the top ranking, one of the criteria is net worth for the year. Each company needs to have competitive bids in order to get work.
4	**Quality of work**	Companies would not achieve a high ranking without being good at work and requiring top quality from their employees as well as subcontractors.
5	**Reliability**	Nothing beats a contractor or subcontractor who comes in on time, performs their work with care, does not ask for petty change orders, and fulfills their obligations according to the plans and specifications.
6	**Professionalism**	In construction, professionalism happens at every stage of the project. You don't make the list of the top 100 contractors without being professional in regard to treatment of coworkers and clients.
7	**Speed of work**	A history of project delays earns a company a poor reputation, and prospective clients are likely to research this when selecting a contractor.

Selection of quality construction companies was my top reason for choosing each company in the research. While the companies are different in projects built and type of clients they deal with, BIM was the main process utilized in all companies' construction management process. Moreover, each company selected utilized BIM a bit differently. The companies selected had all the qualities listed above and were top leaders in each respective area and overall in the AEC industry for incorporating BIM into their daily construction practices. It was for these reasons each company was selected for this research as table 2 below identifies:

Table 2: AEC company BIM selection criteria

	Category	A	B	C	D
	Years Using BIM	8	10	7	13
	Use BIM in over 50% of their projects	90%	100%	80%	100%
	Experienced contractor in their respective areas *Engineering News-Record*'s (ENR) "Top 400 Contractors 2016"	64	24	19	4
	Competitive in bid proposals—keep costs down using BIM	$825 M	$2.1B	$3.1 B	$260 M
	Quality of work	Several client references	Several client references	Several client references	Several client references
	Reliability	Several client references	Several client references	Several client references	Several client references
	Professionalism	Several client & Employee references	Several client & Employee references	Several client & Employee references	Several client & Employee references
	Speed of work	No Projects over timeframe	No Projects over timeframe	No Projects over timeframe	No Projects over timeframe

Participant Selection

Once I identified the companies to represent the four categories of construction company identification, I turned to the selection of individuals from within each company. As with company selection, a set of criteria was employed when recruiting interview participants within the AEC companies:

1. BIM use for each company (person uses or has used BIM)
2. Managing model information for given projects (person knows BIM)
3. Manager of team within VDC or BIM area in company (person oversees BIM)
4. Minimum of five years' experience in construction

A questionnaire (see Appendix A) was used to select people within each company who could give a complete overview of how the company incorporates BIM into business and how it affects daily construction management functions. People work in different areas of construction and are affected differently in their jobs by the companies BIM processes. Their differing BIM experiences might and should be identified and described in order to get a complete picture of the company's BIM processes.

The questionnaire included several demographic questions, along with a complete history of the potential participant's personal knowledge of BIM in their company's processes. The selection of identified information is crucial in validating the individuals as BIM experts. I can think of no better way to gather data about BIM than to interview those participants who see and use BIM every day. To define the AEC participants as experts, they had to currently be working at or be associated (consulting) with an architectural, engineering, or construction firm for a minimum of five years. Five years was selected to ensure each individual had enough experience in the field and really knew the company's process for doing business.
When the questionnaires were returned, a selection of individuals within each company were contacted to determine if they would be willing to be interviewed regarding BIM within their company. Table 3, below, lists the qualifications of participants within the four companies.

Table 3: Qualifications of participants

Company	Number of Participants	Qualifications/Title	Years of BIM Experience
A	1	Head of VDC	10
B	2	Head of VDC in office Head of VDCC on jobsites	12 15
C	1	Head of BIM department	7
D	3	VP of company Head of IT Head of BIM department	20 15 15

Procedures

Data collection utilized face-to-face interviews. Marshall and Rossman (2014) describe interviews as "A conversation with a purpose" (p. 144). I conducted the interviews by developing questions that followed Seidman's (1998) three steps of data gathering when using in-depth interviews. Seidman states, "The first focuses on past experience with the phenomenon of interest; the second focuses on present experience; and the third joins these two narratives to describe the individual's essential experience with the phenomenon" (p. 7). It is important to note that the interviews produced data that were a direct result of an individual's perceptions, knowledge, and experience in each area of focus. In this study, each interview started by discussing how the company began utilizing BIM and/or about participants' past experiences. The interview then progressed to discussing the current use of BIM as a process in the company. All interviews concluded with the participants' personal BIM experiences and current future research within the company.

Development of Interview Protocols

Interview protocols were based upon research by Brinkmann and Kvale (2009), who developed seven stages of research interviewing:

1. Thematizing
2. Designing

3. Interviewing
4. Transcribing
5. Analyzing
6. Verifying
7. Reporting.

Within their book, Brinkmann and Kvale identify Mayo's (2014, p. 65) method of interviewing as a sophisticated method, which I followed precisely in each interview:

1. Give your whole attention to the person being interviewed
2. Listen, don't talk
3. Never argue; never give advice
4. Listen to:
    a. What they want to say
    b. What they do not say
    c. What they cannot say without help
5. Plot out tentatively and for subsequent correction the pattern
6. Remember that everything said must be considered a personal confidence and not divulged to anyone.

From both of these experts, protocols were developed and can be seen in Appendix C.

Interview Procedures

The information provided in the interviews was used to help create an all-inclusive view of BIM processes for each company. The face-to-face interviews were 30–45 minutes long and were conducted at a location of participants' choice within the company. I determined that face-to-face interviews would allow more components to be recorded, noted, observed, and elaborated upon. The only request I had was that interviews be conducted in a private room (i.e., conference room or private office space).

The interviews were recorded and transcribed verbatim and reviewed along with field notes and sketches of the room. The use of a structured protocol allowed me to keep the interview protocols as close to the same procedures for each participant as possible.

The interview protocol (Appendix B) and questions were emailed to each participant two days ahead of the scheduled interview, allowing participants time to review in advance. The reason for advance email notification was threefold:

1. To ensure the company time slot for interview was still scheduled and honored.
2. To communicate the researcher's travel schedule in case of travel delays, since companies were hundreds of miles apart.
3. To give participants time to think about questions globally within the company context.

The questions selected dealt with how BIM is incorporated into company procedures and processes specifically structured toward construction project and information management.

Determination of Codes

According to Baškarada (2014), "The key objective of qualitative analysis is to identify conceptual similarities/differences and to discover types, classes, sequences, processes, patterns, or wholes" (p. 15). Knowing BIM is a process, several professionals have already broken the process down into phases and even further down into components. Messner et al. (2010) list a majority of aspects of BIM that are currently acknowledged in the industry in terms of the phases during construction. These major areas listed at the top of Figure 16—plan, design, construct, and operate—have been utilized for years. Within each area, components are identified.

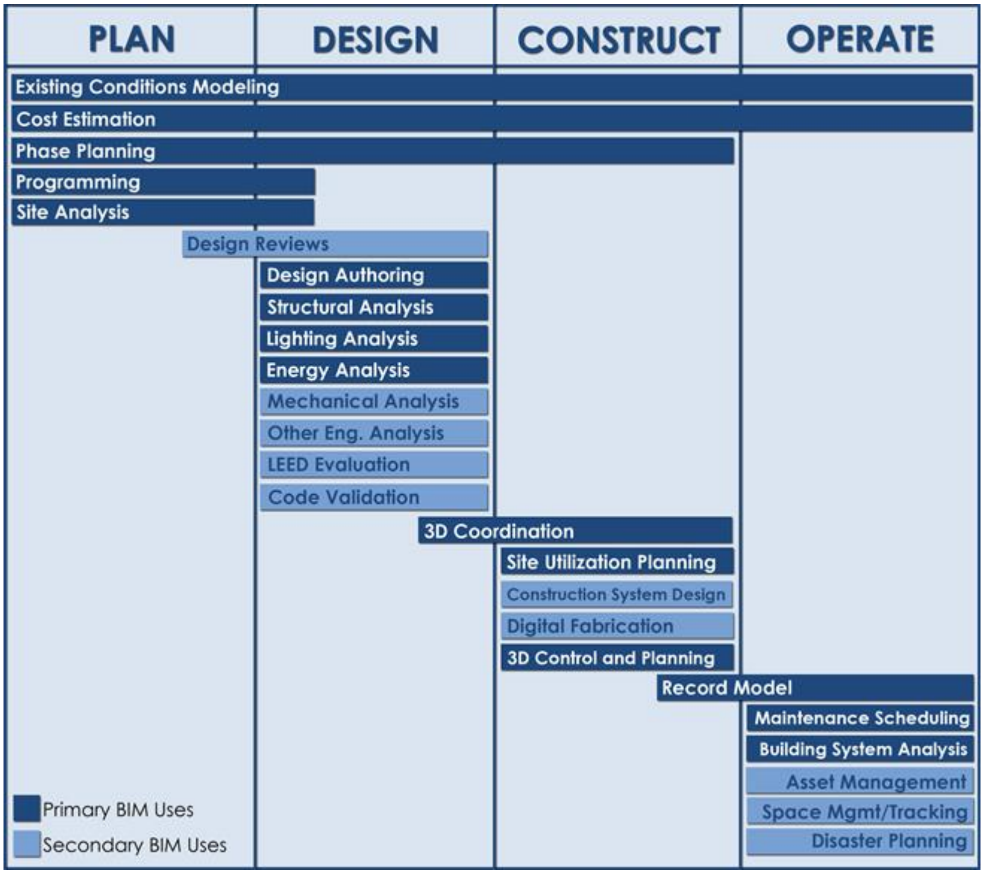

Figure 16: BIM execution plan (Messner et al., 2011, p. 9)

The components under the major areas identify specific elements during the construction process. Each of these traditional elements has evolved to include new terminology, such as the D's of BIM. The image in Figure 17 identifies BIM in terms of dimensions (e.g., 2D, 3D, 4D), as stated in Chapter 2, taken from a SmartMarket Report (2009, p. 22). Within the dimensions of BIM are elements of each dimension, demonstrating how AEC professionals have broken down the D's into clearer components. It is the position of this research to give a holistic view of BIM but also determine which process is utilized or followed within each company.

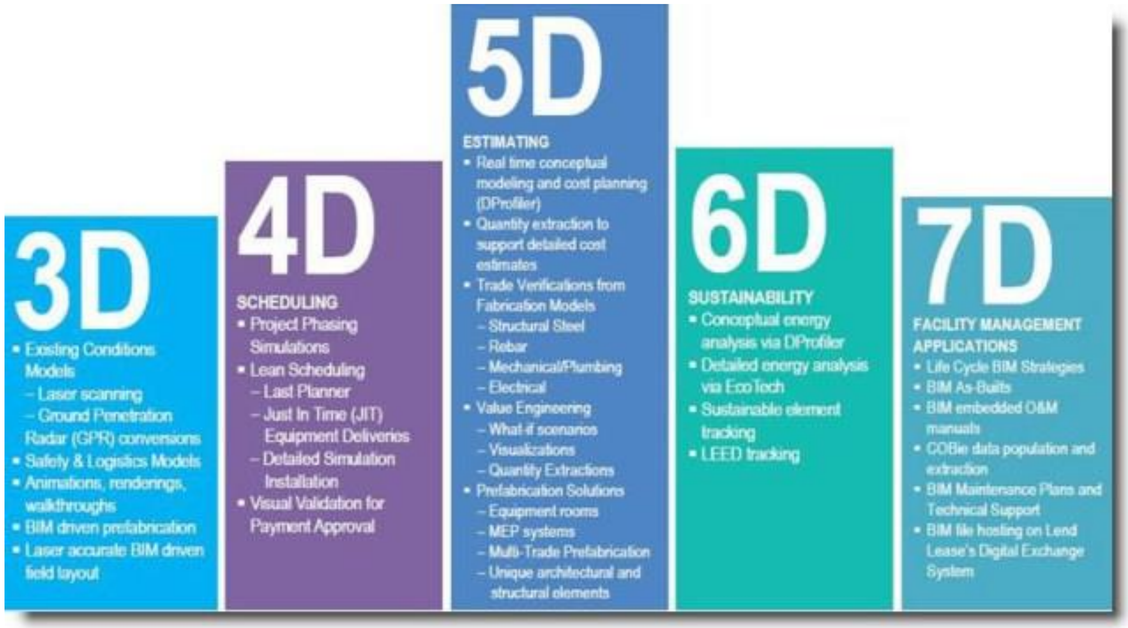

Figure 17: The D's of BIM and subcomponents

The process AEC professionals have started already clarifying BIM as a process gave a tremendous start to develop codes during analysis.

Analysis

The approach of data analysis was to develop a BIM description for each case and then use cross-case analysis for each question in interview to give cross analysis between each company's BIM processes. I utilized Yin's model for case study in the analysis which is shown below.

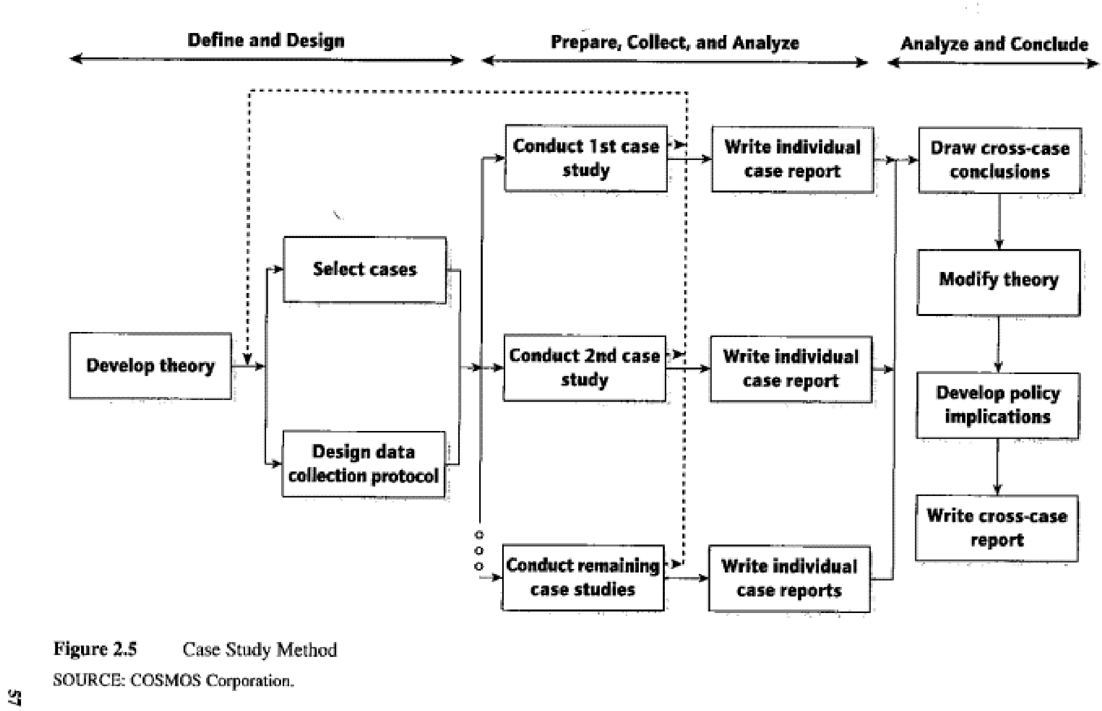

Figure 18: Yin's (2009) case study analysis model

Each case was written up to give a complete overview of that company's BIM process. Pattern matching will be the main analysis model in the cross-case analysis comparing each case to the other three company's BIM model and noting similarities and differences. Interview data were used as the main source of information for each company's BIM profile. Collecting, analyzing, and comparing data on the BIM process within the workplace would develop a grand vision of BIM in construction management practices.

Codes

According to Hartley (2004), data collection and analysis are "developed together in an iterative process," which can be a strength, as it allows for theory development that is grounded in empirical evidence (p. 329). Kohlbacher (2006) explains that "a careful description of the data and the development of categories in which to place behaviors or process have proven to be important steps in the process of analyzing the data. The data may then be organized around certain topics, key themes or central questions, and finally the data need to be examined to see how far they fit or fail to fit the expected categories" (p. 10).

The coding was developed from Figures 12 and 13 above. Messner in Figure 12 breaks the BIM process into categories: plan, design, construct, and operate. This is the start of the codes developed, but was too narrow to completely describe a company's BIM process. Doing a little more research, the D's of BIM (Figure 13) further break down each aspect of BIM. The result of combining the two figures started the development of the codes in the analysis. Knowing that the BIM process is multifaceted, I left room at the bottom of the code analysis table for other items not included. This would allow for additional aspects to be identified if they came up in interviews.

Table 4 identifies codes along the left column for case study analysis.

Table 4: Company coding form

	Company A	Company B	Company C	Company D
	CA	CB	CC	CD
Project Management	Q1			
Planning				
Design				
Bid				
Construction				
Occupancy				
BIM				
Visualization				
2D				
3D				
4D- Scheduling				
5D- Estimation				
6D- Sustainability				
7D- Facility Management				
Site Coordination				
Phase Planning				
Trade Coordination				

Design Reviews				
Programming				
Record & Contract Modeling				
Energy Analysis				
Sustainability				
Digital Fabrication				
Safety				
Code Validation				
Other				

Ethical Considerations

Being in construction for such a long time as well as education, I have realized that I am constantly learning. To ensure the quality and integrity of the research, I followed the six key principles identified in the Economic and Social Research Council (ESRC) framework for research ethics:

- I will endeavor to report all results as accurately and honestly as possible without interjecting personal beliefs or opinions into results.
- I have informed consent from all companies as well as each participant before research began.
- I will keep the confidentiality and anonymity of each company and participant.
- All participants volunteered for the research and were informed they could withdraw from interview at any time.
- I avoided harm in all cases during interviews.
- I will show the research is independent and impartial.

Trustworthiness of Data

Connelly (2016) states that data trustworthiness consists of the following components: (a) credibility, (b) transferability, (c) dependability, and (d) confirmability. Credibility was achieved in this research by asking the same questions of different research participants and collecting data from different sources. Transferability was accomplished by utilizing purposive sampling, since specific information was maximized in relation to the context in which the data collection occurred. Dependability was achieved by reporting data exactly as stated in interviews. Confirmability can be achieved because another researcher could replicate this research.

Yin (2015) identifies three components when building trustworthiness: (a) transparency, (b) methodic-ness, and (c) adherence to evidence. Being transparent, according to Yin, means you must describe and document your qualitative research procedures so that other people can review and try to understand them; all data needs to be available for inspection. Methodic-ness is having room for discovery and allowances for unanticipated events. Lastly, adherence to evidence consists, in this project, of participants' actual language, which is the representation of reality.

Patton (2002) acknowledges that the credibility of qualitative research depends on rigorous methods, the credibility of the researcher, and the philosophical belief in the value of qualitative inquiry on the part of the researcher. The majority of this chapter has been devoted to outlining the methods used in this research. All of the methodological decisions made were based on respected qualitative researchers, their personal recommendations, and their scholarly literature published over the entire range of their careers. Earlier chapters have indicated my passion toward the importance of BIM, and the research approach I have taken.

Researcher Credibility

Due to my construction and teaching experience, I believe I have essential researcher integrity and credibility in regard to this study. Although any researcher can omit important information during the course of research regardless of their years of experience, I have been involved with construction and teaching for the past 20 years, during which my passion for modeling has developed. As the first chapter documented, experiences in construction, BIM, and eventually teaching generated my curiosity, which led to the questions proposed in this research. Continuing my approach, Chapter 2 was to provide a comprehensive appraisal of building information modeling within the AEC industry. While it is up to each reader to determine and draw conclusions about researcher credibility, it is hoped that my years of work and teaching experience, combined with comprehensive literature review and strictly followed protocols, will establish credibility.

Potential Research Bias

There are multiple types of bias in research. Pannucci and Wilkins (2010) state:

> Bias can occur in the planning, data collection, analysis, and publication phases of research. Understanding research bias allows readers to critically and independently review the scientific literature and avoid treatments which are suboptimal or potentially harmful. A thorough understanding of bias and how it affects study results is essential. (p. 625)

Having spent a majority of my life surrounded with design and construction, and almost half of my career teaching, my opinions (bias) are an integral part of my life. In order not to introduce bias into the results, protocols were followed during every step of the data collection and reporting process. Ultimately, readers of this research must consider the degree to which bias was prevented by analyzing the study design and implementation.

Case analysis

A good analysis should, according to Yin (2002), attend to all evidence, address all major rival interpretations, address the most significant part of the case study, and use personal expert knowledge. Yin's definition of analysis "consists of examining, categorizing, tabulating, testing, or otherwise recombining both quantitative and qualitative evidence to address the initial propositions of a study" (p. 109). Yin assumes that through the analytic steps and techniques he describes, researchers are able to reach the objective truth about the case, or the most approximated truth. Yin offers five dominant techniques for analyzing data:

1. Pattern matching
2. Explanation building
3. Time-series analysis
4. Program logic models
5. Cross-case analysis.

In this research, each case was analyzed utilizing a cross-case analysis. In short, the thematic categories derived from the BIM process were used as a simple way to analyze cases using the number of times specific terms were spoken in responses during interview. Identifying how many times each BIM area was utilized vs overall uses gave insight as to company BIM process. The number count of coded themes was examined by subsumption and then deduction analysis. According to Flick, Von Kardoff, and Steinke (2004), "Subsumption proceeds from an already known context of features that is from a familiar rule and seeks to find this general context in the data in order to obtain knowledge about the individual case" (p. 160). This research took the answers to the interview questions and analyzed coded themes for each company based on BIM uses (subsumption) throughout the entire interview in order to find a company BIM process (deduction of case). Once the individual cases were analyzed and a BIM process was defined for each company, they were then cross-compared to the other three cases.

As noted in the literature review in the SmartMarket Report (2009), BIM is a process that encompasses multiple uses within the construction industry. Several components within BIM have been identified, which were the basis for creating the code table identified in Chapter 3. I currently do not know of a single architectural, engineering, or construction (AEC) company doing every single aspect of BIM as their company management process. An important question that needed to be answered was how to record and analyze the interview results. The analysis table below is a combination of Figure 12 in Chapter 3, in which Messner breaks down BIM into planning, design, construction, and operational components, and Table 1 in Chapter 3, which identifies company BIM codes and was utilized in interview subsumption.

Table 5: BIM use overview

Company- XX				
BIM use overview				
2D		Maintenance		
3D Coordination		Manufacturing		**Utilized**
3D Modeling		Marketing		**Not Used**
Activity Simulations		Mechanical Architecture design and Planning		**Research**
Asset Management		Mechanical Analysis		
Augmented Reality		**7D- Operations- facility managemnet**		
Clash Detection/ Trade Coordination		Other Engineering Analysis		
Code Validation		Performance Assessment		
Collaboration		Performance Simulations		
Commisioning		Phase Planning		
Communication		Process Management		
Demolition		Programming		
Demonstration of Compliance		Refurbishment/alterations		
Design Coordination		**Record & Contract Modeling- as builts**		
Design Verification		Reliable Information		
Digital Fabrication		Safety		
Digital Prototyping		**4D - Scheduling**		
Disaster Planning		Sharing Information		
Drone Utilization		Site Analysis		
Embedded Information		Site Logistics		
Energy Analysis		Structural Analysis		
5D-Estimation		**6D- Sustainability**		
Existing Conditions Modeling		Virtual Reality		
Information Managemnet		Visualization		
Laser Scanning		Other		
Lighting Analysis				

CHAPTER 4. RESULTS

Case CA

To keep the companies and people interviewed anonymous, the company names will be given as CA, CB, CC, and CD. If there was only one person interviewed, then that person will be referred to as just the company code (e.g., CB). If multiple people were involved or participated in an interview at the company, then those people will be identified with the company code and a numeral (e.g., the CB employees interviewed are CB1, CB2, CB3, and CB4).

The interview questions asked were as follows:

1. What is your definition of BIM?
2. How many years of experience does your company have with BIM?
3. How did your company make the transition in adopting BIM practices? Did it have a significant impact on your typical design & construction management process?
4. Describe your BIM use within company in terms of the different components of BIM below:

1	2D	
2	3D	
3	4D	
4	5D	
5	6D	
6	XD	
7	Site Coordination	
8	Trade Coordination	
9	Design Reviews	
10	Programming	
11	Record Modeling	
12	Energy Analysis	
13	Sustainability	

14	Other	

5. Describe your company BIM process as it relates to the 4 phases listed below

	Written or Verbal answer
Plan	
Design	
Construction	
Operate	

6. What are the advantages of BIM within your company?
7. What is your companies driving force as it relates to your firms philosophy & goals behind using BIM?
8. BIM is recognized as a visualization documentation creation tool- what about the database component within your company- Can you tell me how your company approaches visual and database information.
9. Will you need to modify your corporate practices (educational needs) incorporating more BIM into projects?
10. How does your company educate its employees on new BIM techniques or technologies?
11. How do you educate your clients on BIM trends for bid projects?
12. Pick one of the questions below as final question—within concluding or additional thoughts

Referring to table 2 in chapter 3 for complete company characteristics, company CA is a midsized construction company that has utilized BIM for approximately eight years. They started out using BIM similarly to other companies, with the upper administration telling everyone the company was going to use it and be successful, as evidenced by the interviews.

CA Findings

The start of the interview questions was intended to find out where the company started and/or to gain a historical viewpoint. A historical perspective gave me a brief look as to why the company decided to pursue BIM use. Current use identified where they were currently at, and then future look gave insight into where the company wanted to go with BIM utilization.

The interview answers for company CA show a path where they have been and where they are going in terms of their company BIM process. CA initially started implementing BIM eight years ago starting to use BIM by doing trade coordination or clash detection analysis of the combined subcontractor or individual trade models. They started BIM because the president of company CA mandated it, but did not know what it was or how to implement BIM into daily processes. As CA1 stated, "It was our company president who basically said, 'We need to pursue this. I do not know anything about it, but I see that the industry is going that way. We need to get on board.'" While their president's insight about using BIM was visionary in regard to where the company needed to be, it lacked a direction for the company's efforts in implementing BIM. According to CA, the president told him to "Learn as much as you can about BIM, what are we going to do with it, how are we going to use it. And by the way, we're going to do it on this project that you're working on." It was one of the most open-ended requests the employee had ever received from his president.

Company CA's starting and utilization of BIM eight years ago happened more than halfway into the introduction of BIM to the construction industry. Having been given a challenge by his boss, CA1 researched aspects of BIM's current status in the industry and ended up recommending and purchasing a piece of software called Revit, which turned out to be not what they needed. CA stated, "We purchased a license of Revit, but as a contractor, that's probably not what we use most. We use Navisworks to do the clash detection. Those are just tools specific to Autodesk products, but the process was what we were trying to learn." Within the last eight years, the company has progressed tremendously to include multiple aspects and uses of BIM. Back in the early days of BIM use, there was a misconception that BIM was only software, rather than the entire construction management process. From such mistakes came actual aspects of BIM ontological representation that company CA utilized until its current BIM use.

