Teaching Non-Technological Skills for Successful Building Information Modeling (BIM) Projects

by

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ABSTRACT

Implementing Building Information Modeling (BIM) in construction projects has many potential benefits, but issues of projects can hinder its realization in practice. Although BIM involves using the technology, more than four-fifths of the recurring issues in current BIM-based construction projects are related to the people and processes (i.e., the non-technological elements of BIM). Therefore, in addition to the technological skills required for using BIM, educators should also prepare university graduates with the non-technological skills required for managing the people and processes of BIM. This research's objective is to develop a learning module that teaches the non-technological skills for addressing common, people- and process-related, issues in BIM-based construction projects. To achieve this objective, this research outlines the steps taken to create the learning module and identify its impact on a BIM course. The contribution of this research is in the understanding of the pedagogical value of the developed problem-based learning module and documenting the learning module's development process.

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Architecture, Engineering, and Construction	AEC
Building Information Modeling	BIM
Computer-aided design	CAD
Problem-based learning	PBL
Specific, Measurable, Assignable, Realistic and Time-based	S.M.A.R.T.
Virtual design and construction	VDC

CHAPTER 1 INTRODUCTION

Building Information Modeling (BIM), as a set of technologies and processes, enables project team members to virtually represent information throughout a construction project (Eastman et al., 2011). The use of BIM has been extensively adopted and has transformed the architecture, engineering, and construction (AEC) industries by generating information that is unachievable from conventional drawing-based design methods (Crotty, 2012). In fact, BIM provides major long-term benefits in procurement, construction, pre-fabrication and facility management (Bryde et al., 2013).

While implementing BIM has many potential benefits, issues on projects, such as technical and managerial difficulties (Azhar, 2011), and the presence of unaligned stakeholders (Hamdi & Leite, 2013), can hinder the realization of those benefits (Ghaffarianhoseini et al., 2017). Furthermore, specific issues such as coordination between project activities and change resistance among individuals can inhibit the success of implementing BIM in construction projects (Tulenheimo, 2015). Therefore, having project team members with the skills for resolving or avoiding issues in BIM-based construction projects is necessary to reap the benefits of implementing BIM.

Technology, people, and processes can all influence the impact of implementing BIM in construction projects (Arayici et al. 2011). However, people and processes are the primary causes of issues that lead to problems or difficulties in BIM-based construction projects (Rahman and Ayer, 2017a). Therefore, in addition to the technological skills required for using BIM, educators should also prepare university graduates with the non-technological skills required for managing the people and processes of BIM.

This research's objective is to develop a learning module that teaches the non-technological skills for addressing common, people- and process-related, issues in BIM-based construction projects. To achieve this objective, this research outlines the development process taken to create the learning module and identify its impact in a BIM course. Specifically, this research has four components, and each component represents different aspects of the learning module's development process:

- 1st component (Chapter 2): Identifies the non-technological skills that are associated with BIM
- 2nd component (Chapter 3): Identifies and the non-technological skills required for resolving the common issues in current BIM-based construction projects and the pedagogies that are most frequently reported to enhance those skills.
- 3rd component (Chapter 4): Develops a learning module that targets the enhancements of the non-technological skills required for resolving the common issues in current BIM-based construction projects.
- 4th component (Chapter5): Identifies the learning impact of the developed learning module on the non-technological skills required for resolving the common issues in current BIM-based construction projects.

The subsequent sections details each of these research components.

1.1 Skills Associated With BIM

This first component aimed to identify the skills that are: possessed by industry practitioners associated with BIM; and demanded by employers for positions associated with BIM. This component seeks to understand the non-technological skills associated with BIM in the AEC industry. In this chapter, this research analyses professionals' social networking profiles from LinkedIn to identify skills that are correlated with ‘BIM.’ Then this research analyses online job advertisements from LinkedIn and Indeed to identify skills that are listed, and job tasks in positions that require ‘BIM.’ This chapter’s results suggest that analytical and problem-solving, communication, initiative, planning and organizational, teamwork skills are the non-technological skills associated with BIM. While the results indicate the non-technological associated with BIM, the findings do not indicate the role of those skills in practice.