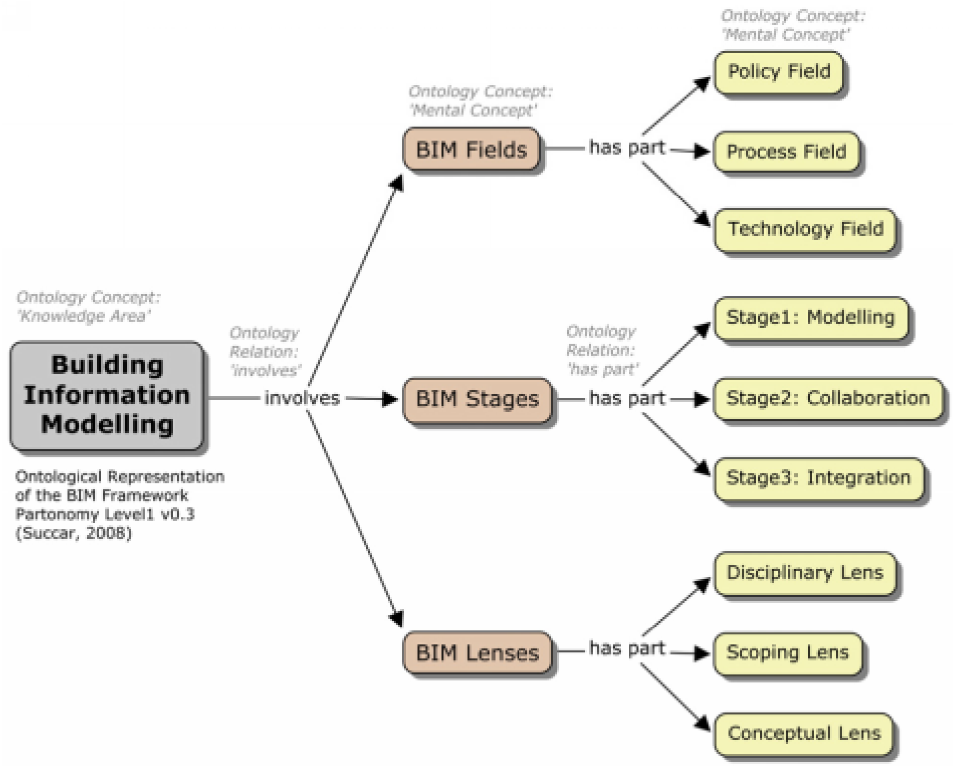

Figure 19: Ontological representation of the BIM framework (Succar, 2009)

Understanding how company CA currently utilizes BIM was crucial as well. This identified BIM ontology within the Succar BIM framework shown above. While the interview questions were not focused on fields, stages, or lenses, it became evident in the answers that multiple components of each were utilized by company CA in their BIM process. Company CA adopted a BIM process across all areas of Succar's (2009) framework.

Looking at BIM fields, and specifically the policy field first, BIM guidelines, contractual agreements, research projects, building standards, and best practices were all utilized and adopted when company CA implemented BIM. In his interview, CA talked about clients requiring BIM contracts now in all of their projects: "It's the way that the world is starting to work in the Internet of Things as a new wave of technology that's coming, and this is a client requirement."

The company decided to change traditional project management over to BIM processes a few years after the initial implantation of clash detection. They were in full use of BIM processes and decided that changing slightly, to the plan, design, construct, and operate model of BIM use, was better for the company than using the D's of BIM. CA stated, "I'm more of an advocate in just explaining those D's of BIM in terms of how we work and what we're trying to solve. I described BIM as a process; it is also a tool that allows us to work more efficiently. So instead of coming up with the new term like 4D to represent estimating, we just use the model for estimating, and instead of 5D for scheduling, we just use scheduling."

The BIM model of plan, design, construct, and operate was developed from more of a traditional construction project management model. Rather than change the entire company's mode of thinking and doing, company CA decided to keep some traditional construction management processes and traditions alive while just modifying content within them.

BIM as a process is used to manage projects effectively, as identified in this response from CA: "You need to recognize that BIM is a tool and identify the ways to use it effectively and not just use it for the sake of using it, and that's where we really tried to focus our energy." The table below provides a look at what the company does in terms of pattern matching utilization of the model and BIM use. Identified with a blue box are all the BIM components that company CA implemented or incorporated into its company and project management. The red boxes over the BIM uses and components mark items that were not implemented, but are a possibility for future research and integration. Several of the green items were currently being analyzed for how they could help the company. CA stated this about their approach to research and utilization of new technologies: "How can we help our project teams be more efficient? How can we make your job easier, provide you information and feedback on what's going on onsite faster?" That is the concept I heard repeatedly within the interview: how any use or process can be done in BIM to help the company be more efficient and communicate effectively. Below is the table of BIM components utilized by the company and recorded in interview answers.

Table 6: BIM use overview for company CA

Company- CA		
BIM use overview		
2D	Maintenance	
3D Coordination	Manufacturing	**Utilized**
3D Modeling	Marketing	**Not Used**
Activity Simulations	Mechanical Architecture design and Planning	**Being Investigated**
Asset Management	Mechanical Analysis	
Augmented Reality	**7D- Operations- facility managemnet**	
Clash Detection/ Trade Coordination	Other Engineering Analysis	
Code Validation	Performance Assessment	
Collaboration	Performance Simulations	
Commisioning	Phase Planning	
Communication	Process Management	
Demolition	Programming	
Demonstration of Compliance	Refurbishment/alterations	
Design Coordination	**Record & Contract Modeling- as builts**	
Design Verification	Reliable Information	
Digital Fabrication	Safety	
Digital Prototyping	**4D - Scheduling**	
Disaster Planning	Sharing Information	
Drone Utilization	Site Analysis	
Embedded Information	Site Logistics	
Energy Analysis	Structural Analysis	
5D-Estimation	**6D- Sustainability**	
Existing Conditions Modeling	Virtual Reality	
Information Managemnet	Visualization	
Laser Scanning	Other	
Lighting Analysis		

From the table, one can see the amount of BIM that company CA utilizes marked in blue. The red indicates no use, and the green identifies researched areas.

BIM Benefits

Today with BIM, the process is more communicative: problems are found early in the 3D model and resolved, while everyone affected by a problem is brought into a meeting to talk about it. As CA identified, "We have eliminated a ton of errors in design over the last seven years when we're involved early. So where I had mentioned putting that effort upfront, the sooner we're involved in design, the better." It is more problem seeking, so when the actual construction takes place, everything is in the correct location. CA stated: "The model is kind of the conduit at which collaboration can happen between designer and builder. I think that's where the real power of BIM may be a benefit that no one anticipated, [that] was actually [that] having that visual representation allows the contractor to come to the table with, 'Hey, what about this?' Given that BIM is a conduit now, communication has increased tremendously across all parties involved in building, including the clients!"

There are multiple benefits to BIM as identified by Le Fevre and Epps (2007). Several of these benefits were identified in the interview answers for company CA. BIM saves them time and money, helps them visualize and understand the structure, improves teamwork, makes items verifiable, and gives the company as well as clients a value-added benefit. While these are specific benefits, they all come from BIM uses on the jobsite and in the construction company's main office.

The following uses of BIM, as laid out by Griffis, Hogan, and Li (1995), were all identified as common usage within company CA:

- MEP Coordination
- Estimation
- Scheduling
- Checking clearances and access
- Visualizing details from non-standard viewpoints
- Using the model as a reference during project meetings
- Performing constructability reviews

This list included a few more items than Griffis, Hogan, and Li described, but essentially, most of the benefits they identified were also stated as utilized by the company in interview answers by CA.

Impediments of BIM: Additional Issues

There were really no impediments to using the 3D model in construction, according to CA, at least not in that company. It did change the way company CA approached projects: "I believe that BIM changes the amount of effort upfront but eliminates a lot of effort on the back end. I would say that BIM is a process that we used to build buildings virtually rather than in the field, and it helps us reduce errors and become more efficient when we actually get out onsite." While some impediments were implied—such as inertia of employees to use of technology, or training costs, which could be perceived as an impediment by non-users—the entire company training helped alleviate other issues, like undetermined economic impacts and lack of trained users. CA never really identified any impediments the company went through during adoption of BIM.

The perceived advantages were evident in CA's answers. All the items listed in Griffis, Hogan, and Li (1995) were identified in every project CA discussed. The benefits identified by CA for their projects were:

- Reducing interference problems
- Assisting in visualization
- Reducing rework
- Improving engineering accuracy
- Improving jobsite communication
- Time
- Money
- Understanding

Despite these real and perceived benefits, the integration of differing technologies continues to be a troubling aspect of BIM. With multiple applications a company could use focusing on individual trades, it is hard to determine the interactivity of those technologies with each other. A technology called Navisworks allows 95% of technologies to be merged into one unified Navisworks file for all parties involved to see how their portion interacts with other trades. CA discussed the issue this way: "How can we provide information that feeds into that so that they don't have to learn any software? So that's what their goals are on the project, and BIM has been a huge—more so than any other project I've been on, it's been an upfront discussion like, 'What is the goal we want out of this job?' It's been 'How do we get the model to make sure we do this? How do we eliminate rework for people?' The owner has been driving that, which has been an awesome thing, and they've asked for us to help guide them through the process of what do they need to be asking for and when." Clients asking for technology to make communication between all parties building the structure is significant. Making changes early, well before actual construction happens, literally saves the client thousands of dollars down the road.

Training for Company

Company CA has monthly newsletters on technology to keep all employees informed on what is being used in the virtual design department. CA said, “One way to educate employees is we send out a monthly publication that is our construction services bulletin. It includes a blurb for quality, for preconstruction, and for BIM, and it keeps them up to date on what’s new or what we’re doing new.” They have a novel approach also: to track who has read it by creating a video and posting on YouTube. According to CA, “You can see on YouTube how many views you get. You can see how much people are actually looking at it.” A library of YouTube videos with the ability for employees to access it at any time is a visionary approach!

They also have monthly training sessions on different technologies. CA stated, “We held training for, we called it a BIM 101 and a BIM 102, on hands-on how to use the software. So how to navigate, how to open up a model if you needed to, how to identify within the selection tree. It’s not clash detection because that’s probably more in line with what we do and they wouldn’t be involved, but recognizing how to use the software, and if you need to open up a model, how to do that. So it was a hands-on training thing.” This happened early in the company’s BIM use. After several project managers (PMs) got used to navigation and use of BIM technologies, they were able to expand their training sessions to include case studies. They called these “BIM and Breakfast” or “Learning over Lunch.” According to CA, “We had a breakfast, we made pancakes, we brought all the PMs and superintendents who wanted to come, and we had presentations on case studies of using BIM where our PMs who were involved in the project. We [the virtual design department] didn’t do the presentation. They said, ‘Let the PM who’s on the project sell it for us. We want them to say what’s the value, and how do they use it, and what do they see as the benefit.’ That was very well received. It was a great thing.”

Time and training, mostly training, are the unperceived issues with BIM. While it is making the company more efficient and effective, there are hidden costs associated with using it. That unfortunately is the case with any new technology. There is a learning curve for everyone, and that costs money and time.

Training for Clients

Training a client in the construction industry never used to be a concept any construction company thought would be necessary. Today's client, however, has instant access to modeled information. Client training has almost become part of the construction process. CA stated, "We went down to [the client's] architect's office there, and we gave them a Navisworks training on how to open up a model, how to section a model, how to go through viewpoints, and inform them on where're some more things they should ask for in modeling." We are in an era when everyone is focused on the end solution—total construction of the building. When there are problems, it is best to let the individuals who know and are expert in that are to resolve the problem. As CA stated, "A lot of times people who don't operate in that environment day in and day out, they're not comfortable with it because they see all these shapes" and have trouble understanding the 3D geometry used by the technology. This open dialog between trades has become extremely beneficial and is mostly due to BIM and its uses and benefits.

Research for Company CA

According to Abudayyeh et al. (2004), "The construction industry is one of the largest and oldest industries in the United States. However it is one of the least researched" (p. 433). It has taken a long time for the construction industry to realize that construction is more than just building structures. It is made up of a multitude of people, from the general laborers who perform the actual construction to professionals who solve day-to-day problems through research and discovery on new technologies and materials that improve methods and processes of construction. Throughout company CA's interview, every response mentioned research. The idea of asking questions that needed to be resolved and then determining the best course of action was evident. CA stated, "What their goals are on the project, and how BIM has been a huge—more so than any other project I've been on, it's been an upfront discussion like,

1. 'What is the goal we want out of this job?'
2. 'How do we get the model to make sure we do this?'
3. 'How do we eliminate rework for people?'"

Every question had some component of research. At the end of the interview, after the recording was off, CA and I got into a conversation over lunch about what they were researching within the company. On a construction jobsite, problems arise naturally and are resolved quickly. Industry professionals don't consider these daily problems to be research or development, but simply doing their jobs. Our lunch discussion, though, was about research into new technologies that could be utilized on a jobsite, like 4D scheduling, drones, robotics, and laser scanning. These seem to be the hot topics currently in construction research.

Many engineer-constructors have in-house research and development units to solve problems, but with a few exceptions, they usually do not interact with research institutions. Harris (1992) states, "One reason for this lack of interaction between academia and construction is that the time between problem recognition and project finalization is too short for a true research study." Time is not something the construction industry has a great deal of. Sitting down with CA over lunch, it was evident that a research partnership is needed between companies and higher education. The model of this partnership needs to be different from current research grants. Unfortunately, construction companies cannot see value in giving higher education institutes 50% of their money to research a topic, only to get in return nothing more than the ability to use that research in their company.

The bottom line is that construction companies want a return on their investment and will sell it industry wide to make all company processes more productive. When higher education owns 100% of the research generated, the construction industry will do all their own research in-house. This was how our lunch discussion ended. I am doing what I can, though, to break the barrier, with this project as a working partnership between construction and academia where both parties benefit. It has been a 15-year struggle and it is due entirely to academia refusing to change their research regulations and policies.

BIM Conclusion of Company CA

While company CA might have started off a little slower than other companies years ago in adopting BIM into their construction management and practices, they have made tremendous leaps in catching the rest of the industry and in most aspects exceeding what industry is doing currently. They have a majority of areas covered in daily practices from utilizing BIM. They have a few more to implement, but by CA's account, BIM is working well in the company, and they only activate new foci if the new process will benefit the company in workflow, time, money savings, and communication.

Case CB

Company CB is a large construction company that has utilized BIM for approximately 11 years. They started out using BIM similarly to other companies, with the upper administration telling everyone the company was going to use it and be successful, as evidenced by the interviews. The interview questions asked were to gain insight into Company CB's BIM process and resolve the problem statement for this research:

- How has BIM influenced a construction manager's current position?
- How has BIM influenced a construction manager's need for continuing education within the industry?

CB Findings

The start of the interview questions was intended to find out where the company started and/or obtain a historical viewpoint. A historical perspective gave me a brief look into why the company decided to pursue BIM use. Current use identified where they were currently at, and then a future look gave insight into where the company wanted to go with BIM utilization.

The interview answers for company CB show a path from where they have been to where they are going in terms of their company BIM process. They initially started implementing BIM 10 years ago through what CB1 identified as organic growth. CB1 stated, "The leadership of our company knew that BIM was the next industry trend, and we needed to do something with it, hired a few experienced people—or that were coming out of school—to really understand what BIM was. As it started changing the face of the industry, we continued to be on the edge of capturing the right people and the right tools, and refining our processes and what we do so then. Now, it's not top down, but it's the way we do our jobs. It's kind of organic growth, and people started seeing the need and continue to grow organically, I think."

While their upper management's insight to using BIM was visionary to getting the company where it needed to be for continued future success, it was lacking direction regarding where the company needed to focus efforts for implementing BIM. CB1 said, "They started out as planning and support service as a way to visualize what we were going to build well in advance of anything else." Unlike most construction companies, which start off with collision detection, company CB utilized BIM as a way to visualize and communicate in the construction process. Company CB did not model structures, either, which was unheard of when BIM started because it was all about model utilization. Company CB was more about management on the construction side as well as BIM integration.

The type of BIM process that company CB identified with was more about calling a process by its name rather than utilization of D's in BIM. The company is invested in areas utilizing BIM that are crucial to their company success. From planning all the way through facility management, company CB utilizes some aspect of BIM. From Figure 16 below, one can see each aspect of BIM that is used and who utilizes it.

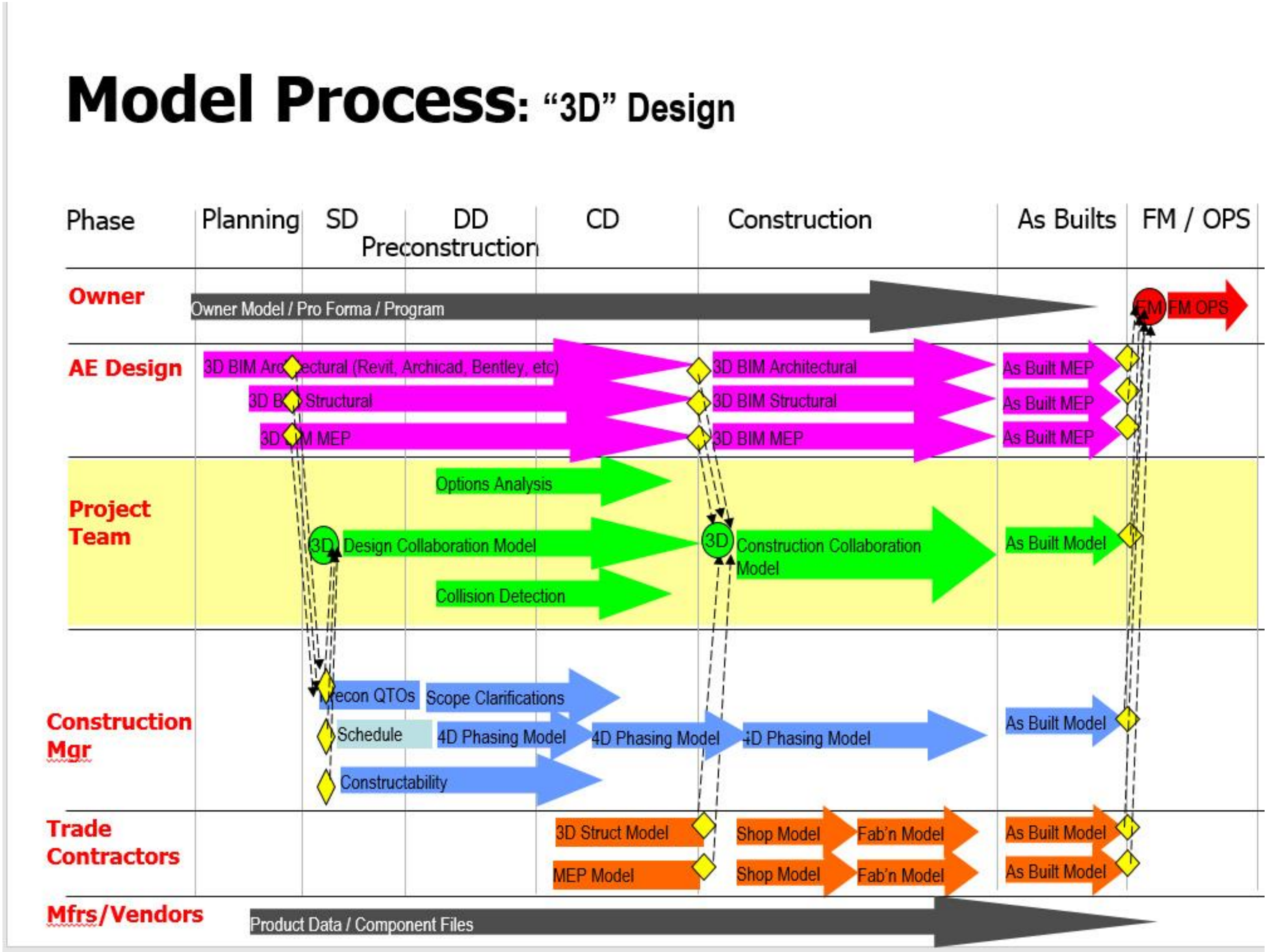

Figure 20: Modeling process and BIM utilization of company CB

As one can see, they try to incorporate BIM into every aspect and person involved with the construction of the building.

Table 7, below, provides a look at what the company does in terms of pattern matching utilization of the model and BIM use. Marked with a blue box are all the BIM components that company CB implemented or incorporated into its company and project management. The red boxes over the BIM uses and components represent items that were not implemented, but remain a possibility for future research and integration.

Table 7: BIM use overview for Company CB

Company- CB BIM use overview	Status		Status
2D	Utilized	Maintenance	Not Used
3D Coordination	Utilized	Manufacturing	Not Used
3D Modeling	Utilized	Marketing	Utilized
Activity Simulations	Utilized	Mechanical Architecture design and Planning	Utilized
Asset Management	Utilized	Mechanical Analysis	Utilized
Augmented Reality	Used + Research	**7D- Operations- facility managemnet**	Used + Research
Clash Detection/ Trade Coordination	Utilized	Other Engineering Analysis	Being Investigated
Code Validation	Utilized	Performance Assessment	Utilized
Collaboration	Utilized	Performance Simulations	Utilized
Commisioning	Utilized	Phase Planning	Utilized
Communication	Utilized	Process Management	Utilized
Demolition	Not Used	Programming	Being Investigated
Demonstration of Compliance	Utilized	Refurbishment/alterations	Utilized
Design Coordination	Utilized	**Record & Contract Modeling- as builts**	Utilized
Design Verification	Utilized	Reliable Information	Utilized
Digital Fabrication	Not Used	Safety	Used + Research
Digital Prototyping	Not Used	**4D - Scheduling**	Utilized
Disaster Planning	Not Used	Sharing Information	Utilized
Drone Utilization	Used + Research	Site Analysis	Utilized
Embedded Information	Utilized	Site Logistics	Utilized
Energy Analysis	Not Used	Structural Analysis	Utilized
5D-Estimation	Utilized	**6D- Sustainability**	Utilized
Existing Conditions Modeling	Utilized	Virtual Reality	Used + Research
Information Managemnet	Utilized	Visualization	Utilized
Laser Scanning	Utilized	Other	
Lighting Analysis	Not Used	**Risk Management**	Utilized

Legend
Utilized
Not Used
Being Investigated
Used + Research

Company CB had something that company CA did not: they were researching areas as well as utilizing them. This changed the results to include a new category in gold. The difference between utilized and used & researched is that when they utilized categories, it was a constant process and utilized on every project. When they used & researched, it was not for every project but for when the company was trying to determine whether a new technology or process would be beneficial in the overall management process to both the company and the client. This changed the table a bit from what was recorded in company CA.

Even though the table changed a bit, company CB is utilizing most BIM processes in company management. CB1 identified these functions in interview as "How to make your job easier, provide information and feedback on what's going on onsite faster." That is the concept I heard repeatedly within the interview: how any use or process can be done in BIM to help the company be more efficient and communicate effectively—a concept that recurred in the second interview as well.

BIM Benefits to CB

Today with BIM, the process is more communicative. Problems are found early in the 3D model and resolved, while everyone affected by a problem is brought into a meeting to talk about it. As CB1 identified, "BIM isn't a software! I want to say, I guess, it's a process. It's not even a process; it's something we use as a tool to facilitate everything we do, between going after a job and just visual, or using the information, or showing information, all the way to the end of passing information over to the owner. It's really, at least for us, just a tool to help us in every piece of what we do as a general contractor." While company CB integrates it throughout their entire company, the Virtual Design in Construction (VDC) department identifies themselves as visual problem solvers. CB2 stated, "I'm a problem solver, I'm a builder, and I have really cool tools that can probably do your job even better; or I'm on the cutting edge of technology, so I can try some new things on my projects, and let my field team see all of the great resources that I have." It is more about finding digital problems well ahead of anticipated installation so when the actual construction takes place, everything is in the correct location.

Throughout their interviews, CB1 and CB2 identified multiple benefits of BIM to their company. Their BIM process saves them time and money, helps them visualize and understand the structure, improves teamwork, makes items verifiable, and gives the company as well as clients a value-added benefit. Company CB identified all the following uses and benefits of BIM, as listed by Griffis, Hogan, and Li (1995), as common usage within the company:

- 2D utilization
- 3D manipulation
- MEP coordination
- Estimation
- Scheduling
- Checking clearances and access
- Visualizing details from non-standard viewpoints
- Using the model as a reference during project meetings

- Performing constructability reviews

One item that was identified by CB1 was risk management. Burtonshaw-Gunn (2017) describes risk management within construction this way: "Risk Management is a means of dealing with uncertainty—identifying sources of uncertainty and the risks associated with them, and then managing those risks such that negative outcomes are minimized (or avoided altogether), and any positive outcomes are capitalized upon" (p. 1). CB1 stated, "Risk management is a huge thing, right, is managing our risk of some of those challenging items or options, or something like that that we really need to analyze our risk on that project, and we can do that through a model, to really understand and plan for it, so we can build it successfully once." I dealt with risk management when I was in industry, but had not thought how BIM could help alleviate those issues that arise on a jobsite. Identifying how BIM helps with risk management utilizing the model seemed to me like a huge benefit, and therefore I included it in the other area on company CB's BIM pattern matching table.

Impediments of BIM: Additional Issues

There were really no impediments to using the 3D model in construction according to CB1, at least not in their company. Similar to what CA stated, CB1 stated "It's really, at least for us, just a tool to help us in every piece of what we do as a general contractor." While the same impediments were implied as for company CA, the entire company training helped alleviate other issues like undetermined economic impacts and lack of trained users. CB1 identified the existence of training and user inertia, but did not refer to these or any other issues as impediments the company went through during adoption of BIM.

Even though there are several real and perceived benefits, one of the real impediments is the integration of differing technologies, which continues to be a troubling aspect of BIM. With multiple applications a company could use focusing on individual trades, it is hard to determine interactivity of those technologies with each other. Company CB also utilizes a technology called Navisworks, which allows 95% of currently used technologies to be merged into one unified Navisworks file for all parties involved to see how their portion interacts with other trades. Even then, they say that with the inclusion of every technology utilized, it is almost impossible for them as a company or individual to know them all effectively. The G2 Crowd website has listed more than 55 different applications potentially utilized in the BIM process.

Training for Company

I found in the interview that company CB has multiple methods of training. CB2 stated, "I do a lot of training on the jobsite. I'll say, I do as much one-on-one as I possibly can. That's the most impactful, particularly to the field side of life, [because] the superintendents, the field coordinators, those guys that are in the field walking the job, don't have time to go back to the trailer midday and get trained up in a training class." Training happens in every industry in one capacity or another; the issue in construction is that training happens while a project is being built with a limited schedule to completion. CB2 stated, "I make training as simple as possible. I do the work on the front end, and make sure all they have to do is open a file. That's something I learned going from office to field; you can never underestimate how valuable ease of use is for the field, and that's why one-on-one and hijacking computers, and spending the time doing the hard stuff for the people who don't have time for the hard stuff, that's real training to me. That's how you get people actually using technology outside the BIM group."

Along with field training, company CB also does corporate training in-house. CB1 stated, "I think at a corporate level, we have our learning management system that houses our training classes that people can access through online, or physically in-person at our offices." I found it interesting that they have an online learning or training program in place: "We rolled out a program a couple years ago with BIM tier training, so get your BIM degree on all the tools you could use for your job. Those resources are always out there as new associates come on board," according to CB1. Aspects of training included "Wiki pages, and on-demand videos, our internal YouTube videos to teach people how to use technology and BIM."

Training for Clients

As for company CA, training clients was part of the process for CB. CB1 stated, "Sometimes, even in interviews, we have to educate on how we use BIM. We do any kind of training as we first start a project; we have BIM execution planning meetings to get everyone on the same level, and then we do training as we see fit with owners, same sort of training we do with our associates."

Everyone is focused on the end solution, including the client—total construction of the building. BIM open dialog between trades, project managers, clients, and architects has become extremely beneficial on projects and within the construction industry overall.

Research for Company CB

Company CB seemed to be doing as much research as company CA. I had the same sort of findings about company CB's research, over lunch after the interview. I found out about how much they were doing, which changed the BIM pattern matching table for company CB. Company CB seemed to be utilizing aspects of BIM on a jobsite while also researching how each component would benefit the company. Items like AR and VR were being utilized on projects for client visualization or safety training. CB2 stated they sent a client a VR headset with visual instructions for how to use it, then log into the company's cloud project storage site to do a virtual tour of his new building. All the while, company CB was having a phone conference call with the client to help with problems or change aspects of the building the client did not like. Drones are not part of BIM currently, but company CB is integrating the model into the flight plan of the drone for safety inspections both outside and inside the structure. Utilizing the model with a drone inside the building has not been researched anywhere to date, according to all my research.

Similar to company CA, company CB is doing all research in-house. Company CB wants to see return on their investment, like all other construction companies, and to partner with higher education would not give them ownership of the product unless they were to give away 56% of what they invest. Their reasoning was they can put that 56% to good use and hire internal people to do the research for them and retain 100% of the ownership.

Case CC

Company CC is a large construction company that has utilized BIM for approximately nine years. Company CC is in the southern part of the US and deals mostly with commercial buildings. The interview questions asked were to gain insight into Company CC's BIM process and resolve the problem statement for this research:

- How has BIM influenced a construction manager's current position?
- How has BIM influenced a construction manager's need for continuing education within the industry?

CC Findings

The start of the interview questions was designed to find out where the company started and/or to obtain a historical viewpoint. A historical perspective gave me a brief look into why the company decided to pursue BIM use. The interview with CC was difficult, to say the least. The interview timeframe had to be strictly adhered to because CC had meetings right afterward. In this interview, I asked the questions and received very precise and compressed answers, rather than the more conversational style of my interviews with CA and CB. To the first question, about how long the company had been using BIM, CC responded, "It started back in 2009 over in Denver for us." In company CC's case, the driving force was outside of the company and came from two sources. The first was clients who wanted it integrated into their projects. The second was government agencies with which company CC worked frequently, that required BIM in every request for bids. It was either utilize BIM to bid on projects or cease to work. I did find out a lot about company CC's BIM process, but where the first two company's interviews went over the time limit a bit, this interview was completed 10 minutes ahead of schedule.

The BIM process CC identified was a combination of both the D's of BIM and the traditional terminology. The interviewee went back and forth, utilizing the D's of BIM and then switching over to traditional terminology like "estimation" and "scheduling." The company seemed invested in utilizing BIM crucial to their company success. Company success came up in responses similar to those of both company CA and CB, focusing on utilizing certain aspects of BIM beneficial to company processes.

Table 8, below, provides a look at what the company does in terms of pattern matching utilization of the model and BIM use. Identified with a blue box are all the BIM components that Company CA implemented or incorporated into its company and project management. The red boxes over the BIM uses and components represent items that were not implemented, but remain a possibility for future research and integration.

Table 8: BIM use overview for Company CC

Company- CC		
BIM use overview		
2D	Maintenance	
3D Coordination	Manufacturing	**Utilized**
3D Modeling	Marketing	**Not Used**
Activity Simulations	Mechanical Architecture design and Planning	**Being Investigated**
Asset Management	Mechanical Analysis	Used + Research
Augmented Reality	**7D- Operations- facility managemnet**	
Clash Detection/ Trade Coordination	Other Engineering Analysis	
Code Validation	Performance Assessment	
Collaboration	Performance Simulations	
Commisioning	Phase Planning	
Communication	Process Management	
Demolition	Programming	
Demonstration of Compliance	Refurbishment/alterations	
Design Coordination	**Record & Contract Modeling- as builts**	
Design Verification	Reliable Information	
Digital Fabrication	Safety	
Digital Prototyping	**4D - Scheduling**	
Disaster Planning	Sharing Information	
Drone Utilization	Site Analysis	
Embedded Information	Site Logistics	
Energy Analysis	Structural Analysis	
5D-Estimation	**6D- Sustainability**	
Existing Conditions Modeling	Virtual Reality	
Information Managemnet	Visualization	
Laser Scanning	Walk Throughs	
Lighting Analysis	**Other**	
LEED Evaluation		

While one can see a tremendous utilization of BIM components, there are several items not explored by company CC. Because the interview was very brief, I cannot say whether this company is just not utilizing aspects of BIM like companies CA and CB or does not have time to determine whether they would be helpful. Either way, company CC is using BIM to manage construction projects. They may not get into the structural components or the other engineering analyses, but like the other companies, they use it a great deal in day-to-day operations.

BIM Benefits to CC

The BIM process is essentially communicative; problems are found early in the 3D model and resolved, while everyone affected by the problem is brought into a meeting to talk about it. CC stated, “Our definition of BIM is essentially using the tool to analyze for constructability, for estimating, for, I mean, quantity takeoffs, a whole myriad of things we can use it for to analyze it on the computer, essentially, to make the construction arm of our company more efficient.” Looking at the whole BIM company process, company CC does the standard aspects of BIM, but that is about all—or, as CC1 stated, “It’s still ongoing. And I’ll be honest about that, it’s still ongoing.” For company CC, it was about finding problems digitally well ahead of anticipated installation so that when the actual construction takes place, everything is in the correct location and there are no conflicts between any subcontractors.

Throughout the entire interview, CB1 and CB2 identified multiple benefits of BIM to their company. With company CC, it was different. CC1 stuck to the specific questions and never elaborated more on them. It was a lot more difficult to identify the company’s BIM processes completely. However, it seems that they use BIM in all phases of construction, as companies CA and CB do, and that their BIM process saves them time and money, helps them visualize and understand structure, improves teamwork, provides verifiable items, and gives the company and its clients a value-added benefit, as for companies CA and CB.

Impediments of BIM: Additional Issues

Company CC saw really no impediments to using BIM within the company. Although this was not stated outright, the amount of training and research done for VDC people to keep up was a very real and perceived issue that gave back multiple benefits. As CC stated, “So, I’m constantly researching. It may not be, I can’t put a hard number of hours to it, because it changes from week to week.” The real question, however, is whether improving one’s self is an actual impediment. Even with all the time devoted to research, CC said that with the inclusion of every technology utilized, it is almost impossible for them as an individual or company to know all technologies effectively. That is why they constantly research and learn.

Training for Company

Company CC started off doing online training that evolved into more hands-on training companywide. This seemed to be limited training because, according to CC, "We don't have the resources there to do as much field training, or as much office training as we would like. It's on a case-by-case basis." Unlike the first two companies, company CC does training only when there is an issue. Research constantly happens, but companywide training does not. A select few employees get together once a month to discuss issues on each jobsite they are working on in order to get different perspectives on resolving issues. Beyond that, I was a bit shocked to find that more in-house training or education does not happen with BIM company use. CC stated, "It's a definite goal that we have to get everyone field trained. Because in my view, I would want my job eventually to be obsolete. I want it to be a part of the industry part of this company, so that everyone has some BIM knowledge, and can move forward and make it part of the culture all together."

Training for Clients

Training for a client is also in development. Company CC has a six-step process for how BIM makes the company more efficient. CC stated, "I think the general education starts when we are solving something like initial design issues. Before we even mobilize to the site, we are asking relevant questions on general coordination, layout questions, that sort of thing. To a lot of our clients who are new to the process, it opens their eyes and makes us, shows that we are a diligent contractor, that we are looking at these things ahead of time, and it opens their eyes to what tools are you using to be generating these questions."

Client training has become part of the construction process for most companies. CC1 stated, "It sets that impression that we were this diligent contractor, so the second phase of that project now has a BIM requirement, right, so they've seen the benefits, they've seen the usefulness of it, and they want to move forward in the future, not just for this project, not just for this campus, but for any projects they have in the future."

Research for Company CC

Company CC seemed not to be doing as much future research as the other companies. It was more about immediate research to solve problems on the digital model so they could keep moving forward. CC1 did attend Autodesk University, where he said he sat in on a photogrammetry session. Photogrammetry is using a series of snapshots to essentially create models from pictures. While this would be ideal for remodeled buildings, I don't see a use in new construction, other than doing as-built documentation once the building was done. Beyond that research, CC stated specifically that they were not looking at drone use or laser scanning or anything else. One can infer that might be due to a large amount of work keeping them occupied. Being busy would be a good reason not to get much outside research done.

Case CD

Company CD is a large mechanical construction company that has utilized BIM for approximately 13 years. Company CD is in the northeast part of the US and deals only with mechanical systems. Mechanical systems can be called the internal components of the building, such as the plumbing and wiring or heating and cooling systems. The interview questions asked were to gain insight into company CD's BIM process and resolve the problem statement for this research:

- How has BIM influenced a construction manager's current position?
- How has BIM influenced a construction manager's need for continuing education within the industry?

CD Findings

The interview questions began by finding out where the company started and obtaining a historical viewpoint on why the company decided to pursue BIM use. This anticipated single-person interview quickly turned into a panel discussion. As I walked into the company to meet CD1 and we proceeded to the conference room, we stopped to meet a person from IT, then met a person from their VDC area, and then met another person from the production line, all of whom decided to sit in on the interview. I thought a perspective from different areas of BIM usage within the company would give the clearest picture possible.

Their definition of BIM was a little different than current industry standards. CD3 stated, “We don’t have some weird three-letter acronym for technology in almost any other area of human activity, but for some reason in construction we had to have our own name. It served its purpose, but I prefer to use words like ‘technology,’ right, to describe what BIM is. So it’s technology as it applies to the construction, prefabrication, modular construction, to the AEC industry.” The construction industry has so many three- and four-letter acronyms already that this company’s refusal to restrict its BIM description was interesting. The use of technology was probably the simplest description or definition of BIM in the entire research.

Company CD is a mechanical, electrical, and plumbing (MEP) contractor or subcontractor, and BIM use is just now hitting most mechanical contractors hard, with mechanical contractors required to create their portion of the model and then give it to the general contractor for coordination. Company CD’s 13 years of utilizing BIM was far longer than anticipated. In fact, it was the most utilized in any of the four companies. CD3 identified the key component of BIM as the 3D model. Instead of just saying “model,” CD3 always identified it as “3D model,” as here: “A central feature of it is certainly 3D modeling, which was the central technology involved in tying together construction activity with pre-planning, with early information, with scheduling, with all these other things that are involved in what we’re ultimately trying to do. So 3D modeling was certainly integral to it. For the [CD] group in particular, 3D modeling is an enormously central component.”

The type of BIM process that company CD identified and utilized was specifically traditional terminology like “estimation” or “scheduling.” They did not like the use of D’s when discussing any part of BIM. CD3 stated, “So I’ll just kick this off here. We use BIM, and again I hate that word, but we use the 3D modeling technology across the board for all of our estimating efforts. So in other words, when we do an estimate, we’re in effect modeling. Now obviously we’re not taking anywhere near the care to coordinate to the level of detail that we would for a job where we’ve been awarded the work, but we are, we’re using really specific technologies to make the ‘modeling process’ very, very quick. And we’ll do very, very high-level coordination because you’ve got to count changes in direction and changes in elevation, because they involve elbows and fittings and different labor factors. And if you go into a job missing all of those changes in elevation and building material, your quantities are going to be way off, right?"

CD2 chimed in from the quantity takeoff department: "Right. And with the estimate portion of it, that if I can say is really just information, pure information, even though there is geometry involved in it, it's not until we get to the coordination portion where that is the main focus, is geometry and coordination and implementing Navisworks now to understand exactly what each trade has to do. The estimating takes into account, like [CD3] said, major things structural, avoiding structure. Now it comes to the point where you have other players involved and bringing everybody else in, and then coordinating not only with the structure and architectural but now with all the trades. So that's where geometry is the main goal, it's the main focus. There's some information that's sprinkled in there at the same time, but this is the only process where it's not really the main goal or focus. So it's really all about coordination, getting to that signoff."

This brought a lengthy discussion from just about everyone in the room. Once CD3 and CD2 had their say about BIM use within the company, CD1 stated, "But the coordination has to be real. So we're building a model with geometry, with constructability in mind—also with real entities. So for example, the equipment that we're purchasing for the job, the type of system that we're installing, whether it be a welded system or a groove system. All of that is required information that we need as a department before we start actually modeling, because you've got to model with what it is that you're going to be building."

Table 9, below, provides a look at what the company does in terms of pattern matching utilization of the model and BIM use. Identified with a blue box are all the BIM components that Company CD implemented or incorporated into its company and project management. The red boxes over the BIM uses and components represent items that were not implemented, but are a possibility for future research and integration. This company is the trade contractor for the research. They are subcontractors who work completely within the building. When they started talking about site logistics, I quickly realized their site logistics were completely different than general contractors' site logistics. This required the addition or clarification of what site logistics meant to a trade contractor. All site logistics were contained completely within the building and had nothing to do with the overall property.

Table 9: BIM use overview for Company CD

Company- CD				
BIM use overview	13			
2D		Maintenance		
3D Coordination		Manufacturing		**Utilized**
3D Modeling		Marketing		**Not Used**
Activity Simulations		Mechanical Architecture design and Planning		**Being Investigated**
Asset Management		Mechanical Analysis		Used + Research
Augmented Reality		**7D- Operations- facility managemnet**		Site means Building
Clash Detection/ Trade Coordination		Other Engineering Analysis		
Code Validation		Performance Assessment		
Collaboration		Performance Simulations		
Commisioning		Phase Planning		
Communication		Process Management		
Demolition		Programming		
Demonstration of Compliance		Refurbishment/alterations		
Design Coordination		**Record & Contract Modeling- as builts**		
Design Verification		Reliable Information		
Digital Fabrication		Safety		
Digital Prototyping		**4D - Scheduling**		
Disaster Planning		Sharing Information		
Drone Utilization		Site Analysis- Within Building		
Embedded Information		Site Logistics		
Energy Analysis		Structural Analysis		
5D-Estimation		**6D- Sustainability**		
Existing Conditions Modeling		Virtual Reality		
Information Managemnet		Visualization		
Laser Scanning		Walk Throughs		
Lighting Analysis		**Other**		
LEED Evaluation		Barcoding Usage		
		Robotics Research		

While one can see a tremendous utilization of BIM components, there are several items not done by company CD. However, company CD utilized more aspects of BIM than any of the other three companies.

BIM Benefits to CD

Company CD was all about collaboration and communication of the model before construction, which seems likely to contribute to their success as a mechanical contractor. Company CD utilized fabrication and verification, which no other company in interviews did. They were also prototyping at different levels. Upon a site visit of their company warehouse, they would prototype entire bathrooms of a hospital project in the computer as a model and then build prototypes in the warehouse to test specific issues that they thought might be a problem. Once they obtained a model that was as complete as possible, they manufactured every bathroom for the hospital and then shipped them to the jobsite to be picked up by a crane or forklift for installation. Because they only had to connect a few plumbing and electrical components once bathrooms were set in place, company CD saved a tremendous amount of time and money for the entire project. It was fortunate for the company that the general contractor allowed them to prototype every bathroom well ahead of installation so when it came time, they could get all 200+ rooms done within a couple days. I heard story upon story about how the early BIM coordination and collaboration was the key to their company success and trickled down to every aspect of their company.

Impediments of BIM: Additional Issues

Company CD saw really no impediments to using BIM within the company. The company did not see advancing knowledge through training and workshops as an impediment.

Training for Company

Company CD yielded the most cryptic discussion of training out of all the interview. CD1 started off with:

> I think we're all going to probably have a different perspective on this, so I'll give you mine and then [CD2] and [CD3] can go from there. My perspective on the modeling aspect of it is twofold. You have the "Is the user able to use the software?," and you have "Is the user able to understand what they're modeling is being constructible?" I think that they're two very different educational paths. So we've, and even if you take a model and you look at like a project manager, it's not something that there's just, "Hey, if you follow all 10 of these steps, you'll be an excellent!" Every project's different, it's based on experience and getting out there and working with people.
>
> So, I think that there's a portion of it that takes time and experience, and I think that there's a portion of it that it is just training and utilizing the software that you can take some classes for. It's hard to find individuals that have both. And we've actually gone through

> concurrent paths in order to do that, with either bringing guys in from the field who have had the years of installation experience and teaching them the software, and then we've gone the route where we're bringing young individuals who are graduated and who might have that computer knowledge and try to teach them the trade. I think running both concurrently has made us stronger because we emphasize team, and people can collaborate and say, "Well, don't do it this way, do it this way," or "I had this," or "Let's go out there and look at it."
>
> That's my perspective on how the best way is for us to continue to improve and train.

CD1's long explanation boils down to stating that they have people specialized in different aspects of the industry and they are utilizing strengths of those people to help others. Also included was that they do a lot more training and workshops than ever, whether it be online or from personnel within the company.

CD2 took over and stated:

> To draw a straight line for me was a revelation, took a month to figure out. So it was—that was enough. But at the same time, that was enough to get by on how on our shop drawings were and how they were perceived to be more diagrammatical than exact, especially for prefabrication at that time, [which] was not a necessity, it was really a pipe dream. It was really just a step above a design drawing, really, is what it was. Since BIM came along, it did change completely. And it really took off, and so we had this conundrum.
>
> We said all right, we have this group of people that know AutoCAD quite well, how to offset and how to make straight lines, x references, layers, everything like that, but they just did not have the knowledge of constructability and exactly how things are done in the field. And we started getting some guys from the field that did have that experience, and we found like you said, it was a little easier to go through the process of getting somebody that had that knowledge from the field to work on the drawings, teach them the software the way that we were taught, and using that experience because that seems to be more invaluable for the work that we do now, the detail that we put in the drawings now.

> But with that being said, though, having that experience in the field, it isn't in a bottle, it is shared with everybody. So everybody, even though they might not have that field knowledge, they have—they know that somebody in the office has that experience, and once they ask that question once, then usually it sticks with them.

CD2 stated what CD1 had, only in a different method. During my tour, I noticed a lot of people walking around and talking to others in the company, which reinforced the idea that everybody has an expertise and others are getting their questions answered—by the experts.

Training for Clients

Training for a client was not as prevalent in company CD. CD1 stated, "Being a trade contractor, we work directly with AEC companies that already support and utilize BIM. Our processes, as internal as they may be, generate the required models a GC needs for trade coordination." The company did not really talk to owners when it came to BIM. CD1 again stated, "Rarely talking to a client other than inquiries about specific components, we assume the GC has already taken it upon themselves to educate the client on BIM practices." They were not opposed to working with the client, but found that most clients really didn't want to know about the mechanical side of their building. CD2 stated, "If, however, a client does inquire about our BIM processes, we are more than willing to help resolve their issues and questions." It did not seem to be a high priority for the company.

Research for Company CD

Company CD was another company that did a lot of personal research in order to solve the problem, but when it came to future types of research, I did not hear anything specific. CD2 stated his future research was about energy modeling:

> I wrote two things here that I want to talk about. One is on the early side of it, with the energy modeling and with the operating buildings and operating building systems, we've talked about that for so long, but it's been—nobody's really figured out how to do it. It's a really difficult problem. I personally have seen some tremendous growth in, and none of these technologies are out on the street yet, but I've seen some growth in that in the last

year, I would say, year and a half. So I think that's going to be an important part of it, right. Because energy and the consumption thereof is going to be an increasingly large part of the market. So I know that, so not only from a reducing first cost standpoint, but operationally, understanding that is going to be important."

Company CD was the only one that even addressed energy modeling as a research component. I imagine since mechanical contractors deal the most with energy consumption, for instance with heating and cooling or the amount of energy a lightbulb uses, they would be the companies dealing with energy research the most. Where all other companies were interested in all types of BIM research, company CD was interested most in the aspects that would benefit their company in the long run. This made total sense to me. Why put a lot of effort into something that is not going to advance the company later?

Company CD participants ended by stating they thought the modeler would be transformed into a new type of manager. CD2 stated, "On the modeling side, you know what, there's more and more tools that are going to be coming out in terms of what I would call auto modeling or automated modeling or however you want to think about it. I think over time, our modelers are going to become more model managers in terms of the actual production of drawing a wall from here to there, a pipe from there to there, [which] is going to be done more by a program. But our people are going to be more involved in looking at different model solutions and evaluating them from a safety standpoint, from a cost standpoint, from a functionality standpoint, from an operability standpoint. So I think that the future BIM professional is—"

CD1: "Is project manager?"

CD2: "In a way, is going to be looking at model solutions and evaluating them as opposed to physically moving components around. I think that technology, computers, and software are going to more take that role on, and our people, our professionals, our BIM professionals if you want to call them that, are going to—we will call them virtual construction professionals—are going to be that layer that more evaluates the solutions the computer comes up with for the criteria that's most important for that particular client, for that unique building."

I completely agree with their assessment of what the future BIM person will be—a virtual construction professional. This individual will have to have a lot more knowledge about more aspects of construction than ever before in history.

Multiple Case Analysis: Questions

The analysis resulted in following Sanders's (1982) guidelines, in which she identifies four levels for analysis. According to Sanders, "The first level is description of the phenomena as revealed by the interviews." Each question will be addressed individually and compared to the other interviews in order to fully understand and compare answers as given by companies CA, CB, CC and CD. The second stage will be "Identification of themes or invariants that emerge from descriptions." As the description states, there will be similarities identified in each company interview and then analyzed. The third level is "development of noetic/noematic correlates," which are subjective reflections on the emergent themes. After all the analysis of the first three levels, a final step in the process is the "abstraction of essence or the why of the experience" (Sanders, 1982). This final analysis will be handled in Chapter 5.

Question 1: Description of Phenomenon

The description of the phenomenon by the companies interviewed is the first step. Question 1 was "What is your company's definition of BIM?" While answering a question dealing with definition might seem to invoke a response that includes a definition, all of the companies interviewed took a different approach in what BIM means to their company.

The definitions came from all angles. Company CA started by stating they got into BIM by using clash detection on a hospital project, and CB stated they did not consider BIM anything other than a process the company pursues with all projects. Company CB also stated that BIM is a process tool that solves problems faster when utilizing the visual model to determine solutions to problems encountered within the model as it changes day to day. CB concluded by commenting it was all about the team using BIM to communicate more effectively during the lifecycle of the building process. Company CC said the industry standard is their definition but went on to say that their use of BIM was a bit more involved, that BIM was both a process and a tool for their company.

CC gave the generic definition and then paralleled with company CB, stating that CC thought of BIM as a tool to analyze during the construction process of a building. CC went into depth by clarifying that they did not use the BIM acronym but, rather, identified the process they utilized as 3D modeling. They then went down the list of things BIM does for their company, which paralleled what companies CA and CB stated, including that it was a tool for seamless communication. Lastly, company CD stated that BIM involved tying together construction activities, from pre-construction all the way through final transfer of the building to the client.

Almost every company started by identifying in chronological order what they did first and how BIM evolved within the company for construction management and company procedures. The start-to-the-end approach was a common theme in all interviews, but quickly went to a singular goal within that company's interview to identify specifically their end BIM process. Each interviewed company defined BIM holistically as the tool within the company that allows seamless communication between different parties involved in the construction process.

All companies' first step was creating a 3D model, even for the very first job where BIM was implemented. Since the definition of BIM includes modeling, each company approached their very first project with the model as the central component to managing the project.

Team building was a common response as well, whether it was said outright or embedded in the answers. Each company stated that BIM facilitates collaboration and communication among the individuals to make a team effort in any project. Technology utilization also came into the answers. Company CD was emphatic about labeling BIM as technology utilization using a 3D model. CB and CC also stated that technology makes the company more efficient in construction projects.

The simple question of asking for a definition led to four different ways of giving a definition of BIM. For each, it was clear that there were commonalities as well as strong opinions about what BIM is and is not within their company. When it came down to it, each company's definition of BIM utilized the 3D model and improved communication and collaboration in construction projects they were building—not for just their company, but all parties involved with that project, including the client.

Invariants

The first commonality was creation and utilization of a 3D model of the building. BIM started with the 3D model, with information and components extracted from that 3D model in the building process. These companies utilized those models by either creating them or obtaining them from subcontractors.

While the 3D model is at the heart of each company's BIM process, an overwhelming/underlying theme among all companies was communication of every part of the project for the entire building process to all parties involved, not only within the company but to other contractors involved with that structure. I found seamless communication to be an almost universal theme between all companies. It was stated in three of the four company interviews and implied in the fourth. Ultimately, communication was the overarching aspect of their BIM definition of how the structure was to be built and of determining errors in the computer before construction began. While communication comes in multiple forms on a jobsite, it essentially was the most important aspect of the job and the companies' process during construction. All companies stated that BIM helped resolve a lack of communication and, in fact, as CA stated, "BIM changes how you start a project and where you focus your energy. And I believe that BIM changes the amount of effort up front but eliminates a lot of effort on the back end." Preparation and communication before the job is even started is a commonality in all areas of the workforce. The larger the object being designed or built, the greater the amount of communication and clarification needed. When communication is at its best, the project runs more smoothly, without many problems or errors.

The next commonality was problem solving. A building is composed of thousands of parts, and how they interact with one another is essentially the construction process. Within BIM, interaction of those parts is called trade coordination or clash detection. Resolving those problems in the computer, days or weeks ahead of the actual construction process, will shorten the time it takes to build the structure. Smooth, uninterrupted construction of all trades is the ultimate goal of any construction jobsite, and as it goes hand in hand with communication, it also is a daily effort of several individuals to solve problems that come up in the 3D model.

Another term identified across all companies was team effort. While construction can seem like an individual effort for a person dealing with only the steel or only the plumbing, those contractors have to deal and interact with every other trade for that structure. From the landscaper to the electrician installing the covers to go over outlets, each at some point deals with other contractors on that same job. It is the unified effort that gets the structure built.