1.2 Teaching Strategies For The Non-Technological Skills Of BIM

The second component of this research came as a result of the first. The social networking profiles and job-advertisement analyses suggested the non-technological skills associated with BIM, but there is a limited understanding of the role of those non-technological skills in practice. Therefore, this component explored the common issues in current BIM-based construction projects and the skills required for resolving those issues. In this chapter, to identify those issues and skills, this research analyses individual interviews with industry practitioners. The chapter’s results suggest that the all of the non-technological skills that are associated with BIM (i.e., analytical and problem-solving, planning and organizational, communication, initiative, and teamwork) are indicated as required for resolving common issues in BIM-based construction projects by industry practitioners. With this understanding, the pedagogies that are most frequently reported to enhance those non-technological skills were identified through a structured analysis of peer-reviewed journal articles. The results of the meta-analysis suggest that the pedagogies that are frequently reported for enhancing most of the non-technological skills for resolving common issues in BIM-based construction projects are cooperative learning, game-based learning, hands-on, problem-based learning, project-based learning, service-learning, student competition, and undergraduate research. These findings defined a list of pedagogies for this research and other educators to prioritize when designing a learning module that targets the skills required for addressing the common issues in current BIM-based construction projects. Also, this research chose to develop a learning module using PBL because it is the most frequently reported pedagogy for enhancing those skills.

1.3 Developing A PBL Module For Enhancing The Non-Technological Skills Of BIM

The second component of this research suggests that PBL may support students learning the necessary skills required to resolve the common issues in BIM-based construction projects. However, a process for developing a PBL module that targets those skills in BIM education is missing from the current literature. Therefore, this chapter's objective is to present a process for developing a PBL module that may be able to address common, people- and process-related, issues in BIM-based construction projects. To achieve this objective, this chapter outlines the steps taken to create the PBL module for their BIM course. This component found that the process can assist educators in creating problems that are plausible and relevant to current industry practitioners. Also, prior works can assist educators in creating assessments that have already undergone validation in another educational context. Finally, the specific, measurable, assignable, realistic and time-based (S.M.A.R.T) criteria can be used as a proxy to assess the non-technological skills required for resolving common issues in current BIM-based construction projects because prior works suggest links between the S.M.A.R.T. criteria and those non-technological skills.

1.4 PBL's Learning Impact On The Non-Technological Skills Of BIM

The last part of this research is a continuation of the third component aimed at understanding the learning module's actual impact. Whereas the prior component presented a process for developing the learning module, this component presents the educational implications of this mode of education through detailed analysis of results from implementations during the Fall 2017 and Spring 2018 semesters in a senior-level undergraduate construction management course ar Arizona State University. These results allowed the researcher to identify the learning module's impact when it is used in a classroom. The results suggest that PBL leads to increased scores for the S.M.A.R.T. criteria among the developed solutions and policies developed by students related to the common issues in BIM-based construction projects. Additionally, students perceived improvements in their analytical and problem-solving, teamwork, and communications skills after completing the activity (i.e., the non-technological skills required for resolving common issues in BIM-based construction projects). Finally, the results demonstrate that the improvement in evaluations of student responses is a result of the structured thought process that is incorporated in the PBL module.

1.5 Conclusion

BIM alters the representation of information in construction projects (Eastman et al., 2011). While implementing BIM has many potential benefits, issues on projects can hinder the realization of those benefits (Ghaffarianhoseini et al., 2017). Technology, people, and processes can all influence BIM's impact in construction projects (Arayici et al. 2011), but people and processes are the primary causes of the issues in BIM-based construction projects (Rahman and Ayer, 2017a). Therefore, in addition to the technological skills required for using BIM, educators should also prepare university graduates with the non-technological skills required for managing the people and processes of BIM. This research develops a learning module that teaches the non-technological skills for addressing common, people- and process-related, issues in BIM-based construction projects. This chapter overviews the steps taken in this research to develop a learning module that specifically targets the non-technological skills for resolving the common issues in current BIM-based construction projects.

CHAPTER 2 SKILLS ASSOCIATED WITH BIM

2.1 Introduction

BIM may result in many potential benefits to the construction industry (Bryde et al., 2013). To realize these benefits, the construction industry needs to cope with inevitable challenges related not only to the technology itself but also to human resources (Azhar, 2011). Prior works over the last decade indicate that individuals with adequate BIM skills may improve BIM implementation in construction projects (Fox & Hietanen, 2007; Gu & London, 2010). Conversely, people who lack BIM training and appropriate skills may hinder the advancement of BIM implementation in those projects (Gu & London, 2010; Ku & Taiebat, 2011). Prior works also suggest appropriate skill development of BIM may prepare students for career success (Ku & Taiebat, 2011; Uddin & Khanzode, 2013) and project success (Peterson et al., 2011).

Prior works have attempted to identify the necessary BIM skills for individuals. However, although prior works provide insights on BIM skills, they did not explore those needed for entry-level positions. Additionally, some works have identified BIM skills using survey-based approaches (Ku & Taiebat, 2011; Wang & Leite, 2014a). While surveys can provide effective perception-based feedback, they may also be susceptible to respondents' bias. Therefore, this research proposes using methods that do not require individual responses to identify those skills that are related to BIM. Specifically, this research suggests leveraging publicly available data from social networking websites to observe the BIM skills that are commonly claimed and endorsed by construction professionals in several major cities throughout the United States of America (US). Additionally, this research proposes comparing this data with entry-level job advertisements selected from the same cities. The same entry-level advertisements are also explored to compare the job tasks between positions with 'BIM' in the title (BIM-specialized positions) and positions without 'BIM' in the title (non-BIM-specialized positions). The exploration of both sets of data may help to validate or question the findings of the prior works.

This chapter presents the results on identifying skills that are related to BIM and how they might be used in the industry. This research identifies those skills for graduating students by analyzing social networking profiles and entry-level job advertisements. Additionally, the job tasks in those advertisements are analyzed to illustrate how the skills might be used in the industry. Specifically, this research performs those analyses to answer the following questions:

- How do the skills differ between those that are possessed by individuals related to BIM and those that are listed in entry-level job advertisements that require BIM? And
- How do the job tasks differ between BIM-specialized and non-BIM-specialized positions from the same entry-level job advertisements?

To answer those questions, this research analyses professionals' social networking profiles from LinkedIn to identify skills that are correlated with 'BIM.' Then this research analyses online job advertisements from LinkedIn and Indeed to identify skills that are listed, and job tasks in positions that require 'BIM.' Finally, the skills and job tasks are compared.

2.2 Background

Identifying skills that are related to BIM may help the education community to prepare students with the appropriate BIM skills. Prior works have also attempted to identify skills relevant to BIM implementation in the construction industry. The works include analyzing job advertisements (Barison & Santos, 2011; Uhm et al., 2017) and published literature on BIM (Succar et al., 2013). There are also attempts in identifying BIM skills needed in graduating students by conducting questionnaire surveys (Ku & Taiebat, 2011; Wang & Leite, 2014a). These works have provided valuable information on those fundamental BIM skills that may assist the advancement of BIM education. However, prior works focus on more experienced positions such as project managers (Wang & Leite, 2014a) and BIM managers (Barison & Santos, 2011; Wang & Leite, 2014a). While surveys can provide effective perception-based feedback, they may also be susceptible to respondents' bias, which may illustrate a higher response rate from individuals who are actively engaged in BIM efforts and may not adequately represent the perception of the entire industry. This research proposes using methods that do not require individual responses to identify those skills that are related to BIM. Specifically, this research suggests using publicly-available data of social networking profiles.

Other studies have also attempted to explore data such as the endorsements and profiles from social networking websites. However, the focus on endorsements includes proposing new methods to compute artificial data (Pérez-Rosés & Sebé, 2015), and improve data consistency (Pérez-Rosés & Sebé, 2016). Also, several works focused on exploring social networking profiles to provide recommendations for improving employability (Zide & Shanani-Denning, 2014; Chiang & Suen, 2015). However, these works do not focus on analyzing raw data that already exists in social networking profiles. Therefore, this research attempts to use those raw data to identify skills that are possessed by individuals.