Technology also was prevalent in the responses—so much so that CD did not like the three-letter acronym for their BIM process, but preferred “use of technology as it applies to construction, prefabrication, and modular construction within AEC.” While the other companies also identified technology as a component of BIM and the entire process, company CD focused heavily on that definition, almost to the point of being confrontational about having what they did labeled as BIM. I did not understand why or where this was coming from with company CD, but accepted it and pushed through the interview. All the companies talked a lot about the technology they used to accompany BIM in the workflow of the building, and all interviews identified how critical it was to keep up with technology in that same process. On my site visits of each company, I could tell that all four companies invested heavily in technology, and it was evident that the BIM process integrated technology into their day-to-day activities.

Question 2: Description of Phenomenon

It is important to determine how long each company has utilized BIM, so the second question was “How many years of experience does your company have using BIM?”

Answers were short and direct; there were, however, answers that went outside the question to provide more detail.

Each interviewee identified a number of years of use right off the bat, then proceeded to elaborate. Companies had been using a BIM process for between seven and 13 years. So each of these companies did not start right off using it 20 years ago, but figured out after a while that BIM could help them, and then slowly implemented it into everyday procedures. Seven years’ use for company CC was the least amount, which is still almost half the entire time BIM has been around. Company CD had the longest duration, 13 years, although the interview went into a very long and informative explanation trying to determine whether they started in 2003 or 2005. It eventually came down to determining when they actually utilized a 3D model, which is the basis for BIM, and it was determined they could not remember exactly.

Company CB stated they had created an actual department within the company 10 years ago and that before that, the company had CAD services that were involved with various areas of construction. Company CC was very blunt and had no other reflections as to why they started, but said they had started in 2009 using BIM.

Each company said that their first utilization of BIM came about for a specific reason, and each except company CB identified collision detection or trade coordination as their means of entry into company BIM process acceptance. Company CB, in contrast, said their initial plunge used modeling as a materials assembly clarification, figuring out how an existing exterior façade could be attached to new construction. This led to a very detailed model being created with a process that was not done according to common practices. Their model eventually got so large in file size that they were unable to do anything with it other than open it and wait 10 minutes to turn it and view components. According to CB1, it was a huge disaster in terms of using the model in hopes to clarify information, but a huge success in the company to start utilizing BIM as a process for future projects.

All companies combined, the answer to this question was averaged to be about half as long as BIM had been in existence.

Invariants

The entire group of interviewees in each of the companies had on average been utilizing BIM for half as long as BIM has been around and used within AEC. A duration of about 10 years was evident in every company. Another common theme was that each company started a BIM department that came from the CAD departments already established in each company.

In reference to the rules of adopting technology and innovation shown in Figure 21 below (Rogers, 2010), almost all companies were early adopters of BIM. In previous communication, I have seen

AEC professionals commonly refer to adoption of technology in relationship to Rogers's (2010) model, so it is a relevant measure here.

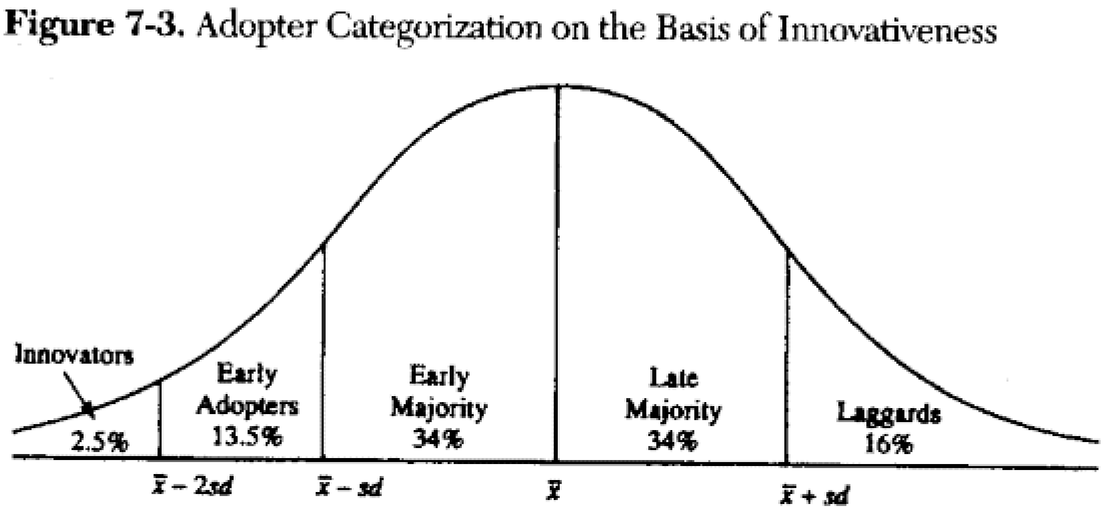

Figure 21: Adoption of technology (Rogers, 2010)

While Rogers's model follows a traditional bell curve, most of the companies were in the early adoption of BIM, and one company was in early majority for BIM utilization at or before 50% falloff. Each company answered with resound, though, as if the decision had been instantaneous, except for company CD, which discussed the answer in depth between the interviewees.

Question 3: Description of Phenomenon

Question 3 asked, "How did your company make the transition in adopting BIM practices, and did BIM have a significant impact on your typical design and construction management process?"

Each company—CA, CB, CC, and CD—answered by going to the start of BIM use and giving a brief history of when their company started using BIM in everyday activities. Company CA recalled it all starting with their president saying that they needed to incorporate BIM and the CAD department needed to learn as much as possible to accomplish it. There is nothing like an open-ended request from the president of a company to get BIM implemented. Company CB had a similar account, saying that their leadership had said "they knew BIM was coming and would be the next big change and they needed to be ahead of the change." Company CC was unique in the fact that they stated their BIM process changed and was still changing, but CC never explicitly said who in the organization wanted the direct changes, or what BIM projects caused the change. CD had the most involved response, stating that the change started with the company utilizing 3D models and was a decision shared by all upper management, with employee input. CD was the company that had been utilizing BIM the longest, 13 years.

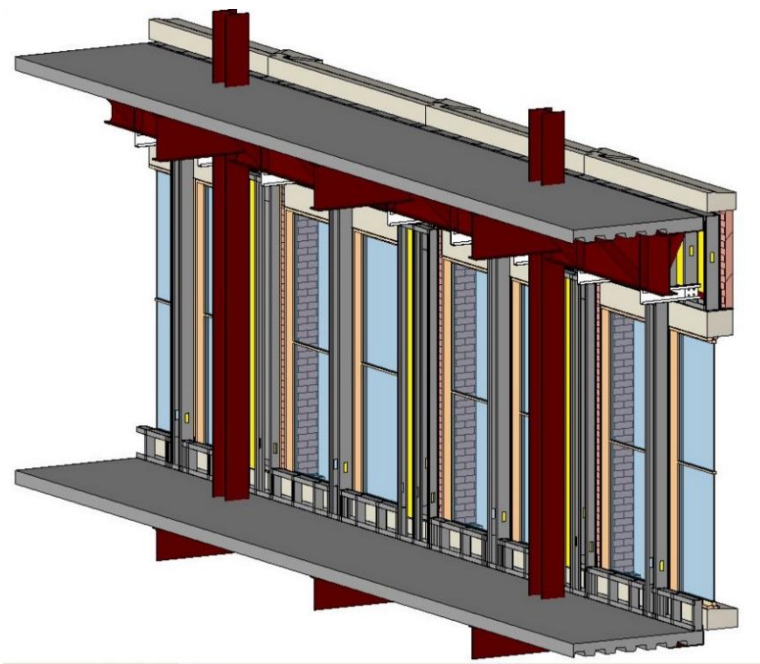

Figure 22: A model for a remodel (Cory & Jenkins, 2008)

Of all four companies, each identified creating a 3D model for a project as the start of the process that got them all into using BIM as a construction process for managing projects or collaborating with other companies working on the same project, as in collision detection. All four also stated BIM started when they were about to build a structure in which the construction documents were not of the best quality and they needed to figure out and clarify several aspects of the structure the architect neglected to design. I can say that before the BIM process, it took designers and CAD operators substantially longer to create a 3D model because modeling was being utilized where not all modeling procedures were proven efficient. According to company CB, their first modeled project took in excess of 200 hours and only produced a portion of the wall in question. See Figure 22, above.

Designers were not accustomed to creating models, so their design modeling process was substantially slower than their 2D drawing of the same feature. Therefore, for these companies to create models in the construction process was incredibly time-consuming and costly. As CB2 stated, “I think how BIM impacted design and how construction was, 10 years ago design teams weren’t producing models. So we don’t ever design the buildings, but we got the paper documents, and had to turn that into some sort of visual. So we modeled a lot back then. We didn’t play the role of designer, but sometimes we had to supplement the construction documentation by creating models.”

Three of the companies started with research and clash detection for one of their projects. Not even knowing what clash detection was, each company that started using the BIM process went into research mode to determine what all was needed in order to accomplish the required task onsite. Planning and support was another common component, which is another name for clash detection. Most companies identified clash detection as trade coordination, and in each company’s case, this was essentially the start to their company BIM process.

The fourth company did not start with clash detection, but did start in the BIM process by modeling a portion of a building for component assembly clarification. They were working on a remodel of a historical building. The entire inside of the building ended up removed (floors included), and the front face, sidewalls, and back wall of the building were the only parts remaining. Great lengths and measures were taken to ensure those historical walls did not blow over or collapse while the remodel was underway. The designer of the remodel building neglected to inform contractors how the new components would attach to the existing walls, but only stated it was up to the contractor to determine the best solution—with the designer’s approval. Company CB started to visualize how not to damage the historical building while trying to attach the new components to it. Their solution was to model out every component to the problem, as shown in one of multiple solutions below.

These models allowed the architect to determine which solution would be best and gave the contractor valuable documentation to give to carpenters for installation. It also gave them tremendous knowledge about generating a company BIM process: what to do and what not to do.

The file size for the portion of the wall was almost 1 gigabyte, resulting in a model that was almost unusable, according to CB1. Extracted information did come from the model, like the support struts and anchor ties that came out from the new wall to attach to existing historical walls, below.

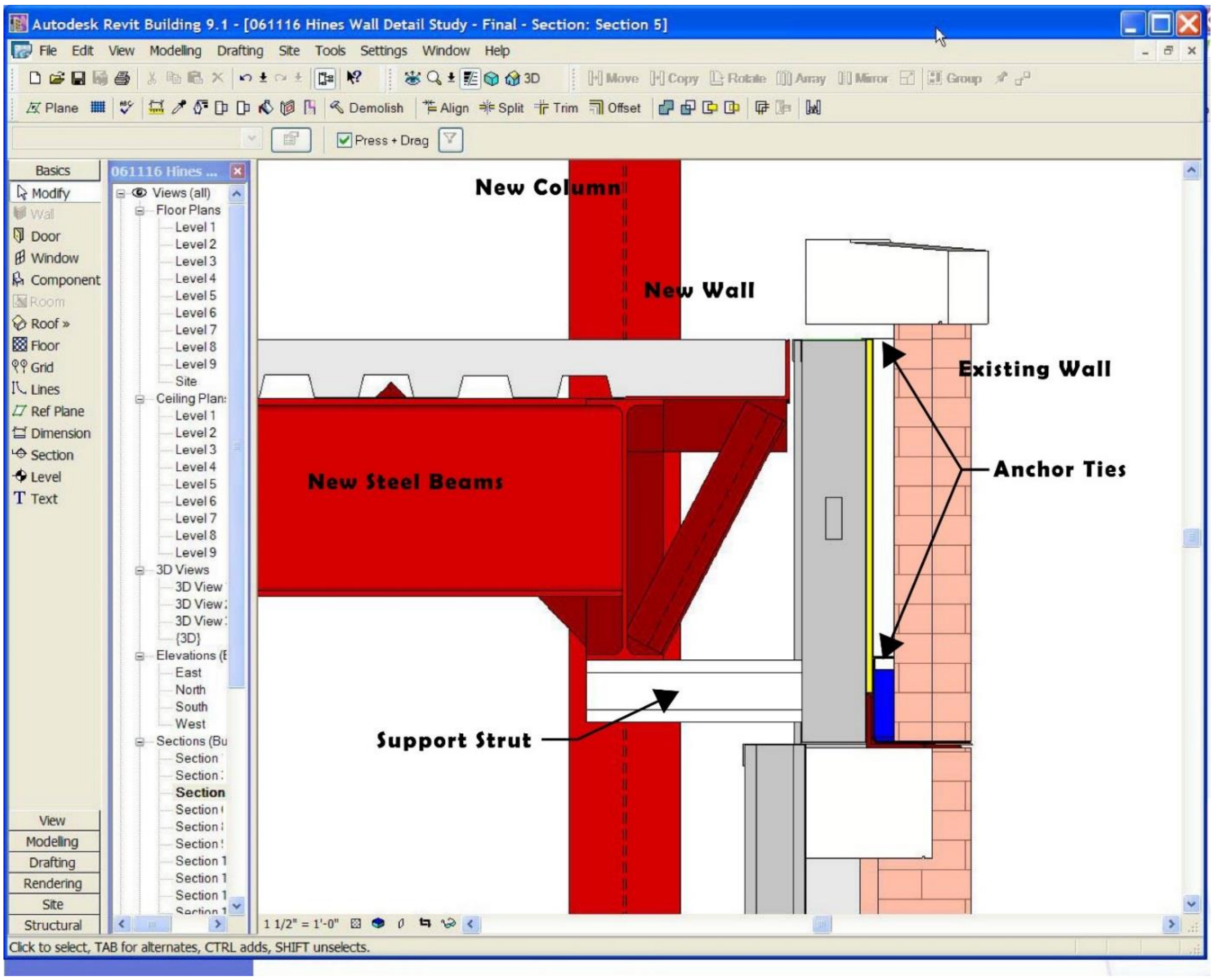

Figure 23: Detail drawing of attachment between old and new walls

This allowed the construction company to proceed with the job with a clear understanding of how to attach new to old. It also gave them valuable insight on BIM as a process for their company. One individual had approximately 200 hours invested before the model was completed, which was never recouped in the total cost of the project, so they chalked it up to a valuable learning experience. Since then, they have streamlined their process and include BIM cost into overall project bids.

Visualization was another common thread between interview answers. It can be difficult even for the seasoned construction manager to visualize all components of a design in a way that is detailed and comprehensive in order to communicate that information to installers. CB2 stated, “Yeah, it started out as a planning and support service, as a way to visualize what we were going to build well in advance of anything else.” Spatial visualization has been a key component to successful construction in years past, but usually internalized by individual people, whose ability to see the building as a 3D structure in their mind and pinpoint all the issues with the structure is what made them great and successful. Now the 3D model, according to all companies, is utilized in all construction projects for everyone’s benefit, clients’ included.

I did not notice it at first, but technology was a reoccurring theme throughout each company’s answers. Company CD shortened BIM to just “technology” or “tech” in general, due to not liking acronyms. Technology was mentioned several times in all companies. Short answers or long ones, each company mentioned coordinated technology as the way they managed construction projects.

Answers given to this question ranged considerably. Each company approached their answer in a different way, but ultimately they all said the same things. 3D modeling, communication, collaboration, and visualization were the main reasons for implementing BIM into their company processes. Most did not see a return on profit instantly but persisted in using BIM to become proficient at it, and now it is at the heart of each company’s day-to-day activities to help build and communicate.

Invariants

Whether stated or implied through each interviewee’s answers, common components of the interview answers were modeling, communication, collaboration, and visualization. Each company also started using it due to a project they were working on that either required BIM or needed clarification. All interviewees stated that the upper management foresaw a need and asked employees to make it happen for their company success. The AEC industry is very social in terms of collaborating using different methods, like verbal and visual information. Using a model to build a structure takes the collaboration and communication to new levels—as long as all parties involved know the BIM language and process.

The fact that it took time to learn was another similar characteristic in the start of BIM into each of these four companies. While it takes time to learn anything new, BIM had to develop for each company in the midst of all other construction projects managed. BIM evolved into a complete construction management process extremely quickly overall, with several advocates touting the benefits of 3D, 4D, and 5D while companies could not keep up with the evolution. At times during the interviews, I sensed despair about the amount of information—new knowledge or processes—they had to learn in order to be successful implementing BIM. One may think this is just part of the industry, but when bosses are telling you one thing that needs to be learned, and other managers are complaining production is going down, it can be frustrating and overwhelming. The one example of learning time given above was 200 hours of effort, but what was not identified was the duration for the 200 hours. A month would be acceptable, but in this case, it was completed in a little under two weeks.

Another constant throughout interviews was visualization. As CB2 stated in their response, "Yeah, it started out as a planning and support service, as a way to visualize what we were going to build well in advance of anything else." Spatial visualization has been one of the key components of successful construction management in years past, but usually internalized by individual people, whose ability to see the building as a 3D structure in their mind and pinpoint all the issues dealing with the structure made them great and successful. The visualization that BIM brings allows even the client to see what is happening at any given point during the design throughout construction process. In some cases, it allows the client to make decisions about the overall look of the building. Figure 24, below, was presented to a client to help determine the look of a hotel suite. During a pre-construction presentation, the general contractor presented the client with several rooms and overall costs of each in model form to help them determine the overall look for different room configurations. It helped them not only see the room but determine overall costs for differing room layouts.

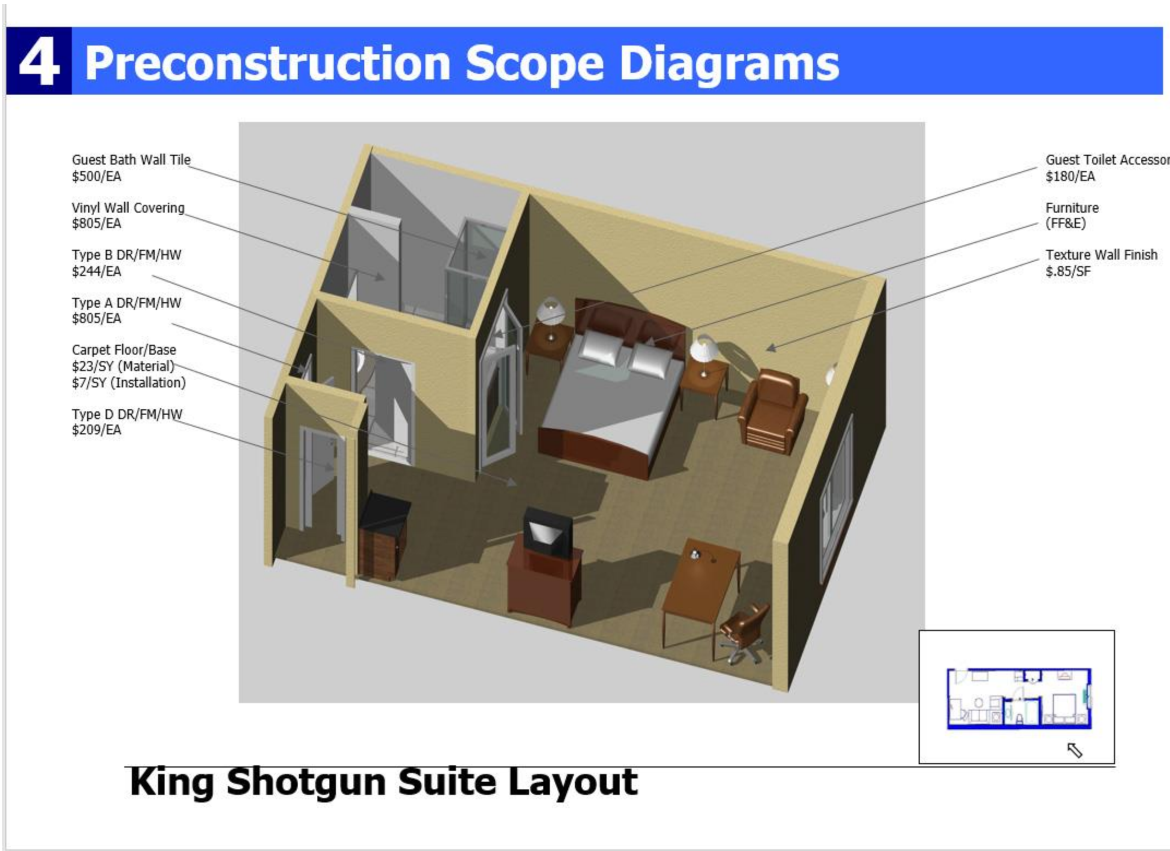

Figure 24: A prospective layout for a hotel suite (Cory & Jenkins, 2008)

While many elements were common throughout the answers, they all had taken time for the company to develop, and, in CC's words, "It's still ongoing." That aspect that BIM was still ongoing also resonated throughout all companies. I notice in my own job that I have become a lifelong learner, and these professionals are doing the same with BIM in their companies. I heard it in their voices: research, research, and more research. While none came out to say it, you cannot change an entire corporate process without doing research. I sensed these interviewers were constantly looking at new technologies in ways beneficial to their companies.

Questions 4 & 5: Description of Phenomenon

This asked participants to "Describe BIM use within company in terms of the different components of BIM below or four-phase process:"

This question evoked quite lengthy responses from all participants, as it should when a company is trying to explain an entire process it uses daily. Companies CA, CB, CC, and CD started and approached BIM in the past starting by using the traditional sense of BIM or as 2D, 3D, etc., but then stated, "That is not where they are at today but more a proponent of explaining 'how they accomplish' work within the BIM process." This would parallel what is done in Question 5, though, where they have broken everything down into the four phases: plan, design, construct, and operate. Very simple terms, if not traditional terms, were used in the companies for the process they were to accomplish, i.e., "estimation" for using the model for estimation, and "scheduling" for scheduling. The interviewee said that there are enough acronyms in construction, so why include several more when there are already terms used for what you are trying to accomplish?

Companies CA, CB, and CC also elaborated that BIM was used in more areas within their company than ever before: site logistics, visualization for the client, and safety, to name a few. It was the first time I had heard of anyone using BIM for safety, and I found three of the four companies utilizing it extensively. This extends the definition of BIM beyond current standards. Interviewee CA also broke down collision detection into something he called micro and macro management. He defined macro as milestones for the client and micro as the detail interaction of each component. Collision, or clash detection, was also mentioned to refer to trade coordination (e.g., plumbing interacting with structural steel and HVAC or electrical). Historically, all coordination was done in the field and often caused problems with trades damaging components from other trades in order to get theirs installed. Project managers would have to recall the trade contractor to fix the damaged portion.

Construction companies can and usually do coordinate to keep all the individual components inside the model of the building from intersecting with each other. Preventive model intersection reduces the possibility of delays between trades later on in the construction phase. Prefabrication of wall panels or any component in the building also helps expedite the schedule of erection of said components. According to CA, the entire company process was involved when it came to using BIM in management of projects.

Companies CB and CD started off by emphatically stating they don't do the D's of BIM, but more like what company CA did to explain it as "how we accomplish work." They have moved away from being model creators to becoming managers of information within the model. While day-to-day project management includes multiple phases of construction, from design through facility management, all companies utilizing BIM thought of it as normal work, rather than the current terminology used in journals to indicate the complete process of building. This one statement made by each company suggests that BIM leads to normal workflow for every project, and the 3D model has just helped clarify information between all parties involved.

Even more emphatically, interviews gave the message that each company is using the model to analyze the impact of decisions made during the course of construction. Running through iterations weeks ahead of assembling a part or using a product can have tremendous implications in the flow of work schedules when the time comes to actually put those items together.

The trade contractor also stated the same application of using the model within company processes, but was more focused on fabricating of parts they had to assemble at the jobsite. A simple example is a bathroom sink, which is made up of the sink overall, but also a cold water line, a hot water line, a drain line, and multiple pieces of the faucet. Company CD is assembling entire bathrooms to install on a hospital jobsite. Walls, sink, shower or tub, floor, ceiling, and toilet are all built so that all they have to do is pick it up with a crane and place it in the correct location—attaching mechanical components in bathroom is done in about 30 minutes instead of days. Their portion is a smaller piece of the whole project, but not any less important. In some cases, the trade contractors know more about assembly and construction of a building than the general contractor because of how their parts interact with the structure of or materials within the building. While the general contractors have done fabrication in the past, it is the trade contractors that have taken it to new levels. I was able to do a site visit in CD's warehouse, where the bathroom was a small portion of what they were assembling. All of the ductwork for each project was created from a model that was exported to a CNC machine for assembly.

In summary, the description of how each company used BIM was similar across all interviews: help during the entire process, design through facility management, a top-down approach in which upper management told everyone the company would do BIM within a year or less. Some companies use BIM more than others, but each sees the model as the focus of the construction management and decision-making during all phases of that project. It is helping analyze the decisions made daily. The trade industry is also taking giant steps in fabrication, using BIM as the main determining factor for all parts. Each is not too terribly fond of BIM titles, but of the processes that make their company productive and profitable.

Table 10: BIM process—D's and phases

D's of BIM		
1	2D	
2	3D	
3	4D	
4	5D	
5	6D	
6	XD	
7	Site Coordination	
8	Trade Coordination	
9	Design Reviews	
10	Programming	
11	Record Modeling	
12	Energy Analysis	
13	Sustainability	
14	Other	
4 Phase Process	Written or Verbal answer	
Plan		
Design		
Construction		
Operate		

Invariants

The one commonality was that each company had a top-down approach for implementing BIM. Stated repeatedly, upper management told the entire company they would be using BIM, or asked the employees how BIM could change the way they did business and lead their company into future projects. A couple participants identified owner-driven projects that utilized BIM, which I found interesting. Most of the time, owners care only about costs—how little they can pay in order to build the structure. When an owner is demanding BIM to be used, it sparks questions within AEC companies of how and why. It is more commonplace now that owners require BIM for a proposed building. Times are changing in every aspect of construction, not just within companies.

There were multiple invariants across each company interview. The next one that jumped out was the tremendous dislike for standardized terminology, like BIM or 3D, 4D, 5D, and so on. I read and witnessed the disapproval on their faces and in replies as the interviews went on. I came across that same response and distaste for the D's of BIM in blogs while researching—nobody likes the acronyms or D's. It seemed that all participants' first response was to state this emphatically. It seemed to hit a nerve in an industry of very opinionated people, and perhaps each company interviewee would rather stick with standard terms they had been using for years. The change from creating documents to creating a model might have been change enough—changing terminology for estimation or scheduling might have been too much to bear for each company. All components in the list of D's of BIM above (Table 9) were noticeably identified in company processes during interviews, but only in tasks with original names, not designated as D's. Every interviewee mentioned that all the D's of BIM were utilized in their company processes when they first implemented BIM into company processes. Currently, however, each company had gone to the four-phase model process of identifying BIM within the company.

Visualization was another common thread that kept popping up. Visualization to help what was being built or to help the client make decisions. Company interviewee CB2 stated, "It started out as a planning and support service, a way to visualize what we were going to build well in advance, but now BIM has an impact in every aspect of the construction process." Using technology to solve problems in a visual way was how interviewee CA identified BIM in his company. The model was the main concept behind BIM when it started, a way to visualize all components together like a symphony. The ability to instantly go to any area of the virtual building to see what interactions were taking place made problems easier to resolve. Interviewee CC stated, "If we are solving issues on the computer, that takes maybe a couple weeks, rather than one issue being out on the field and it's stopping us from actually building something for a week, then that's worth the price of admission right there."

Across every interview, each participant stated the “process” was the main focus of using a 3D model in their project management. The process was the number one invariant identified in every interview and the common theme for the entire question when it came to BIM.

One intriguing area was that two of the companies identified research areas they were conducting to help different components of the process become more efficient. 3D laser scanning was used in a variety of capacities and mentioned in both of these company interviews; it was used to create as-built documentation at the end of the construction. An as-built document identifies the final components and layout of the building, and the client receives these documents in order to manage the property during occupancy. As-builts in years past were blueprints that had been revised to include all changes during the construction. These changes could have been due to collisions of trades, as discussed previously, or the client’s wishes, such as moving a door. Regardless, the original prints were essentially redrawn to include all changes during the construction. Now, those changes are documented with 3D laser scanning and modeled, and then all the 2D documents are extracted from that laser-scanned model. Laser scanning is becoming more of a standard process in construction, and not just for one area but across all disciplines of construction. While the trade contractor, CD, did not specifically state 3D laser use, they were familiar with it and acknowledged its use even with their portion of the construction of the project.

Drone use was also identified as part of the company’s research focus. Between CA and CC, site logistics for the project during construction as well as safety checks on the building were the common answers. Company CB identified drone use in a later question. The only company that did not was the trade company, which would not necessarily need any overhead or aerial site logistics unless they were doing outdoor utility assemblies.

One last area of research or use of the 3D model was simulations. Company CB uses simulations in a large portion of projects. One example that they mentioned was deliveries: “Because we have those models, we have the foundation with which to animate a truck driving through the building to make sure there’s room for material deliveries. Things like, we have a retractable, operable roof, making sure that opens correctly and then stops in the right place; that’s how modeling geometry works, to be able to do." They utilized one simulation to see how the world's largest crane (called Big Red; see Figure 25 below) could be used to pre-assemble the roof of a stadium and then lift it into place without the boom hitting anything, and then, when the entire roof was on, to see how to remove the crane from the inside of the stadium. All done with simulations, according to CB1.

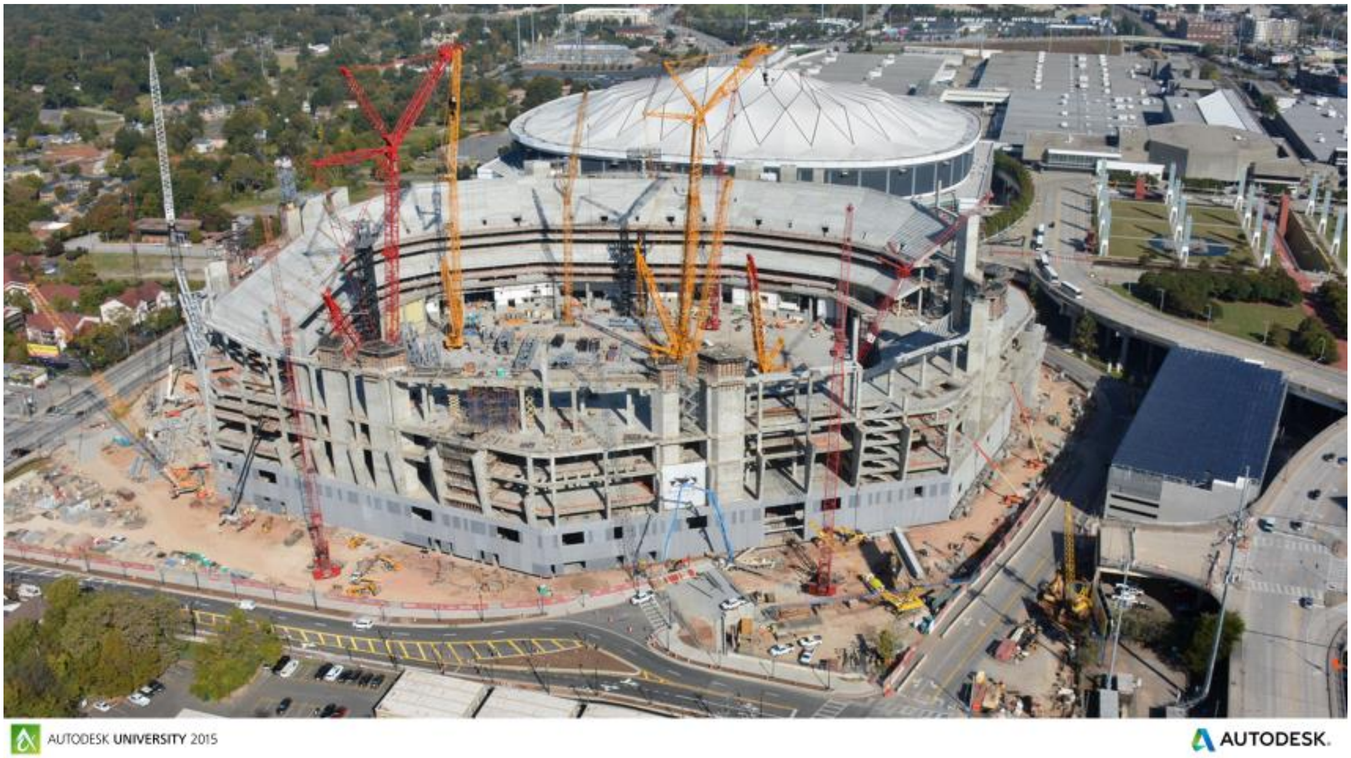

Figure 25: A simulation of Big Red assembling the roof of a stadium. Atlanta Falcons (2016, February 18). Mercedes-Benz Stadium Construction Time-Lapse - February, 2016 [Video file]. Retrieved from https://www.youtube.com/watch?v=s3U3oDz4oWo

The common idea for invariants in this question was definitely process. The process for building using the 3D model resonated throughout each company's answer and could have been for entire buildings or just a small portion. Research also came across in answers to solving problems, but in the sense of using the 3D model as a basis for resolving issues. While the answers to this question were the longest, the common theme across all companies came down to using BIM to make the construction process run smoother.

Every company had different starting points for BIM, similar stories about top-down approach, and almost exactly the same invariants throughout the interview. All ended by saying that it was a companywide transformation. Interview CD3 stated, “BIM was top-down, but that was just for such a brief amount of time before we realized how much we could build in our shops and how much we could pre-fabricate, that it became—It wasn’t top-down at that point. At that point, it was everybody; it was all hands on deck and was like a little revolution.”

Question 6: Description of Phenomenon

This question asked, “What are the advantages of BIM within your company?”

Very simply put, each company stated that BIM helped them throughout the entire project—design through facility management. It was not just one company, but all of them that stated this to be true. According to CA, “It has changed the mindset at which we approach a project if we’re involved early. The opposite is true from the amount of impact we can have on a project if we are not involved early.” Information management for an entire building was the largest advantage each company identified. Each company described advantages when they discussed BIM. All companies but CA mentioned that the advantage of being informed at every aspect during a project is what BIM gives to their companies.

Some identified the major advantages when they were describing BIM, which all kept coming back to collaboration and communication. Saving money was a byproduct of BIM, but the major advantage identified was collaborative effort. When everyone is talking about the project and their portion of the job, it means everyone is on the same page about what needs to be done to finish. While there were other advantages stated, as in Figure 26 below, ultimately every company appreciated the collaboration and communication throughout the project. Company CB gave me some amazing graphics to use of what they thought were the benefits of BIM within their company. The first gives a clear summation of the amount of money and time spent, with decreases in both, and also shows an increase in information benefits. The second image pretty much sums up what they thought the benefits were in terms of visualization, understanding, and teamwork. The BIM process is more than just the sum of its parts. This describes all interviews completely.

Figure 26: Company CB's summary of BIM benefits

Invariants

Common themes ran throughout each company representative's answers. As I went back to read the transcribed answers, the increased collaboration and communication was the key factor that stood out most. Figure 26, above, identifies multiple advantages from the company's perspective.

While most construction companies are concerned about keeping costs low, collaboration and communication helped them achieve just that in each project. Keeping costs low was listed as the number one benefit in the figure, but according to the interviewee, this image was created to sway a client's decision to use their company. While it is not uncommon to identify factors that will save the client money, company CB used this image in presentation to help a future client identify what past clients benefited from in their projects.

Time was another definite benefit. Shortening the amount of time it took to build projects was identified as another huge benefit with the increase of communication and collaboration. Company CB also shared this image below comparing the traditional method of construction project management (CPM) to current methods of CPM.

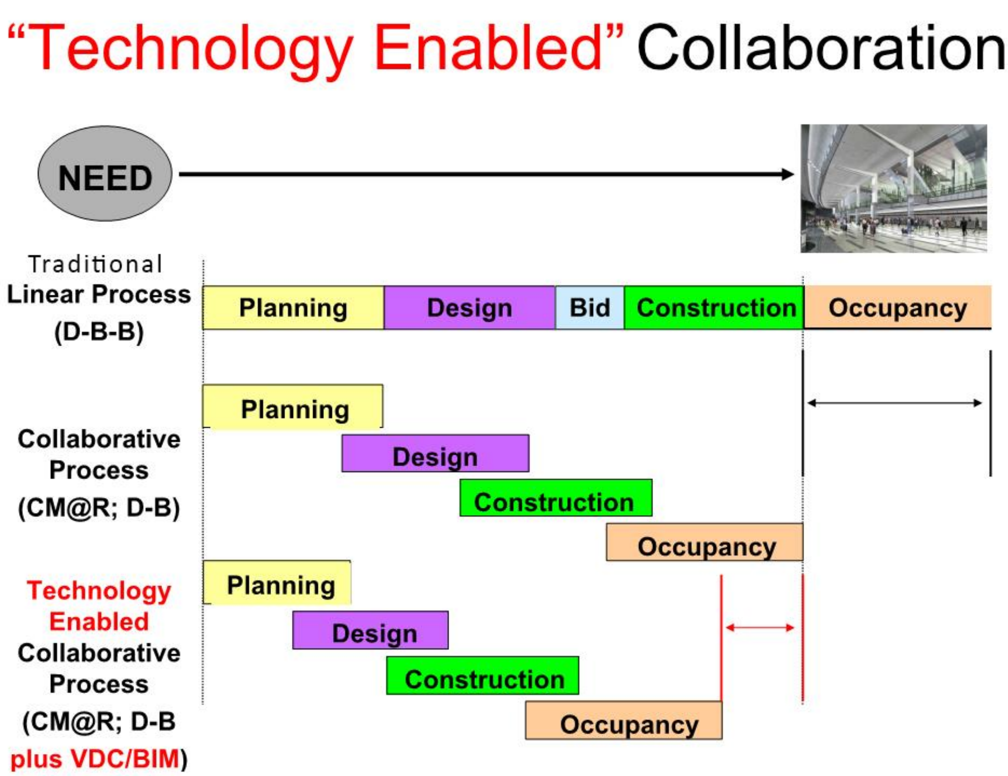

Figure 27: Company CB's graphic showing time savings with BIM

Notice the linear nature of the traditional process, whereas the further they got into the technology-enabled process, the quicker the building was occupied. The enhanced collaboration and talking to all connected parties to the project early allows components during the planning-design-construction-occupancy phases to overlap, reducing the overall duration of construction.

Complete understanding and visualization of the project was another invariant noticed. As company CB noted in the graphic above, they have been able to understand building better and faster than ever before. Timelines for this spatial visualization used to take individuals years to master, but with today's technology, everyone is able to see and understand how the building goes together completely.

A complete process that saves time and money while fostering understanding that brings everyone together was the overall picture painted in interviews. I like to think of it this way: a picture is worth a thousand words—so 1000 pictures = ??

Question 7: Description of Phenomenon

Question 7 asked, "What is your company's driving force as it relates to your firm's philosophy and goals behind using BIM?"

The start of this question made each of the participants recollect the previous question's answer because it extracted components of that answer in this question. Each company interviewee stated that the driving force started out with upper management, but then became using BIM for the benefit of the project. Moreover, they used the technology for the sake of adding value to the process and project. The answers were long for each because they were describing a process in their respective companies.

For each company, upper management decided years ago to implement BIM into the company's construction management process, and since then, the entire company has adopted each of the processes extracted from the 3D model as the way the company does business now. This rang true across all interviews that the entire company has bought into using BIM in everyday processes for each component of project management.

Company CC also included that their philosophy was owner-driven. (The other companies stated this within answers to different questions, but not here.) As CC stated, “One is owner-driven. To say that that is not the case would be fooling ourselves.” Although I agree that owners dictate a lot when building a project, I am not convinced that being owner-driven hits to the heart of the philosophy and goals of using BIM, but think it may be more a reaction to requirements. In some cases, however, a reaction might be all a company needs to get started and change.

One last item that needs mentioning is that company CD stated that upper management started the use of BIM for them, and it was administrative support that required and developed BIM use, which translated into the overall mission of the company. I have heard during my years of building and consulting that what contractors and carpenters do is part of their family and culture with the group of people they work around daily. It is this culture or sense of family that gets everyone into a common goal: to make the company successful.

Invariants

The common themed items came across in many forms. In all cases, each participant stated without hesitation that upper management was the main reason for BIM utilization. While upper management may have started the ball rolling, all participants claimed that it was a whole-company effort now to use BIM in everyday management of buildings.

Other invariants were not so noticeable across all answers. “Owner-driven” came across in previous answers as well as in the answer to this question. Clients often dictate how their building should be built. In just about every project, they want a certain look or for new technologies to be installed or used in the building’s construction. Some clients know enough about new technologies to be dangerous, while others are very well versed in the subject. In an industry that is based on client satisfaction, changes in everyday processes are commonplace. I have consulted enough with AEC professionals and personally dealt with clients to verify that changes due to clients’ demands are common from the start of the project until they get the keys and take ownership. Changes happen in construction, and it is those companies that deal with change gracefully that earn good reputations among clients.

Another invariant was use of new technologies. While it was stated outright by company CA in this answer and by all companies in previous answers, the other answers implied use directly. BIM was at the time considered part of new technologies, and while it technically was not technology hardware, the software side of BIM could have been included as new. The overall process integrated into a company's management processes would be considered new technology if it projected into differing areas of the overall process. Creating a model that kept all material in a database would and could propel that information into the company's estimation practice. The model is essentially the same building in the computer, so if a timeline of when items in the database of material could be used, that would help the scheduling department come up with a predicted start and end date for all materials and the building as a whole.

The fact that upper management introduced BIM use was the most common thread in all answers. The fact that everyone in the company transitioned to BIM use also was a common thread. It was essentially a completed computer model used to build from, and that was the overarching commonality to all answers, whether outright stated or implied.

Question 8: Description of Phenomenon

Question 8 asked, "BIM is recognized as a visualization documentation creation tool—what about the database component within your company?"

The description was a repeat of previous answers. CA described it as "So here's how we've described it is coordination, visualization, modeling, and other stuff. We do design model coordination review, MEP trade coordination, and those are at different phases, but we break it down by, 'Here's the services.'" Each answer talked about problem solving on a jobsite. Each identified what technology they could use to solve that problem quickly and accurately. On company CB's jobsite visit, I was able to watch a simulation of multiple structural steel connectors being applied to a specific problem. They had three or four structural members coming into one spot and were looking at ways to connect each to give the strongest joint possible for carrying the loads and more. A problem might have a dozen solutions, but it is the best solution that needs to be identified and utilized. The simulation ran through all possible solutions and then identified the best in that situation. I was told they had done that same simulation on every joint and steel connection on the entire project. That modeling and database capabilities are utilized in all areas to resolve issues was a point made in all interviews.

Company CB went off track by stating that 2D use was extremely important. They extracted the 2D documents to be used onsite to build, but claimed the 2D use is just as important. I had known 2D documentation is used to build because there is not one company out in industry that uses only the 3D model to build. However, specifically identifying that 2D is as important in the BIM process was a bit unexpected.

Invariants

While each interview was different in many aspects, all evoked the same responses in this question: using BIM throughout all phases of construction, in MEP coordination, in estimation of materials, or essentially solving problems. The key variable identified was solving problems with the model forecasting across all phases. I would like to say there were other similarities in the answers, but solving problems was evident in each answer as the number one invariant identified. All company participants pride themselves on being problem solvers, not in a reactive sense, but a proactive one where they find a problem long before it has a chance to cause delays in building. The model or the technology is helping them do just that by addressing all problems weeks, if not months, ahead of physical construction.

Coordination of information in the model and along each phase of construction is clearly a branch of the problem solving.

Questions 9 & 10: Description of Phenomenon

These questions asked:

- "Will you need to modify your corporate practices (educational needs) incorporating more BIM into projects?"
- "How does your company educate its employees on new BIM techniques or technologies?"

These two questions were similar enough that the answers for each were identical in all company responses. Each interviewee answered Question 10 by referring me to Question 9. I will combine the results of these two answers into one report.

Each company identified two distinct types of education:

1. Individual or one-on-one training
2. Corporate training

It did not matter which type of training was implemented, though, because all companies did educational training and workshop components. Overall, each company took measures to ensure every person was trained or educated on the company's BIM process. One company went as far as sending out monthly publications with step-by-step instructions to use in starting new technologies.

Companies are spending big bucks to ensure each employee is completely informed. Company CA has what is called a BIM and Breakfast session, in which the employees come into work early and are provided with breakfast while they participate in workshops about BIM processes. Company CB is more into social media, where they have Wiki pages of help, and on-demand videos, both external and internal to the company; they also have scheduled walk-in sessions to help with BIM training. Every company has taken on education and training responsibilities for the entire company.

I like CD1's approach, where they have broken out training into software and company BIM process training. They have people with physical installation experience that can only be acquired in the field doing said installations, and they have people with software or computer experience, but it is hard to acquire employees with both abilities. This company is bringing field workers together with software experts to learn from each other what each does daily. The combination of work experience with software knowhow creates the ideal individual to work and resolve project setbacks. This company stated that this approach has made the company stronger because nobody feels like they cannot ask a question or get help. Field people walk into a vice president or president's office to ask questions if those individuals have the knowledge they are seeking.

While training has always been an integral part of any corporate and individual growth, the amount of training each of the interviewed companies undertakes is staggering. From one-on-one personal training all the way up to entire company workshops and events, the AEC industry realizes learning does not end. A focus on lifelong learning is taking place within the AEC industry.

Invariants

Constant learning and education was the main category and number one invariant for these questions. It did break down to subcategories, though, in the ways that each company educated each employee. Whether it was personal learning one to one, or corporate workshops that everybody attended, these companies were dedicated to the employees' knowledge and how quickly change happens when they need educating.

Learning comes via several approaches. One-on-one training was the first commonality across all companies. According to CB2, "I do as much one-on-one as I possibly can. That's the most impactful particularly to the field side of life, so the superintendents, the field coordinators, those guys that are in the field walking the job don't have time to go back to the trailer midday and get trained up in a training class." This one-to-one training was evident in each company interview.

Workshops were the next type of training and education, organized into either personalized department training or corporate-wide training. I did not get a sense that corporate-wide training happened that often, but that more often a departmental workshop would be scheduled so only one aspect of the project would be down at a time.

Company BIM 101 and 102 training was also a common theme for two of the companies. Company CB went as far as offering certificates and eventually a degree in BIM. This took training to an entirely new level. I am not sure the degree or certificate would mean anything outside the company, but inside, it might have been a financial incentive or a means to push themselves to do better with new technologies. None of the company representatives made any comments regarding any personal benefits or incentives. Overall, the outcome of training is a better company employee overall.

The last significant invariant came only from company CD. During the interview, CD1 said:

> Technology's not stagnant, right? It's dynamic. It's not static, it's not just going to stay there, so while bringing in guys that have the construction experience and teaching them something has been valuable on that end, I think having the younger individuals that question the status quo has really helped [CD3] with his team. It's kind of like, "Well, why are we doing it this way?" Or there's this! Why don't we write a script that can do this or can we write a piece of software that will allow us to extract this? I think a lot of those ideas stem from some of the thinking of, or challenging the status quo. And I think that we do that fairly well here.

It is a huge question every AEC company asks of its employees, that I personally do not see in higher education.

Challenging the status quo is what all companies should consider doing. Constantly asking why this way or what about that way is how companies succeed and become better. It is the determination of those who constantly ask *why* or *what* that evolves the company into new processes, procedures, and technologies. If you want the true commonality across all companies when it comes to education—it is "How can we do this better?" Currently, BIM is their better solution!

Question 11: Description of Phenomenon

This question asked, "How do you educate your clients on BIM trends for bid projects?"

Each company does personal training for clients, which would include a variety of individuals. Each company did not really have an identified process for educating the clients, but stated that when and if the occasion occurred, the BIM specialist would be sent to resolve problems. One company stated they have sent their BIM experts to architectural firms to train and give workshops in several of their BIM processes. All companies identified specific training for new clients unfamiliar with BIM, both to provide general knowledge and to let the client know what exactly goes on within the company related to BIM and how diligent the company is toward the client's project.

While three of the four companies did training, the trade contractor deals directly with general contractors and does not usually need to give clients BIM education or training, since the general contractors already utilize BIM in their projects.

The fact that BIM training happens in all aspects of the company is standard across each. Client training or personal, each company takes pride in keeping up on the latest technologies while informing their clients what will happen during the construction of their building. Training and continued learning show clients just how up to date each company is and how education will help the project run more smoothly.

Invariants

The one commonality was that they did training for clients. The difference was the definition of the client. In some cases, it was the actual or future owner of the building. In other cases, it was an architectural firm. Education of BIM keeps evolving and changing. The AEC industry is going through incredible changes currently to make their management and construction processes more efficient while spending less time physically building the structure.

Question 12: Description of Phenomenon

This question simply asked, “Other and additional thoughts?”

There was really no description for additional thoughts. Each interviewee stated components they failed to mention in interview questions.

Invariants

Grouping this question’s answers into one category, I would say future BIM uses or technologies was most commonly mentioned. Each interviewee described areas they were looking to get into, using the 3D model as the basis for this research. Company CA identified LEED Green Building, while company CB discussed laser scanning and 3D printing uses. Company CC talked about aerial photogrammetry, and CD discussed energy analysis from the computer model. Each is looking at ways to improve processes each does manually. When their entire management process is accomplished using the 3D model, the virtual construction professional will be relied on more in the construction process.

Comparison of Companies

From the BIM framework of Succar (2009), BIM was divided into several components, as in the illustration below.

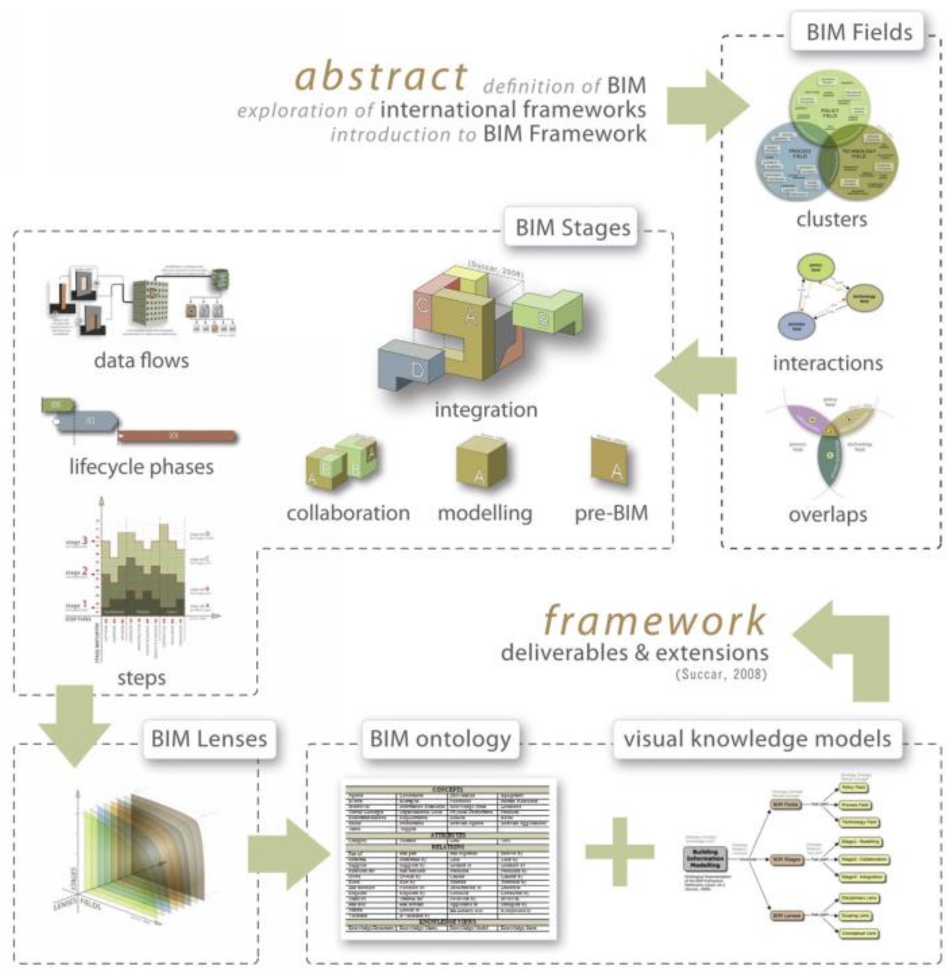

Figure 28: Components of the BIM framework (Succar, 2009)

I will start with BIM fields of each company and compare clusters, interactions, and overlaps for each company, utilizing the identified codes. From there, BIM stages will be the next level of comparison between the companies and all of their components. From there, I will move into BIM lenses and then develop the comparative BIM ontology for each company.

Overall Comparison

From the table below, we can see how each company utilized BIM from the answers given in interviews by employees of each company. The first aspect was years of experience. All companies were comparable in how many years they had implemented the BIM process within their company. Company CC, which had the quickest interview, had the least number of years integrating BIM into their company, with seven. Company CD had integrated BIM the longest, with 13 years.

Table 11: BIM use overview for all companies

Company	**A**	**B**	**C**	**D**					
BIM use overview									
Years Experience	8	10	7	13					
2D	CA	CB	CC	CD	Maintenance	CA	CB	CC	CD
3D Coordination	CA	CB	CC	CD	Manufacturing	CA	CB	CC	CD
3D Modeling	CA	CB	CC	CD	Marketing	CA	CB	CC	CD
Activity Simulations	CA	CB	CC	CD	Mechanical Architecture design and Planning	CA	CB	CC	CD
Asset Management	CA	CB	CC	CD	Mechanical Analysis	CA	CB	CC	CD
Augmented Reality	CA	CB	CC	CD	**7D- Operations- facility managemnet**	CA	CB	CC	CD
Clash Detection/ Trade Coordination	CA	CB	CC	CD	Other Engineering Analysis	CA	CB	CC	CD
Code Validation	CA	CB	CC	CD	Performance Assessment	CA	CB	CC	CD
Collaboration	CA	CB	CC	CD	Performance Simulations	CA	CB	CC	CD
Commisioning	CA	CB	CC	CD	Phase Planning	CA	CB	CC	CD
Communication	CA	CB	CC	CD	Process Management	CA	CB	CC	CD
Demolition	CA	CB	CC	CD	Programming	CA	CB	CC	CD
Demonstration of Compliance	CA	CB	CC	CD	Refurbishment/alterations	CA	CB	CC	CD
Design Coordination	CA	CB	CC	CD	**Record & Contract Modeling- as builts**	CA	CB	CC	CD
Design Verification	CA	CB	CC	CD	Reliable Information	CA	CB	CC	CD
Digital Fabrication	CA	CB	CC	CD	Safety	CA	CB	CC	CD
Digital Prototyping	CA	CB	CC	CD	**4D - Scheduling**	CA	CB	CC	CD
Disaster Planning	CA	CB	CC	CD	Sharing Information	CA	CB	CC	CD
Drone Utilization	CA	CB	CC	CD	Site Analysis	CA	CB	CC	CD
Embedded Information	CA	CB	CC	CD	Site Logistics	CA	CB	CC	CD
Energy Analysis	CA	CB	CC	CD	Structural Analysis	CA	CB	CC	CD
5D-Estimation	CA	CB	CC	CD	**6D- Sustainability**	CA	CB	CC	CD
Existing Conditions Modeling	CA	CB	CC	CD	Virtual Reality	CA	CB	CC	CD
Information Managemnet	CA	CB	CC	CD	Visualization	CA	CB	CC	CD
Laser Scanning	CA	CB	CC	CD	Other				
Lighting Analysis	CA	CB	CC	CD	Walk Throughs	CA	CB	CC	CD
LEED Evaluation	CA	CB	CC	CD	Risk Management	CA	CB	CC	CD
					Barcoding	CA	CB	CC	CD
					Robotics	CA	CB	CC	CD
						CA	CB	CC	CD
						CA	CB	CC	CD
						CA	CB	CC	CD

Legend
Utilized
Not Used
Research
Used + Research
Site means Building

BIM Fields

BIM fields are broken down into three areas, and each of those areas is broken into smaller subcategories. BIM fields include clusters, interactions, and overlaps. All three BIM fields according to Succar (2009) contain "three interlocking activities, technology, process and policy with two sub-fields: players and deliverables." In each company, technology was at the heart of the discussion. It was translated into either the 3D model or information extracted from the 3D model, such as estimation of costs. In every case, the technology field grouped several people within the company who specialized in specific areas in order to improve productivity or increase efficiency while managing the construction of their projects. CB1 stated it best: "It's more about the VDC aspect of it, and—I'm a problem solver, I'm a builder, and I have really cool tools that can probably do your job even better; or I'm on the cutting edge of technology, so I can try some new things on my projects, and let my field team see all of the great resources that I have."

While I heard this from every interviewee, there was also the statement that BIM is a process and *not* technology! CB1 again stated, "To start off, BIM isn't a software. I want to say, I guess, it's a process. It's not even a process; it's something we use as a tool to facilitate everything we do, between going after a job and just visual, or using the information, or showing information, all the way to the end of passing information over to the owner. It's really, at least for us, just a tool to help us in every piece of what we do as a general contractor." While the process is helping construction companies in every aspect, BIM has technology at the heart of its process.

Succar's (2009) BIM process is the next aspect of BIM fields. According to Succar, "The process field is a specific order of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action (p. 359). In this case, the process deals with people: the client, the architect, the engineers, and all other AECO industry players in the ownership, delivery, construction, and operations of the building. Each company talked about different roles they played in the BIM process along with every other player within the construction process of a building. Of course, the client plays a huge part in deciding how the building looks and what its functionality will be. The contractor is in charge of actual construction, while the engineers ensure the structure will hold up to all forces. The mechanical contractors are in charge of all the internal aspects of the building like the heating and cooling, electrical, or plumbing systems. All aspects of the BIM process were continually referenced in the answers of the interviewees.

The BIM policy field is the last component and, according to Succar (2009) is "written principles or rules to guide decision-making" (p. 359). Succar explains, "The policy field clusters a group of players focused on preparing practitioners, delivering research, distributing benefits, allocating risks and minimizing conflicts within the AECO industry." This would equate to the managers of projects or the individuals who make the decisions when they obtain all the information. This is just a branch of how the management of construction projects had been done before BIM came along. All projects had one individual who oversaw the entire project and was responsible for it its timely and accurate construction. Usually this individual had multiple years in the industry and was able to weigh all aspects of the problems in order to resolve them in the most efficient way.

CHAPTER 5. CONCLUSIONS AND REFLECTIONS

Overall Summary

When I started working in construction all those years ago, I quickly realized there was always something to learn and the industry never stood still. When I started this research, I thought I knew what BIM was and how to utilize it or teach it to students, but I was mistaken. Rezgui and Miles (2011) were correct in saying, "New approaches to the management of knowledge within and between firms imply major changes in individual roles and organizational processes. While potential gains are desired, the necessary changes are resisted" (p. 31). Recalling the significance in Chapter 1, before BIM: "Much of the construction knowledge, of necessity, resides in the minds of the individuals working within the domain, and the intent behind decisions is often not recorded or documented" (Rezgui & Miles, 2011, p. 85). From everything I have learned about BIM in industry, it is a multifaceted process in which each company selects certain parts to integrate into their corporate process. What components they utilize are very specific to each company, and there is no quick way to determine which component each company is utilizing. Also, the changes each company integrates into the everyday construction management process have an impact on the entire AEC industry. When companies share models to coordinate building a structure, part of what one company does as a BIM process transfers to other companies. Inevitably, they start to see what other companies are doing and whether it is more efficient than the process they already have in place.

I have learned a great deal about BIM from the corporate interviews I did for this research. According to Smith (2007):

> The concept of Building Information Modeling is to build a building virtually before the actual construction process to identify, analyze and solve potential problems and conflicts that can arise during construction as well as through the life cycle of the structure. BIM enables architects, engineers, designers, and construction managers to create a virtually realistic accurately detailed three-dimensional model of the building that takes the speculation out of design intent and construction process from the initial design stage throughout the construction process, and even into facility management. (p. 12)

I learned, however, that not all aspects of BIM were completely utilized within a company. Most are used, but some components of BIM are too cost prohibitive currently to incorporate into company management processes. Changes are occurring, though, to make those processes easier and more cost effective. I also learned that some companies are using the building model in ways I never knew were possible, interconnecting components and applications so everyone has the same information to use in building.

In this respect, I believe the study was successful. Becerik-Gerber, Gerber, and Ku (2011) are correct in saying, “The industry is embracing new modes of information, sharing and adopting emerging and fast-growing concepts such as building information modeling (BIM), sustainability, collaboration, and related technologies” (p. 412). I have come to an understanding that the AEC industry does not stand still for change of any kind, and I know that education has yet to embrace the same kind of change wholeheartedly. I also confirmed Luth’s (2011) definition of the project manager’s role in the construction of buildings. He states:

> A construction manager/engineer has familiarity with, knowledge of, and appreciation for the fundamentals of engineering and architectural design and deep knowledge of construction means and methods. The construction manager/engineer uses this knowledge to create safe and reliable alternatives for the construction plan, in collaboration with the design team, to help identify the optimum design concepts and details for a constructed project and to execute the construction activities in a safe, economical, efficient, and timely manner to maximize the quality and value of the project to the owner and society (p. 907).

Recalling what Ahn et al. (2010) identifies as the competencies of a project manager, I realized from the research that all aspects of a project manager entail every attribute they defined. Not only did I learn a lot about project managers, I learned about several aspects of the AEC industry I had not realized existed. For example, based on what I observed in all four of these companies:

1. Problem solving happens at a blistering rate.

   What we or I had taught my students about problem solving was nothing like what happens in industry. If a person cannot figure out a problem within 10 or 15 minutes, they are up and asking an expert for the answer. Higher education in engineering has pushed students to find the answer no matter what, but that is not the case at all in industry. It is time to change our way of thinking in higher education to emulate what AEC really does in practice.

2. Access to information is instant.

   The employees have quick access to information and are able to call upon a wealth of internal libraries, the knowledge and experience of everyone within the company. Office doors are open all the time, and people are easily accessible and approachable to share valuable information that will save the project time and money.

3. Utilization of new technology also happens at incredible rates.

   If the company's research identifies a new technology that has any benefit at all to the company and projects, they will adopt it and expect everyone to utilize it. So employees are constantly learning how to use and integrate new technologies, both individually and in conjunction with other technologies.

4. Meetings happen all the time in every company, but in AEC, they happen regardless of attendees' physical location.

   Employees are expected to participate whether they are on the premises or not (via phone, for example). Virtual meetings are becoming commonplace in AEC.

5. A workday is not 9–5, but is planned around the jobs and what needs to be accomplished that day.

   I was able to spend the day with several companies; one day in particular started at 4 a.m. and ended around 8 p.m. The jobsite was a 2.5-hour drive away, and we needed to be there at 7 a.m., when everyone working on the job arrived. We spent the day working, in meetings in the jobsite trailer, walking the jobsite, and resolving issues using the model until the jobsite closed at 4:30 p.m. We then headed back, and while on the way back, each person from the company in the vehicle was on the phone continuously, and one was in a formal meeting with everyone from their department.

6. Each person is responsible for and takes pride in every part of the job because it is their life and the culture of company.

7. When the workday ended, everyone gets together for social activities. It may be the company softball team's game, the bicycling group riding off on their evening trip, or those

who go out for dinner together with their families, but something happens to take employees' minds off work and bring them closer together as good friends or even family.

This study began with a need to determine how to change current construction graphics curricula to meet current trends of companies and project managers within AEC. It evolved with the help of my committee to break all components down in the statement to determine the path I needed to research. That breakdown helped me determine that the BIM process within the AEC industry was the first step needed in order to change current curricula. That led to deciding what type of study would be most effective. From all the research, a complete understanding of the phenomenon was needed, and therefore I selected a case study specifically in order to understand the companies' BIM processes along with their overall construction management. Little did I know how engrossed I would get in reading about and researching the case study as well as BIM overall.

What I Know That Nobody Else Does

BIM as a process is taking over as the primary means of managing construction projects. It is evolving perpetually, like the companies I visited. Ending with what I found out from the study helps me determine the path for the BIM curriculum I will eventually create in the future for students. It will be based on current AEC practices—or as many of them as I can incorporate.

Reflection of Questions

Question 1: Company's Definition of BIM

When I started interviewing each company and the people within, I thought I would get answers that paralleled what I found in readings by scholars and industry professionals. That was not the case at all. I found that people in the AEC industry really don't have time to stand still when it comes to building and need to find methods that make their company more effective and efficient. They need to communicate all aspects of their jobs to each other in a seamless fashion in order to keep the workforce smoothly assembling the building.

A schedule for a jobsite is how long each trade will take to start and finish their portion of the building. This, added to every other trade, makes up the building schedule. According to one of the interviewees, the building construction schedule and process are becoming increasingly shorter. As an example, a job that should have taken one year in the past is now finishing in nine months or even six. It is not so much the construction managers' doing, either; it is being requested or required by clients and designers. Looking back on the interviews, although this was not mentioned outright in all companies, the hidden theme was a shorter duration for building the structures in order to satisfy contracts. I am not sure BIM can take all the credit for shortening the construction process, but initial usage and utilization of BIM was a direct result of scheduling pressures put on contractors and their resultant solution.

The most common themes were communication and problem solving. Having done the interviews and been fortunate enough to visit jobsites during the interview process, I could tell that communication within an AEC job has increased tremendously from years past. In my experience, it was not uncommon to put something together one day, only to come in the next and have your work be completely destroyed by other trade contractors because they had to get their portion installed. As an example, one day I witnessed a structural wood beam being installed in the basement of a building, holding up a considerable amount of weight above. Two days later, I went back to the jobsite and noticed a 12-inch hole cut through the middle of this structural beam so the plumber could get pipes to an outside wall kitchen sink. This practice seems not to be seen anymore due to the coordination of trades. If each component or trade gets installed in the exact location identified, then other trades don't have to worry about their part being removed or made useless or unsafe, such as having a hole drilled through a structural beam.

Although I anticipated generic definitions from what I had read for their company definition of BIM, I was happy and a bit surprised at the variety and depth of the answers given by each of the four companies. Use of technology came across loudly, as with CD, or very subtly, as with CC. The interviewees considered it to be included in the BIM process or what BIM should be identified as within the industry.

Essence of Q1

Why did these common themes come across in the interviews, that each company needs seamless construction processes in order to keep on the shortened and tight construction schedule?

Preemptive problem finding is the only way to accomplish this task, and BIM helps companies be proactive in finding problems instead of reactive to problems when they arise. A lot of preliminary communication and collaboration with every trade helps the entire construction process run more smoothly. This was evident in the answers received to the first question. Each company approached the question differently, but ultimately the resolution was that the definition of BIM, and more specifically the companies' use of BIM, helped in day-to-day activities to make the construction process run smoothly and without errors or problems.

Collaboration and communication was a sub-theme that was evident in each company's interviews. When defining BIM, each company had in mind the end goal of a completed structure that exceeded code requirements and in most cases came in under budget; this goal is why they utilize the BIM process in their everyday activities within the company.

Being in higher education and consulting with several construction companies across the United States, I am able to witness BIM from an outside vantage point, but it is only when I get to ride along with these individuals that I can observe the true benefits of BIM while constructing a building. I always knew the construction industry was very social and collaborative, but BIM has taken that collaboration and communication to a new and better level of work.

Question 2: Company's Years of Experience with BIM

From the second question, I did not expect to get anything other than a recollection of when exactly the company started using BIM, but when I look at the answers, it seems that each company went through more than just saying, "We are doing this now." Each company thought about the answers before coming out and stating a number. To each, BIM means something different, yet with commonalities across all AEC companies. Each company had made the BIM process unique to their company, though in some ways it was the same across different types of AEC companies. I was expecting a quick number to each answer and ended up with each trying to remember when BIM use began, as well as exactly what was done at that time.

According to Rogers (1995), most companies go through a five-stage process of innovation and adoption. I witnessed a little of this in the answer to Question 2 with company CD. The employees thought back, discussing what they did and when. I could see it a little in company CB, also, when the conversation went back to a time before the BIM process was completely used in the company. And while it was not said outright, their facial expressions went through the five stages of innovation adoption (see Figure 25 below).

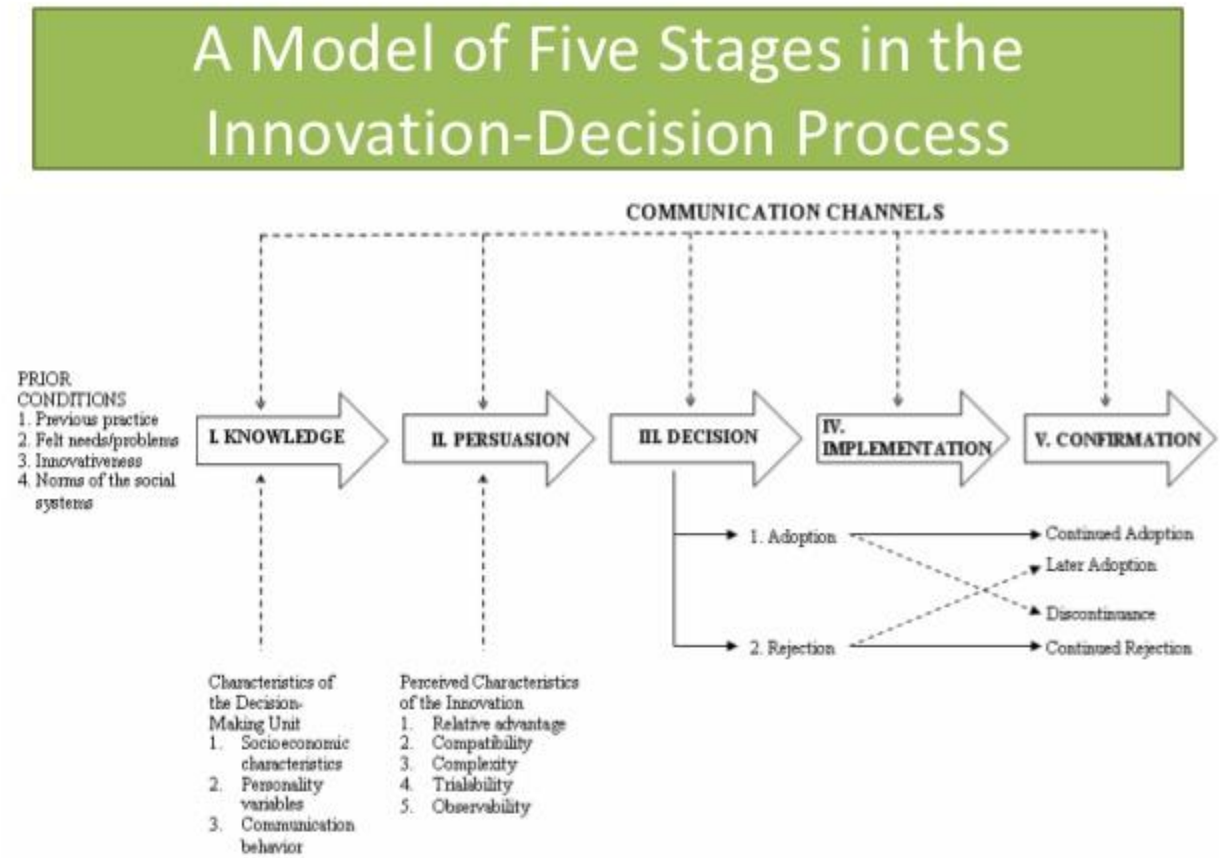

Figure 29: Five stages of the innovation-decision process (Rogers, 1983, p. 165)

Company CD's answers made me look past most of the interviewees' brief answers and words to realize that most changes within any company happen as identified in the five-stages model above. They started a dialog that ended up determining the eventual answer. It was that discussion that prompted me to look into how companies make decisions about adopting innovations, and what steps go into answering those questions. We in higher education can be swayed to take on new technology and teach it to the students in hopes they take that knowledge to industry to make it better, but ultimately higher education does not have a monetary stake in anything.

There is always prior knowledge and research into the innovation. Once that knowledge gets to a point where you are convinced it is beneficial, the persuasion of those in charge of decisions comes into play. It is up to those researching to weigh the pros and cons of the innovation and identify benefits as well as drawbacks to the company. Ultimately, a decision has to be made to either adopt or reject that innovation. If it is adopted, implementation is accomplished, and at some point down the line, confirmation of that decision needs to be determined.

Companies have to make decisions based on whether the new innovation will save time and, ultimately, money, not for just one project but for all current and future projects they undertake. I did not expect variation in the answers regarding when each company went to adopting BIM as a process. I did, however, learn that a company I thought would have used BIM longer than others had not, and the one I thought would have used BIM for the shortest time had actually used it the most.

Essence of Q2

Why did an average of 10 years keep coming up as an answer? It made sense that each company was not into the innovation phase—some were barely in the early adoption range, but all were willing to take a chance in early innovation adoption on or before the early majority area. Having something proven to save time or money was the deciding factor for adoption. While a couple of companies were earlier than the others, all four companies realized the benefits early on of using BIM in construction management. The difference in timeframes could have been due to the sizes of the companies, compatibility with existing hardware or software, training issues, or whether upper management were present to say yes. Eventually, each company interviewed did find a way to get over the hump and use BIM in every project. Their answers led me to the next question.

Question 3: Adopting BIM

This question got similar responses across all companies. It came down from either the president or higher-up administration that the company would adopt BIM as their project management process. What that process was had not been defined by the administration, but each graphic planning and support area was being converted to a BIM department. Another similarity was that most companies started by doing what was called the low-hanging fruit of BIM, clash detection.

It was common several years ago to run a collision detection report to see if any modeled components occupied the same space in the building. This process was where most companies got their BIM start, but soon their BIM process evolved to be much more.

Within company CA, the VDC person hired was hired specifically to develop the BIM process for the company. Company CA did their first BIM coordination on a hospital addition and remodel. Hospitals are extremely complicated, with the extent of the plumbing and mechanical systems that need to be included. From the story CA told me, they broke the hospital down into floors first and ran a collision report. A report can be created using any or all of the following groups:

1. Architectural
2. Structural
3. HVAC
4. Electrical
5. Plumbing
6. Fire protection

A BIM specialist would compare the architectural model with the structural, the architectural with the HVAC, and so on. Eventually, the BIM specialist would compare every aspect of the model with every other aspect. When done, there should be about 20 different reports comparing building components. If the designers had modeled it correctly, there should be no collisions between modeled objects.

All companies stated that the graphics departments within the company were used for creating 2D blueprints or planning and supporting each project. Each also said that the graphics area changed considerably when administration decided to transition into utilizing BIM as their company management process.

The transition for all companies happened to be creating a 3D model of the building. As company CD stated, “It certainly starts with 3D modeling, which was the central technology involved in tying together construction activity with pre-planning, with early information, with scheduling, with all these other things that are involved in what we're ultimately trying to do. So 3D modeling was certainly integral to it, but again, it's…I would say it's really two things central to that model." The other component is information. CD3 named as examples "labor codes and fabrication labor and material pricing," adding, "So it evolves from there to have so many other components of pieces of information that we tie to that data, but I think that's—All of that is predicated upon you having an accurate three-dimensional, digital representation of your work product."

Essence of Q3

There was a commonality among all companies in the fact that upper management wanted each graphic department to adopt BIM as the new corporate process. While this was no real surprise because BIM was in the semi-initial stages of use within the AEC industry, what was surprising was that upper management had no idea how to tell the graphics departments how to achieve BIM use and eventually the process for the company. Ten years ago, AEC companies didn't even think about creating models, let alone using them to manage the entire construction process. I liked CA1's response summing up their company's adoption of BIM:

> "It was a decision made at the executive level. You have to have executive leadership; that's probably point number one. And point number two, is you need to recognize that BIM is a tool and identify the ways to use it effectively and not just use it for the sake of using it, and that's where we really tried to focus our energy. I believe especially, probably more so now than ever before, that because technology is advancing so quickly, that you need to have, if you're going to be successful, an approach that effectively evaluates the value of these tools, whether or not it's just someone trying to sell you something or whether or not there's some real value there."

I believe this really sums up why companies adopted BIM as a process, and thus the essence of Question 3.

Question 4 & 5: Company's BIM Use

This question evoked a tremendous response from all participants. The answers were lengthy to ensure a complete view of each company's process for project management. I thought this question would gather long and detailed answers, and I was correct. I was, however, a bit shocked that all company answers had two or three single components in common. Maybe it was the teacher in me, always asking “Why?” or “What more can there be?,” but researching BIM use in companies has come down to the corporate process of management of a physical project’s construction—be it an entire building or portions for trades. I went into the question expecting similar answers to corporate BIM definitions, but ended up changing my mind to thinking about the entire construction process and how to educate young minds that way instead of only focusing on BIM.

While I was captivated with each answer early in the interviews, I started seeing patterns emerge after interview CB, all the way through company CD. I tried to keep my mind on the interviews and not let it wander off thinking about past interviews. This was difficult because each interview just reinforced what the previous company had stated about BIM uses within their company. The patterns were very noticeable and showed commonalities with what industry had identified as the process of BIM: design through facility management support for construction management. It was cyclic, too, with everything revolving around the model. This brought me to the below image (Figure 26), which could become a standard in both higher education and AEC.

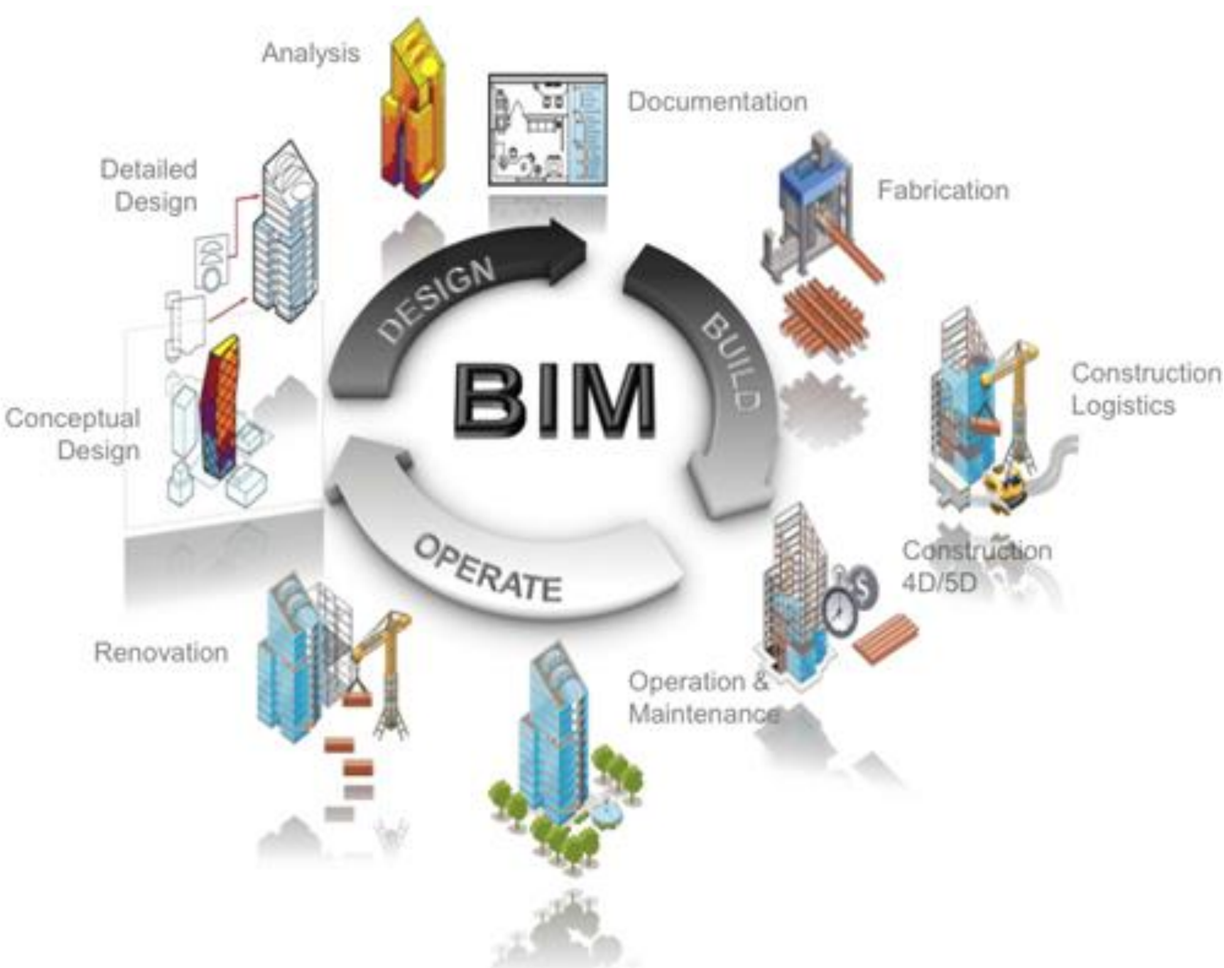

Figure 30: The cycle of BIM. Syncronia (2012). Retrieved from http://blog.syncronia.com/en/autodesk-bim-conference-2011

Whoever created this image grasped the true essence of BIM and what it could do for AEC companies at every phase of a building's life, design through demolition. While I did not get any company talking about using the model in demolition, there are a few new technologies out currently that utilize the 3D model in demolition.

Essence of Q4&5

The process of construction management has evolved over years of trial and error for each company in similar ways as well as different ones, depending on several factors within each company. What is constructed or focused on differs between companies, whether they are design/build or a trade contractor. The only thing these factors have in common is that they are part of a process within the AEC industry to build and assemble new structures. Within that industry, those companies that have foreseen changes coming and adapted to those changes have succeeded and gained years of experience building. Those companies that resist change end up failing. All the companies interviewed have been in business more than 50 years and have amassed several hundred employees, all focused on company success. The primary change over the last 25 years has been BIM.

The essence I took away was that modeling is done to make projects work and flow better together. When you have dozens or hundreds of people working together, the better they are informed as to where to be and what to install, the more smoothly the project will progress.

Question 6: BIM Advantages

This question evoked a tremendous enthusiasm in responses. While I was aware of some of the benefits, hearing the interviewees talk about the benefits in their company and visiting the different jobsites where BIM was implemented were nice ways to witness and validate the advantages of the process. Money saving was at the heart of why a client liked using BIM, and smoother building was at the heart of the construction company, while ease of building was what the laborer liked. Having the chance to talk to a few laborers onsite, it gave me an appreciation for what they do and how hard it is to pull everything together without accurate documentation. This does not happen overnight and was definitely something each company did not accomplish quickly either. It really took each company's entire workforce to buy in to the process. Ultimately, the company benefits, but unless everyone truly believes that at the start, then the entire thing would fail, and the company would be back to traditional methods.

It is hard enough to find a dozen people who will wholeheartedly believe in something in order to change for the better for themselves or for their company, and yet these companies did just that with several hundred employees and even several thousand people on jobsites.

I was reassured that all my efforts over the years to teach the concepts and processes of BIM to my students had been worthwhile and beneficial. I could identify aspects of my teaching in each phase, while also seeing new technologies being implemented that I had no idea could be done. This made me realize how far behind in utilizing technology I was in current course curricula. It gave me a new appreciation and regenerative look at redefining the BIM courses.

Essence of Q6

The essence of BIM advantages was the tremendous benefits to so many parties involved with projects. Throughout the entire process, everyone has something to benefit, while giving up only a few things—usually time and effort. In all company interviews, each interviewee identified repeatedly how their construction management process saves time and money and is more efficient and beneficial for a better building. Having been on current jobsite visits, I witnessed each person taking pride in what they were building. In all cases, as we drove across town to get to those construction sites, the interviewee would point out other projects they had been involved with and built, with almost a sense of pride and accomplishment. In these interviews, all participants took tremendous pride in their work, all the while reaping the multiple benefits of a newly developed process of managing construction projects within their company.

Question 7: Company's Driving Force for BIM Use

This question evoked a tremendous response from all participants. Answers were lengthy to say essentially the same thing: that upper management might have gotten the ball rolling, but it was a company effort in the end that kept it moving forward. It was interesting to hear that upper management started the BIM process in the company, but I did not hear why or what made upper management decide on BIM process for each company. I was not able to meet any upper management people during my company visits. I think that might have been an oversight in this question and could potentially be a future research focus.

As the interviews progressed over months, I really began to see a common theme across answers. I was expecting a bit of variation but found that not to be the case. Even in the specialized trade contractors' case, their company started and used BIM for the same reasons as the large general contractor and even the design/build firms. They all saw the need to handle information, already created in the computer, in a manner that communicated intent of that material to all parties involved. It might sound cliché, but it is akin to a well-oiled machine with all parts working together in harmony. I saw that process across each of the companies—a family working together for one goal, a culture driven by computer model use in the construction of a single building.

Essence of Q7

This question opened my eyes to the fact that construction companies are a bit more than just a place to work. Each participant truly enjoyed the work and got up each day ready to tackle any problem that arose. While the question was to provoke responses of BIM usage, it was the meaning behind the answers that made me look in a different light at what each company did and the employees behind the scene.

Each participant took pride in the fact that they worked for a great company, or should I say family. My site visits to the companies gave insight into how each functioned and the different areas of focus each department played in the overall construction process. Each participant was proud to identify past projects they had worked on, pointing out components, successes, and challenges of the building and its construction process. It was refreshing to see people enjoying what they did for a living. I stated it above in my subjective reflections: a family working together for one goal, a culture driven by computer model use in the construction of a single building. That was the essence of this question. It might not have anything to do with the answers, but I did see beyond those answers partnered with other aspects of the company visit to get the true meaning of each company's philosophy and goals: use what they can to build a quality product and work as a team!

Question 8: BIM as a Database Tool

I had my literature review done going into this question and expected a response that paralleled what I had read. It was true that all companies were using BIM to help resolve issues and coordinate information in every phase of their company process, but it caught me a little off guard to hear how much they did rely on the model. Where once each phase worked independently to obtain the desired output, they were now all working in unification with each other. I actually found that this paralleled what BIM had originally been developed to accomplish. While each company focused on different aspects of BIM, all were focused on the end goal of creating something as complex as a structure with management that flowed and communicated smoothly.

Essence of Q8

The process of construction management has evolved over years of trial and error for each company in similar ways as well as different ones, depending on several factors within each company. Whether they are design/build or a trade contractor, each company is very different, and yet similar in so many ways. They have in common that they are part of a process within the AEC industry that builds and assembles new structures.

The fundamental nature of construction requires information accessibility, including, of course, using that information to construct. While accurate information allows everyone to benefit, it could not be guaranteed in the model used for several decades. It was the potential for inaccuracy and the little silos of information each person kept that caused companies to include extra waste factors as well as contingency costs in their estimates so as not to lose money. BIM has opened up the entire industry to a new way of doing business and communicating—openly and collaboratively.

Question 9&10: BIM Education within Company

Being in education, I came into this question hopeful that I would get a predetermined answer—and I did. I also got more. It was refreshing to hear companies are constantly learning. It was also refreshing to hear that each company placed a high value on every individual in the company to continue to learn and grow. I was a bit overwhelmed by the amount of training and education that takes place, though.

The companies interviewed are investing a huge amount of time and money to educate and train their employees—not just at any one level, either, but across the entire company. The responses included such tools as corporate wikis used to help everyone figure out technical problems and online in-house videos to walk them through processes. I got a real sense that the companies were dedicated to lifelong learning and questioning the status quo, which I found refreshing and appealing. They are training and educating in ways each employee learns best which is a tremendous amount of material to create, manage and disperse. While interviewees also stated that some outside training sources were used, a vast majority of sources were internal to employees only. This was amazing to hear.

I have spent many years helping students learn, but these students are still acquiring the skills and knowledge they need to prepare them for the workforce. I have taught in an industry where the primary product is learning. I believe in lifelong learning and constantly want to better myself in order to help students be prepared to enter industry. I do not think my efforts are enough, though. I have stopped asking why or how procedures and processes are done a particular way in industry. I do not think I have failed my students, but I have not completely enlightened them either.

I have always heard about the fast pace of industry, but during this research, I got a real sense of how these participants handled multiple problems at one time. In a road trip to a site visit, I was told I could not speak at all. Confused, I asked why. The participant said she had to be in a phone meeting and that it was confidential. I put on some earphones so I wouldn't overhear the meeting. She had all her notes available on an iPad held up with a car holder. The meeting lasted about an hour as we drove, and then the participant touched my shoulder to let me know it finished.

I later found out that traveling meetings happen all the time. No longer are individuals restricted to the office for the meeting. In contrast, it seems unlikely that an educational meeting would allow individuals to phone in while driving to a different job. I guess it is the different worlds we live in, but that is what made their world appealing to me during each interview. I wish education had that same mentality about change. Too many times, I see colleagues who refuse to learn something new in order to better prepare their students, or who do not know what practices go on in industry. It is disheartening to think that they chose education and lifelong learning but do not practice what they advocate.

Essence of Q9&10

When it came down to essence, lifelong learning and change were common themes across each company philosophy. Each company invested huge resources to accomplish this for every employee. If a part of change affected the janitorial, secretarial, administrative, or installer departments, they all received training. It is not so different from any organization, but it was astounding to hear the amount of resources these four AEC companies were putting into corporate and employee training and continued learning.

Question 11: BIM Education of Clients

While I did not expect much variation in answers when asking about educating the client, as I did when asking about educating the employees, I found it interesting that all three of the contracting companies sent employees out to clients and architectural firms to give workshops or training. Coming from education, I would have thought an online training session would be more cost effective, but maybe the personal touch of sending a representative shows the client that their contractor cares. I did not have a chance to resolve the issue personally, but would like to think that the component of caring is the reason for personal touch.

Essence of Q11

The process of construction management has evolved, and each AEC company has to change with it in order to continue to be successful. Employees of these companies also need to change with the company process, which would indicate constant education and training. In essence, what's required is a commitment to lifelong learning and an understanding that technology, materials, and management processes are moving targets. It is the responsibility of individuals to constantly challenge themselves to learn better ways of accomplishing tasks or resolving problems. Simply stated, change happens, and only the prepared will succeed.

Question 12: Qualifications of BIM in New Hires

I honestly could have continued chatting about this last question for hours. It was industry thoughts that validated my personal research in the agenda. While I could not justify taking the participants away from their jobs for this, I thought it would be great to have a once-a-month meeting to discuss what was going on in industry and to let them know what I was researching in higher education. A consortium defined for the betterment of both industry and future employees of AEC companies would be beneficial for both worlds.

In the last company interview, I was the most intrigued when they were defining or speculating what the future project manager would look like and what kinds of skillsets they might have. That ultimately would be how I use the research: to define curricula for all future virtual project engineers.

It saddens me that the companies interviewed are not physically closer so I could have an evening out once a month to discuss future needs, requirements, and traits of a project manager as well as future research possibilities.

Essence of Q12

Change is happening and each company is doing everything possible to meet the evolving needs. It is not anything new to the AEC industry, but this change is a large enough to be causing ripples in everyday processes. In order to keep up to date on technologies, AEC professionals are reading more, integrating company training (both face-to-face and online), participating in workshops, and attending conferences to keep up to date on that technology currently used within their company and to do research on future trends.

Importance to the RQs

1. *How has Building Information Modeling influenced a construction manager's current position?*

As most of the interviewees stated in the above answers, BIM has significantly changed their position into a more efficient means of managing the construction process for every project. It has changed the person's responsibility from drawing the object to modeling it, and now to just managing the information of the model and all components within the building. Knowing how to manipulate the model and information is essentially what a construction manager does—along, of course, with actually managing people to build that structure.

The BIM process has come with several modifications to interviewees' daily routines. For employees of these companies, getting together to discuss the BIM process once a month and then communicating with upper administration about it has become part of their culture. Preconstruction meetings with all parties who will be involved in the future project have adapted the project manager's responsibilities to integrate discussions about the material and location of every component within the project, well before ground is broken. In this research, it was clear that each company wanted to identify every possible location where issues might arise well in advance.

When I first started building, the AEC industry was more reactive to problems than proactive. An issue would arise onsite, and it would bring all production to a halt until it was resolved. In some cases, that took a few days when nothing was accomplished. Utilization of BIM has changed the entire industry, making it proactive about finding issues within projects. Each company manager has noticed a considerable reduction in construction duration, how long it takes to build the structure. What used to take a year is now getting done in six to eight months.

CD2 stated it best:

> In a way, BIM is going to be looking at model solutions and evaluating them as opposed to physically moving components around. I think that technology, computers, and software are going to more take that role on, and our people, our professionals, our BIM professionals if you want to call them that, are going to—we will call them virtual construction professionals—are going to be that layer that evaluates the solutions the computer comes up with for the criteria that's most important for that particular client, for that unique building.

I thought there would be a place for a graphics modeler, and what I realized is that the job requirements of the project manager are changing to become the 3D spatial visualization project manager. BIM still continues to be at the forefront of use for AEC professionals, since it has been universally identified as a disruptive technology. Its implementation came in parallel with the willingness of AEC professionals and clients to collaborate and share model information.

2. *How has Building Information Modeling (BIM) influenced a construction manager's need for continuing education within the industry?*

I always knew that the construction industry was in a constant state of learning. I saw it daily in the work I had to accomplish. Whether it was new products coming out or new processes for assembly, every day was a new challenge to learn and grow. It was reinforced by every interviewee, but I had not realized the extent of that learning. As a carpenter and a project manager for a small company, my education and training were limited to being self-taught or being fortunate enough to get formal training at a two- or three-day workshop.

Every company in this research had an internal educational aspect, where employees could go onto the internal server and select learning modules to follow. It did not matter which area, either; each department had created their own learning modules about what they do daily and how others can learn from them. It seemed that the VDC or BIM areas had the most learning modules for each company because BIM affected so many people within the company. It only made sense that BIM education be distributed across the entire company workforce.

As each company's BIM process evolved, so did the educational training modules. One company stated that they have an entire server dedicated to online learning, which is accessible to all employees. While most individuals learned at their own pace, BIM was complex enough for formal training to be used throughout this company in order for the company BIM process to work seamlessly and effectively.

BIM just happened to be the change the AEC industry needed to jump-start lifelong learning within companies. It is not only confined to education within the company, but has expanded to include clients. While most clients were visually illiterate, now the model is helping them understand the complexities of their future building or structure. In addition, the competencies and education gained are more than visualization. Each person has gained technical knowledge as well as about the materials and methods of construction. While each person is learning how to model, that is translating into actually how the structure is assembled. One of my students discussed the educational value of BIM this way:

> I have learned so much more about structural design and construction in your BIM course than I ever did in my regular steel construction course. I only learned the theory behind steel assemblies, but when I had to create all the structural components inside the technology, all that theory came to life and I finally understood what it took to erect steel on a jobsite.

I hear it from clients too, where they are able to "see" what their building will look like and what all goes into its creation.

Recommendations or Practical Implications

The reality is that all of these BIM processes are evolving daily. Industry is learning at an exponential rate, and higher education cannot keep up with that evolution. The construction industry is changing rapidly, driven by outside influences like advancing technology, innovative materials and methods of construction, and information globalization of the economy. Higher education for the construction manager has been affected by these changes only marginally or has remained constantly stagnant. Most changes currently in higher education seem to be focused on better classrooms or better residence halls, and Wieman (2014) states, "One would be hard put however, to name institutions where sustaining changes have included embracing widespread adoption of new approaches to teaching and learning that experimentally have been shown to lead to greatly increased student learning" (p. 8320). This study would transform and disrupt traditional methods of construction management education into a new model: growing opportunities for CM education that would improve and increase student learning, giving them real-world knowledge that prepares them for their careers within the AEC industry.

This transformation presents a path to the expansion of current BIM courses within a construction management or virtual design & construction curriculum. This expansion is aimed at updating the current content of the existing courses being offered, as well as mapping out the creation of both undergraduate and graduate options for further BIM education. The growth in BIM courses offered will provide a more diverse and broad repertoire from which students from various disciplines can learn and explore more aspects of BIM usage. This endeavor would culminate in the establishment of a BIM embedded curriculum that would utilize the Building Information Model and BIM tools as the drivers for learning (Underwood et al., 2015).

For Construction Management Students

Looking back at the current ACCE curriculum requirements, it is evident from the research that any aspect of construction management integrates BIM into current industry practices.

	Curriculum Categories	Minimum Academic Credit
1)	General Education ……………….	15 semester (22 quarter) hours
2)	Mathematics and Science ………..	15 semester (22 quarter) hours
3)	Business and Management ………	18 semester (27 quarter) hours
4)	Construction Science*……………	20 semester (30 quarter) hours
5)	Construction* ...…………………..	20 semester (30 quarter) hours
	Total Combined Construction Science and Construction*	50 semester (75 quarter) hours
	Subtotal: Prescribed Category Credits	98 semester (146 quarter) hours
6)	Other Credit Hours (As needed to complete 120 hour threshold or to meet additional institutional and program requirements)	22 semester (34 quarter) hours
	Total ACCE Accreditation Requirement	**120 semester (180 quarter) hours****

* Construction Science and Construction are separate subject categories. The minimum aggregate of both Construction Science and Construction combined requirement is 50 semester (75 quarter) hours of academic credit.

* One semester hour equals 15 instructional hours; one quarter hour equals 10 instructional hours

Figure 31: Curriculum: baccalaureate program ACCE accreditation requirements (ACCE, 2014, p. 10)

While there is a common focus across any higher educational curriculum with general core requirements like math and English, construction management curricula hit business management and construction science hard, with almost 60 hours of classes throughout a four-year stay. Within those construction science classes are estimation, scheduling, trade processes (MEPF), and overall information coordination and collaboration—all of which would and should incorporate BIM.

All of the courses would not need specific software or models to implement. In fact, all companies interviewed stated that they utilized the application that solved the problem quickest. I would propose the same for construction management curricula. Software-specific curricula will not educate students to current industry standards and processes. Today's student must be able to adapt and use whatever the company uses or whatever would resolve the issue in the quickest fashion.

For Virtual Design in Construction Students

Construction graphics students could also benefit from this research. Current curricula across the nation and world indicate a lack of BIM-specific courses within higher education institutes. As noted in the table in chapter 2 of universities, programs, and BIM courses included in review by Barison and Santos (2010), at most, there are six BIM courses offered within higher education institutions. I would propose an interdisciplinary curriculum based on BIM graphics coupled with a traditional construction management curriculum. Without the skillsets of materials and methods of construction, modeling a building is pointless due to the knowledge required.

Before the enhancement of BIM education provided to students can begin, there has to be a clear path defining the desired outcomes of each course. The overall competencies and skills that students will be expected to have mastered at the end of the BIM pathway in order to achieve those overarching outcomes also need to be identified. The following competency sets and learning objectives have been adapted from the BIMe initiative, a document that outlines an approach for classifying performance and provides a structure of achievements for individuals and teams seeking advancement in BIM-related skills.

Competency Sets

A competency set can be described as a collection of topics or objectives that need to be completed before one can be declared as having mastered said competency (Succar, Sher, & Williams, 2013). Students that go through all the BIM courses to be fully outlined in the subsequent sections will emerge with a mastery of these three identified BIM competency sets, as well as all the skills associated. For the purpose of BIM growth in CGT, three such competency sets have been adopted from the BIMe initiative (Succar et al., 2013).

The Functional Set

This covers the overall abilities required to initiate, manage, and deliver projects (Succar, 2016). These are geared towards developing a BIM project manager mindset among students, and they include skills such as collaboration and project management. This involves equipping them with the knowledge of project and team management of BIM projects, as well as being well versed in the options available for BIM tools, their interoperability limitations, and their workflows.

The Operational Set

This set involves using the daily, hands-on knowledge of the BIM tools required to complete a project partially or fully (Succar, 2016). This set focuses heavily on the students being able to master the proper and efficient manipulation of software in order to achieve project goals.

The Technical Set

The technical set requires a more advanced level of BIM tools. It involves the application of skills across disciplines and specialties (Succar, 2016). These abilities are required in order to generate and present project deliverables.

Although presented as distinct pieces, each of these competency sets as well as their corresponding learning objectives constantly work simultaneously. The proposed BIM pathway would require students to gradually build their skillset in each competency objective field until mastery is achieved.

Figure 32 displays the BIM competency sets as well as their learning objectives. The following section will define and describe the learning objectives.

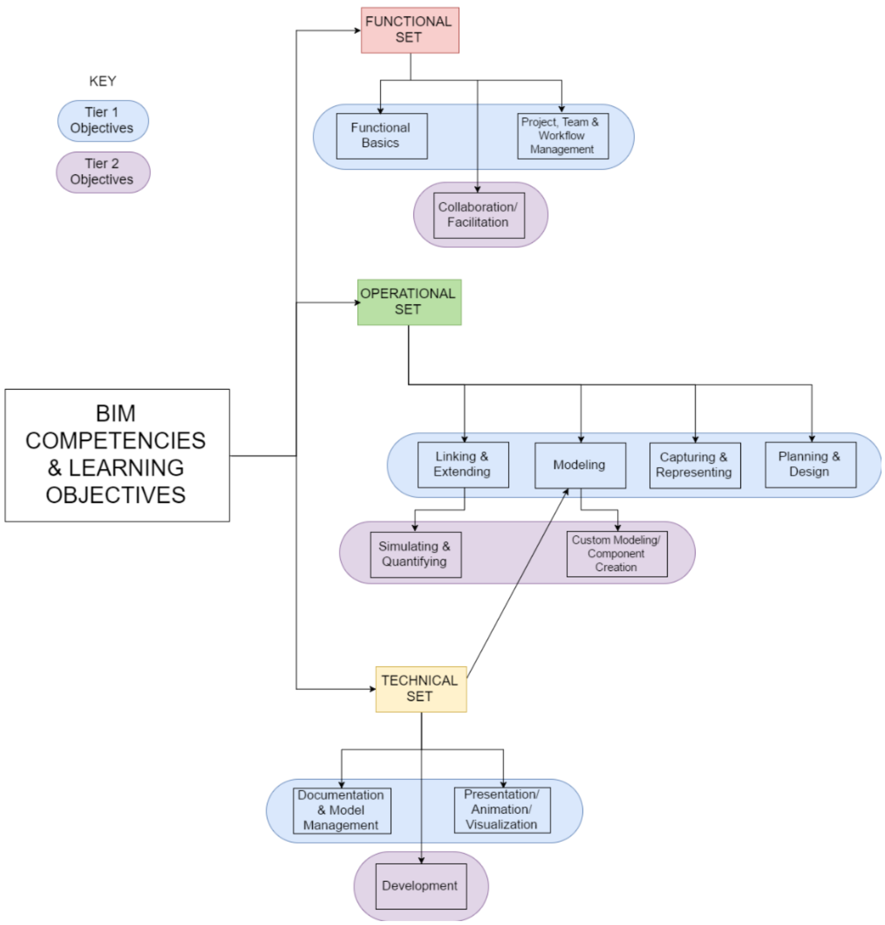

Figure 32: BIM competencies and learning objectives

Overarching Learning Objectives – Tiers and Levels

With each of the competency sets come respective learning objectives. These learning objectives are further divided into tiers and levels. The division of the objectives into tiers and levels directly corresponds with the course level they are applied to.

The overarching learning objectives identified under each of the competency sets span several semesters, increasing in complexity and required skills over time. Out of the total list, however, four of the overarching learning objectives were identified as being more applicable to the 300-level courses and above. These were thus separated into the Tier 2 overarching objectives.

The definition of each overarching objective was separated into levels in order to show the gradual buildup of skills learned and required as the students progressed up the ladder. Each level was also identified as being applicable to a specific corresponding course level. Thus, Level 1 of the overarching learning objectives applies to the 200-level courses, Level 2 of the overarching learning objectives applies to the 300-level courses, and Level 3 of the overarching learning objectives applies to the 400- and 500-level courses being offered in the BIM pathway. The tables below detail the separation of the overarching learning objectives into tiers and levels.

Table 12: Progression of Tier 1 learning objectives

	TIER 1 - OVERARCHING LEARNING OBJECTIVES	**LEVEL 1 (Introductory)**	**LEVEL 2 (Intermediary)**	**LEVEL 3 (Advanced)**
1	**Functional Basics**	Identifying the basic capabilities of BIM tools	Developing an efficient workflow for achieving deliverables using various BIM tools	Understanding interoperability limitations of BIM tools; identifying appropriate BIM tools and workflows for use in achieving main deliverables
2	**Project, Team, & Workflow Management**	Engaging students in short-term initial group decision making on projects	Engaging teams in long-term project workflow for efficient teamwork on BIM projects	Engaging teams in strategic planning of project workflows and team management techniques for efficient teamwork on complex BIM projects
3	**Modeling**	Generating non-complex BIM models based on pre-defined modeling standards and protocols	Generating BIM models based on complex pre-defined modeling standards and protocols	Generating BIM models based on complex pre-defined modeling standards and protocols across knowledge domains
4	**Capturing & Representing**	Using BIM software tools to replicate physical spaces	Using BIM software tools to design and modify physical spaces and environments	Using BIM tools and specialized equipment to capture, represent, and modify physical spaces and environments

Table 12 continued

5	**Planning & Designing**	Using BIM software tools for conceptualization and design of simple projects	Using BIM software tools for conceptualization, planning, and design of projects	Using BIM software tools for conceptualization, planning, and design of complex projects
6	**Linking & Extending**	Linking AutoCAD software with BIM modeling software tools.	Linking BIM-created components to other BIM-related tools	Extending use of BIM models and their components by linking to other databases/analytical tools
7	**Documentation & Model Management**	Generating drawings using standardized details	Generating construction documents using standardized details and workflows	Generating, managing, storing, and sharing construction documents and BIM models
8	**Presentation/ Animation/ Visualization**	Generating quality renderings using native software tools	Generating professional-quality renderings and walkthroughs using specialized software tools	Generating professional-quality renderings, walkthroughs, 4d sequencing and/or 3D animations using specialized software tools

Table 13: Progression of Tier 2 learning objectives

	TIER 2 - OVERARCHING LEARNING OBJECTIVES	**LEVEL 2 (Intermediary)**	**LEVEL 3 (Advanced)**
9	**Model-based Collaboration**	Utilizing model-based collaboration between project participants	Utilizing cloud-hosted model-based collaboration between project participants
10	**Simulating & Quantifying**	Using software tools to conduct model-based estimations and take-offs	Using software tools to conduct various types of model-based simulations and estimations
11	**Custom Modeling/ Component Creation**	Using software for designing or customizing model components based on documented modeling standards	Implementing a structured approach for developing or customizing specialized model components using documented modeling Standards

Table 13 continued

12	**Development**	Exploring extensions for BIM software tools	Developing extensions for BIM software tools; using productivity software or web portals to improve BIM deliverables

Undergraduate courses

The next step after the modification of the existing courses is to expand the repertoire of BIM courses in CGT in both the graduate and undergraduate level. The proposed course will introduce much-needed depth into various aspects of BIM modeling and technology, partnered by their construction management education, by delving into the technical and practical aspects of construction modeling technology.

Introduction to Modeling

While traditional graphic courses dealt with 2D documentation and blueprint reading & understanding, new courses will need to get into 3D modeling at the freshman level. Such proposed transformation of the construction sector has significant implications for construction management and graphic education providers in ensuring they meet the demands required of future professionals.

Construction Education

A critical part of the VDC or BIM degree would be a complete understanding of methods and materials of construction as well as all aspects of estimation and scheduling. To go as far as a traditional construction management degree would not be necessary, but might be helpful to the BIM students in their careers. Without knowing how the structure is built and all components within, how can anyone be expected to model the building in the computer or manage all the information dealing with the building?

MEPF Modeling

Mechanical, electrical, and plumbing components of building information modelling will be tackled in this course. Advanced print reading for MEP plans will be taught. The simulation of alternative mechanical design layouts will be explored.

Structural Modeling

These courses will dive into the technical and practical aspects of structural modeling in a building information model. Advanced print reading of structural plans will be taught. The simulation of building structural designs will also be explored.

Advanced Modeling + Programming (Dynamo)

Advanced modelling deals with the creation of custom family models within Revit. Students will be taught how to create and edit masses, generic models, family specific models and parametric models that can be dynamically adapted for use. Detailing of their creations will also be taught and computational BIM using Dynamo will be introduced. Using dynamo, students will learn how to create their own Revit functionalities that can lessen workload, access, management and manipulation of Revit elements.

Research

All of these items for a Virtual Design in Construction or Model Information Engineer culminates in the need for the student to be able to research and resolve problems. Without this ability, all the modeling in the world will not help the student in the AEC industry.

Graduate Courses

Graduate courses that will allow for a more advanced look at technological changes as well as new developing modeling techniques and workflows are currently non-existent, yet critically needed. The following proposed courses will be aimed at graduate students, and could also serve as electives for senior undergraduate students.

AR/VR & Technology in Construction

The contents of this course will shift over time, as technology in the AEC industry evolves. This main objective of this course will be to introduce students to the use of cutting edge technology in the construction industry. This course will cover topics such as the use of Virtual and Augmented reality, Drones, Photospheres, 3D printing in conjunction with BIM tools and their role in the technological advancement of the AEC industry. Discussions of current BIM policies and execution plans as well as how risk and liability are managed in the industry. Students will be exposed to how technology and collaboration is changing workflows, roles and responsibilities in the industry.

Laser Scanning

This course will introduce students to reality capture technology such as laser scanning and photogrammetry in construction. Courses contents will include topics such as: workflows for capturing and editing point cloud data, conversion of laser scans into 3d meshes, comparing laser scans with 3d models for construction verification, as well as photo to mesh conversion. All items currently being used as research determined.

Proposed Curricula

The proposed BIM courses offer more flexibility for the students to explore varying topics while being exposed to more BIM tools and applications, thereby increasing their skillset and marketability to various companies. The increase and redistribution of BIM courses also allows instructors to devote much needed time to teaching skills the students need at a deeper (mastery) level as opposed to only receiving a superficial amount of information on several topics during the semester.

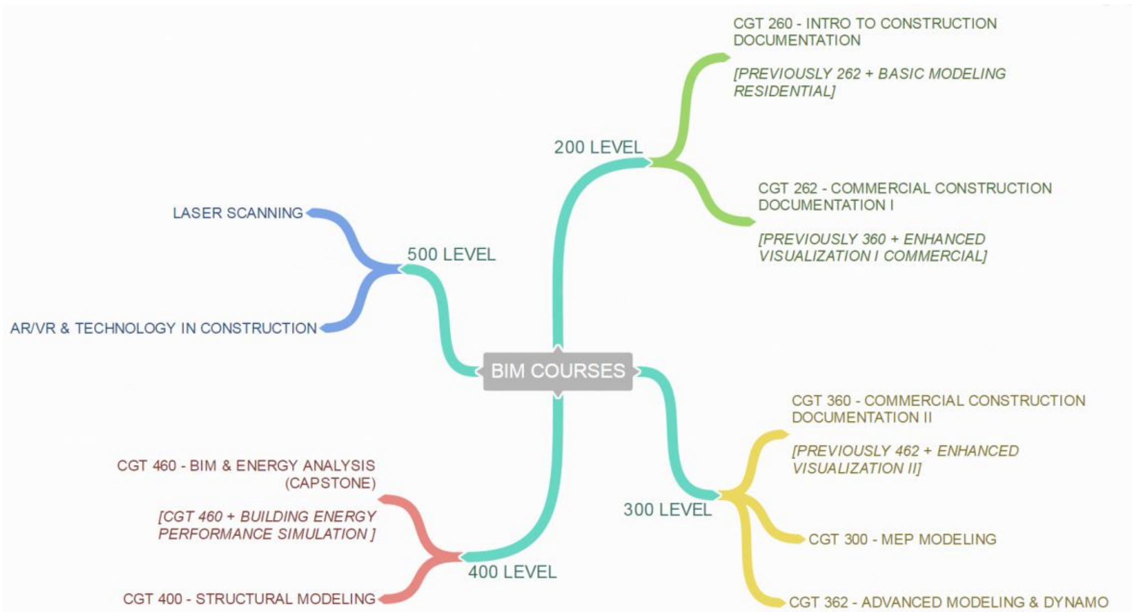

Figure 33: Existing modified courses and proposed new courses

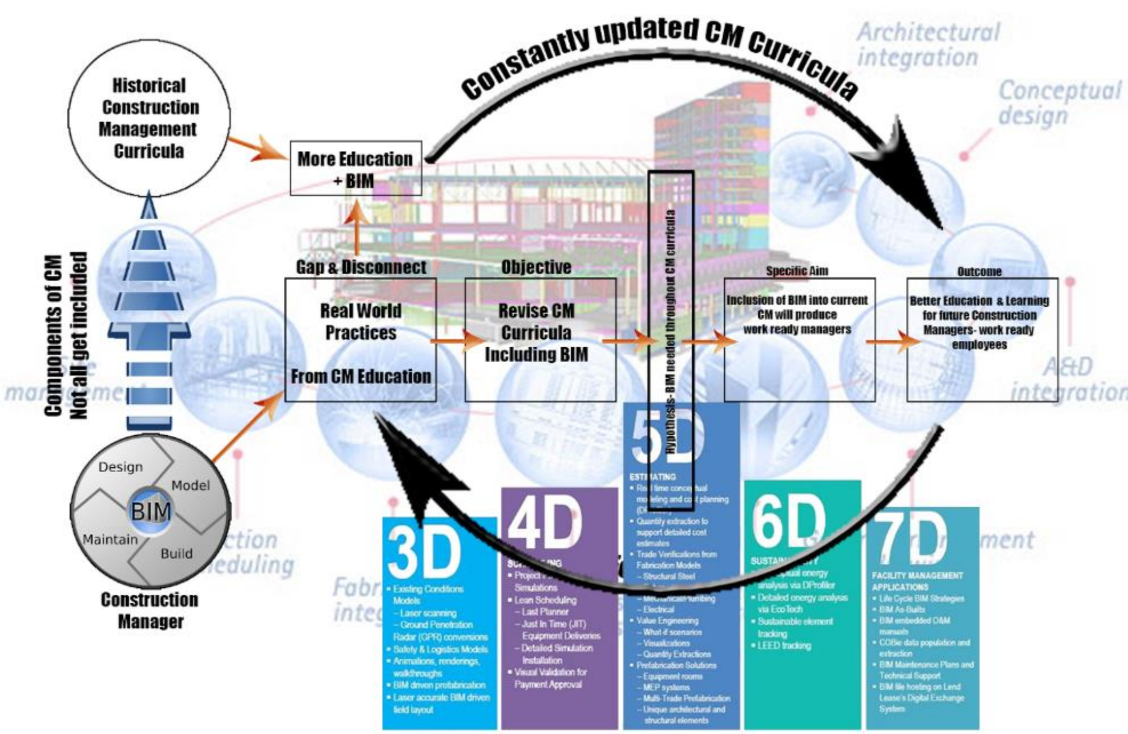

Figure 34: A new educational model

Advances in the AEC field are resulting in the creation of a new era where technology meets the traditional way of construction and design. Skills such as programming, database knowledge and web design can thus become specialized assets with which students will be able to mold a unique skillset. As such, a trans-disciplinary approach can be achieved through the incorporation of courses and minors from areas such as construction management and computer programming. These skills would open the door to advanced skills, making them invaluable to the research and development of future tools as well as techniques the AEC industry is currently utilizing.

Future Research

- How are the education and background of a construction manager changing?
    - I think a construction manager's higher education program and curricula have to change as that role changes in industry. A redesign of a project manager's core competencies needs to be considered, as well as proposed to American Council for Construction Education (ACCE).
- Who owns the model in BIM?
    - This is probably the most discussed topic within AEC currently and a top area for future research. For years, the architect owned the drawing, and every decision needed to go through them, but in BIM adoption, the Architect is behind the construction companies. While a few architects are generating a model used in BIM, a majority are not, and those who are creating models do not want to take any responsibility for what is contained within the model if it truly will be used for construction. While an architect is still only worried about the design, general contractors and subcontractors have decided to give the model to the client. This, however, still does not identify who owns the model during construction. The final model being turned over for facility management would only make sense since the client is paying for the building and all created assets during the building's construction. Clients are taking the model for future facility management. Even though the client is getting the model, debate still goes on as to who owns the model before and during construction—mostly from the architect's standpoint.

- Who takes responsibility for problems in BIM?
    - While most AEC companies and subcontractors have taken responsibility for their own models within the total model, issues arise from other disciplines that affect other subcontractors' modeled components. This issue has been going on since before BIM was used, and it continues to be a heated discussion within the BIM process.
- What are the legal issues using BIM?
    - Similar to who owns the model, legal considerations are attached with any construction project. Traditional contracts spell out every aspect of what contractors are and are not responsible for within a project. Essentially, each discipline is responsible for what they put into the project—from the design being the architect's responsibility to the plumber being held accountable for all plumbing in the building. Now, along comes BIM, in which nobody can determine who owns the model or even agree that discipline-specific models are not owned by anyone, and you have issues. The American Institute of Architects (2008) identified all legal issues dealing with BIM in Figure 35 below.

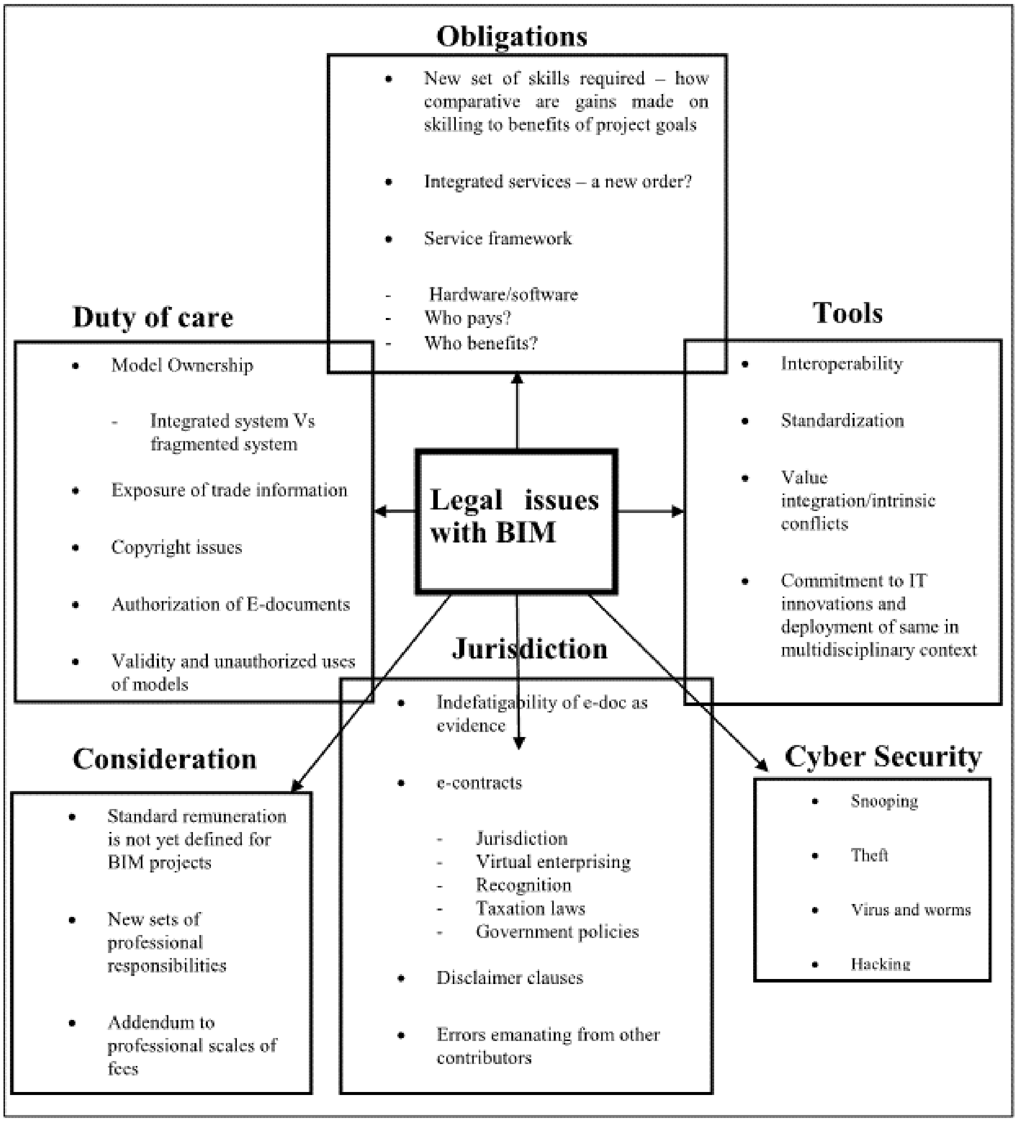

Figure 35: A taxonomy of legal limitations in BIM (AIA, 2008)

- What impact is BIM having on your overall project schedule and budget?
    - While I don't have any specific information about budget, I know from the interview that schedules (duration of the build) for projects have been reduced considerably due to BIM utilization. In some cases, what used to take a year is now taking six months or less to build. Budgets, however, are tricky to determine. Material costs are always changing, and what a company bid initially for, say, concrete may not be the current costs of concrete. Also, companies are identifying

unseen cost savings. What those are can be explained this way: Say you have a 40-story hotel. As a project manager, you find on a drawing that a door location in the model needs to be moved, and you find it out while you're building the fourth floor. Anything above that will be fixed, but Floors 1 through 4 need to be changed. Approximate costs to change that door are around $2500.00 per door. You might think this is excessive, but when you take into account that a carpenter needs to move the door—a drywall person needs to change the drywall around the door, an electrician needs to move the electrical switch and wires to meet code, and the floor installers need to come back and repair the open concrete areas—one can see $2500.00 might be a bit low. You spent $10,000 fixing the doors from Floors 1 through 4, but managed to correctly place the door on 5 through 40. If you had not caught it, it would have cost an additional $87,500 to repair each door on each floor. This is what contractors are calling unseen cost savings for the client while using BIM.

- How is GIS incorporated into projects using BIM?
    - Utilization of GIS to model the land is becoming extremely popular. I was able to participate in an online workshop where they were showing how to model the land as well as utilities under the ground. Current construction companies are also incorporating locations of pipes underground into BIM. In one case during my interviews, underground utilities were modeled in relationship to where they were located to the building as well as how far under the finish grade elevation. The BIM coordinator noticed that part of the water pipes in a location where the landscape architect had changed and incorporated a slight hill into the finish grade were sticking out of the ground. Underground utility pipes and electrical lines are a huge problem today when people dig. More and more, construction companies are modeling every aspect of the building site, including underground.
- What are the attitudes and behaviors regarding implementing BIM into projects?
    - The largest reason not to utilize BIM seems to be the fear of the unknown. There are multiple companies out there that have not taken steps to utilize BIM into their current construction management process.

- How can BIM be used in higher education to influence and change current curricula?
    - As any educator will tell you, they believe the curricula they designed is the best one for the future of their students. Some of it is determined by accrediting agencies for the department. Those agencies may not want to change or update as often as curricula may need to change. I researched a lot of areas in industry, and all incorporated BIM into the process. There is no viable reason not to include BIM into every aspect of construction management education—at least, in my opinion. If you teach scheduling the traditional way, there does not seem to be any good reason not to use a 3D model—it helps visualize the construction process. If you are teaching estimation, the 3D model can generate quantities of everything used. I am pretty much pro-BIM in this subject.

I could go on and ask at least a dozen more questions. The last one would certainly be, "What is BIM's future & direction?"

It is hard to hit a moving target during the research process, and once research is done, it will be already be moving toward being outdated. Ending with what I found out from the study helps me determine the path for the BIM curricula I will eventually create in the future for students. It will be based on current AEC practices—or as many of them as I can incorporate. What I take away from this research is that I need to improve my teaching and constantly read up on current AEC technologies, change curricula often to constantly emulate AEC industry practices and standards, collaborate with my industry contacts more often, and challenge students to use what they know and have available in order to be effective model managers. In the end, for someone to really know construction and its processes, they must be constantly learning and researching, and that is what I want to challenge my current and future students to strive for in their education and careers.

Ending Thoughts

I met a lot of wonderful people in the construction world who are passionate about what they do and amazingly helpful in showing me their management processes. Yet at the heart of any qualitative study is the researcher and their past knowledge and relationship with the subject. I was a carpenter for several years, which is how I paid my way through college, working for a local contractor. After college, I was a construction superintendent for a local residential builder, and when I started teaching, I then realized the need for compilation of all information in one location for project management. I noticed the AEC industry had some unwritten rules about work ethics or company policies about employees:

- Employees were a company's biggest risks.
- Top-down management was the process.
- Skill was regarded over behaviors.
- One had to manage time effectively.
- There was a rigid work schedule.
- Employees had to be at their desks at all times.
- Employees worked on weekends.
- Corporate jargon and politics are part of company culture.
- Double standards were a common occurrence within company.
- Fear of failure always loomed overhead.

While these outdated rules were applied early in my career, today it seems all those standards have changed and new rules apply. The new rules gleaned from my visits would be:

- Employees are a company's biggest asset.
    - The companies I visited were tremendously concerned about their employees, so much so that in almost every corporate visit, the president came down to talk to me either before or after the interviews. They want to create a work environment and culture similar to family. The end goal of being successful and building quality resonated throughout the building. A culture that incorporated community and pride was beyond evident.
- Open communication is commonplace.
    - I noticed people walking into offices asking questions about problems they could not figure out. This was not done years ago; if you did ask too many questions, you would have been considered for termination. Today, people seem to know when they are stumped with a problem, and in order to proceed, they need to understand they don't know everything and ask a specialist who does know the answer so a solution can keep the production on track.

- Behaviors are regarded over skills.
    - Work ethic has taken on a different approach, and I am not sure I agree with it. A behavior does not necessarily constitute quality work. I will just say I am on the fence about this issue.
- Empowering results is privileged over managing time.
    - I am, however, all about results and agree with the change here. If an individual is able to get things done more quickly, then neither I nor the company they work for care about justification as to where that person is located during the day. While on my trip, I noticed multiple cubicles and offices empty. Several people I met simply explained, "They are working at home or are in transit working." I was privileged to see a meeting happen while the two individuals and I were traveling back from a jobsite. It was amazing to see that each were able to add valuable input to the meeting even though they were driving 70 mph back to the company headquarters.
- Work hours are flexible.
    - The standard work week is definitely a thing of the past. Several employees came in during the wee hours of the morning so they can get off to pick up children from school. Others strolled in around noon and did not leave until late at night. It seemed that every employee was able to determine when they worked and from where. Results allowed each to do just that, work when they could.
- Mobility work in terms of location
    - It was mentioned above about a traveling meeting. From every company, I heard the same things. While traveling, you can still be productive in one form or another. Your knowledge is needed no matter where you currently are located.
- Work is what you love—weekends are bonus.
    - Each employee was generally happy to be at work. I used to have that passion in higher education, waking up beyond ecstatic to go to work, being able to challenge young minds and help them learn how to overcome problems. It was the best job in the world to me. I, however, see so many people working in higher education who see it as an imposition rather than a pleasure. Every company I visited, though, had truly happy people about what they did through the day.
- Genuine honesty is valued.

  - I was able to witness an employee taking responsibility for an error on the jobsite. They were not punished or ridiculed, but were encouraged to figure out why the mistake was made and what was needed to correct it.
- One standard is maintained.
  - Success and quality were terms used throughout my visits. Each person strived to create a quality building in order to make the company successful.
- Employees are encouraged to fail often—but fail fast and learn from mistakes.

While my research opened my eyes to a great number of working standards, much of this change was due to the 3D model created to manage the construction projects. I have been a strong advocate for BIM during and over the last 20 years of teaching and 50+ years of working or consulting in AEC. It was challenging and demanding not to include that advocacy and thoughts into the research results. As I went along, that urge became less distinct, and I felt more obligated to report just on the facts and results. As I was researching all the components, I came across the below quote, from a press conference with the CEO of Nokia when the company got bought out by Microsoft:

> During the press conference to announce NOKIA being acquired by Microsoft, Nokia CEO ended his speech saying this "We didn't do anything wrong, but somehow, we lost". Upon saying that, all his management team, himself included, teared sadly.
>
> Nokia has been a respectable company. They didn't do anything wrong in their business, however, the world changed too fast. Their opponents were too powerful.
>
> They missed out on learning, they missed out on changing, and thus they lost the opportunity at hand to make it big. Not only did they miss the opportunity to earn big money, they lost their chance of survival.
>
> The message of this story is, if you don't change, you shall be removed from the competition.

> It's not wrong if you don't want to learn new things. However, if your thoughts and mindset cannot catch up with time, you will be eliminated.

This entire statement rang true to what I had learned about BIM within AEC. Most companies are using BIM as a modeling project management process. Those who are not are doomed to the fate of Nokia. A company can be making good money using ancient techniques and still fail as a future company because more and more clients are requiring BIM to be used on their projects. The lack of change will inevitably be their downfall. This is not just commercial construction; BIM is even trickling down into residential construction. The advantage and successes you had yesterday will be replaced by the new trends and technology of tomorrow. Virtual design in construction or BIM is the ability for every company to do the right things in order for them to be successful. BIM is taking the industry by storm, and it would benefit higher education professionals to take notice and make changes now!

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APPENDIX A. DEMOGRAPHICS QUESTIONNAIRE

1. Name—first and last
2. Company Name
3. Type of company- (General Contractor- Design/Build—Architectural.. etc….)
4. Project types company performs
5. Company Location
6. Number of people in company
7. Department you are in
8. Position title
    a. Examples: CEO, president, vice president, Project Manager, Site Manager, BIM Specialists, Contractor, Tradesman
9. Primary activities within company
    a. Project manager- site coordinator- BIM specialist- estimator- scheduler—….etc.
10. Age
11. Gender
12. Education
13. BIM related activities within company
    a. 2D, 3D, 4D, 5D, 6D, Collision detection, site coordination…etc.

APPENDIX B. INTERVIEW QUESTIONS

The interview takes about 30-45 minutes.

***Date and time of Interview*____**

***Person interviewed*____**

***Location of Interview- description of space*_______________________________**

13. What is your definition of BIM?
14. How many years of experience does your company have with BIM?
15. How did your company make the transition in adopting BIM practices? Did it have a significant impact on your typical design & construction management process?
16. Describe your BIM use within company in terms of the different components of BIM below:

1	2D	
2	3D	
3	4D	
4	5D	
5	6D	
6	XD	
7	Site Coordination	
8	Trade Coordination	
9	Design Reviews	
10	Programming	
11	Record Modeling	
12	Energy Analysis	
13	Sustainability	
14	Other	

17. Describe your company BIM process as it relates to the 4 phases listed below

	Written or Verbal answer
Plan	
Design	
Construction	
Operate	

18. What are the advantages of BIM within your company?
19. What is your companies driving force as it relates to your firms philosophy & goals behind using BIM?
20. BIM is recognized as a visualization documentation creation tool- what about the database component within your company- Can you tell me how your company approaches visual and database information.
21. Will you need to modify your corporate practices (educational needs) incorporating more BIM into projects?
22. How does your company educate its employees on new BIM techniques or technologies?
23. How do you educate your clients on BIM trends for bid projects?
24. Pick one of the questions below as final question—within concluding or additional thoughts

APPENDIX C. INTERVIEW PROTOCOL

Interview Protocols - Overview of Process

- Interview participants were first contacted via e-mail, and asked to participate and fill out demographic questionnafire.
- Following the initial e-mail, face to face interviews were scheduled so researcher could travel the distance between AEC companies.
- Interview was conducted with the participates at companies identified that use BIM in construction management of building projects.
- Each interview was recorded and transcribed verbatim.
- Demographic questionnaire sent to participants a week prior to formal interview were picked up after interview concluded.
- If demographic questionnaire was not filled out—researcher informed participants they could email it to him.

Overall, the interviews were designed in a semi-structured format to allow for flexibility in fully exploring BIM within the AEC company. Outline below gives outline of interview structure.

Pre-Interview Talk

This was done with all companies to lessen the mood and hopefully get everyone talking freely.

Key Points Announced

- *Just to let you know participation is voluntary and you are free stop at any time.*
- *Before we get started, do you have any questions?*
- *As you know, our study is focusing on BIM processes in AEC companies - I would like to ask you about your experiences on this topic within your company.*
- *The interview should take approximately 30-45 minutes:*
- *Let's get to the questions then:*

Interview Questions

The information you provide in this interview will be used to help create a holistic view of BIM within an AEC company. My interest is in learning from your experience. The collected comments, experience and suggestions from interview will be summarized, reviewed and included anonymously in my dissertation.

The interview takes about 30-45 minutes.

***Date and time of Interview*____**

***Person interviewed*____**

***Location of Interview- description of space*_____________________________________**

1. What is your definition of BIM?
2. How many years of experience does your company have with BIM?
3. How did your company make the transition in adopting BIM practices? Did it have a significant impact on your typical design & construction management process?
4. Describe your BIM use within company in terms of the different components of BIM below:

1	2D	
2	3D	
3	4D	
4	5D	
5	6D	
6	XD	
7	Site Coordination	
8	Trade Coordination	
9	Design Reviews	
10	Programming	
11	Record Modeling	
12	Energy Analysis	
13	Sustainability	

14	Other	

5. Describe your company BIM process as it relates to the 4 phases listed below

	Written or Verbal answer
Plan	
Design	
Construction	
Operate	

6. What are the advantages of BIM within your company?
7. What is your companies driving force as it relates to your firms philosophy & goals behind using BIM?
8. BIM is recognized as a visualization documentation creation tool- what about the database component within your company?
9. Will you need to modify your corporate practices (educational needs) incorporating more BIM into projects?
10. How does your company educate its employees on new BIM techniques or technologies?
11. How do you educate your clients on BIM trends for bid projects?
12. Pick one of the questions below as final question—within concluding or additional thoughts

Wrap Up Interview

Thank you again for your time in participating in this interview and for providing such detailed answers.

Reminders

- Follow-up on Site tour schedule and
- Possibly receiving archived construction documents of projects where BIM was used in construction management.