Understanding the job tasks that are related to a skill may illustrate how that skill is used in the industry. However, part of the challenge with identifying best practices for BIM education may be due to the differences in how BIM skills are implemented in the industry. Some companies may want a consistent BIM skill set among all new employees, while others may seek individuals with skill sets for specialized BIM positions such as BIM managers, BIM coordinators, or other BIM specialists (Gu & London, 2010; Sacks & Pikas, 2013). Additionally, these BIM-specialized positions may help to deliver the potential benefits of implementing BIM in construction projects (Succar, 2009). The job tasks of these BIM-specialized positions may contribute to the success of integrating BIM in construction projects (Merschbrok & Munkfold, 2015). In other words, because BIM skills are used differently in different organizations, there are also exclusive tasks for BIM-specialized positions.

This research initially analyses the job tasks in entry-level job advertisements that require BIM to help illustrate how graduating students may be expected to use their BIM skills in the industry. However, there should be differences between the job tasks of BIM-specialized and non-BIM-specialized positions from the existence of those exclusive tasks. Therefore, this research compares the job tasks between those positions in the advertisements to further illustrate the different usage of BIM skills in the industry.

2.3 Methodology

This research analyses information from social networking profiles and entry-level job advertisements to answer the research questions. The process of analyzing this information involves collecting data from social networking and job advertisement websites. This process is followed by comparing the skills from the profiles and advertisements. Finally, this process ends by comparing job tasks between BIM-specialized and non-BIM-specialized positions from the advertisements. The following subsections discuss the methods of collecting and analyzing information from social networking profiles and entry-level job advertisements.

2.3.1 Data collection

BIM may be used differently in different locations throughout the nation as well as around the world. In an attempt to identify skills that are commonly required throughout the country, several major metropolitan areas across the country are strategically selected. The cities include: (1) Phoenix, Arizona; (2) Los Angeles, California; (3) Seattle, Washington; (4) Chicago, Illinois; (5) New York City, New York; (6) Washington D.C.; (7) Jacksonville, Florida; and (8) Houston, Texas. Seven of those cities have either the largest population or the highest GMP in their region. Phoenix, in particular, was selected for this research to both broaden their perspective on trends while advancing the curriculum at their home institution.

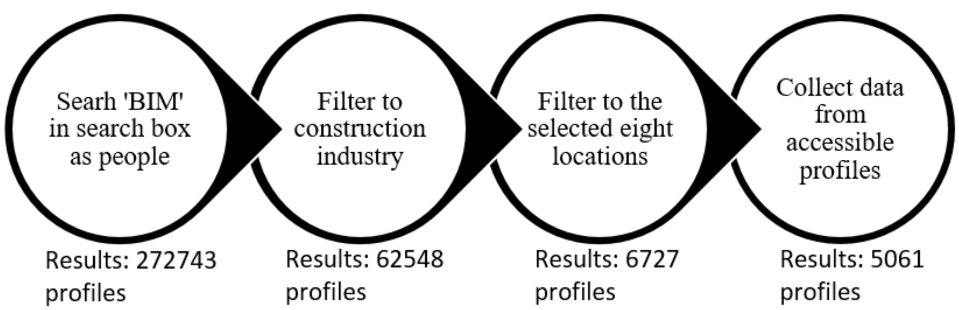

Figure 1 The process of identifying social networking profiles in LinkedIn

This research collects information from LinkedIn social networking profiles. Figure 1 presents the steps taken to identify the profiles. This research uses the search term ‘BIM’ in the available search feature to identify the profiles. The profiles are filtered to the ‘construction’ industry, and the eight targeted locations. The profiles are also filtered to ‘people,’ which removes organizations, job advertisements, and groups from the search results. The search feature limits the results to one thousand profiles per search results. This restriction led to locations with more than one thousand profiles having a lower percentage of profiles collected. The data collection involves collecting the name, location, industry, skills, and endorsements from each accessible profile. The names, locations, and industries are used to remove duplicate profiles and profiles out of scope while the skills and endorsements are used for data analysis. The ‘skills and endorsements’ feature in LinkedIn allows individuals to list skills in their profiles. Other individuals can endorse those skills or nominate other unlisted skills to be added to the profiles. Since the feature permits individuals to list or designate skills in a free manner, skills that differ based on their letter case, singular and plural forms, additional special characters, or extra spaces are grouped in this process.

Additionally, this research collects information from entry-level job advertisement listed on LinkedIn and Indeed. This research select these two websites because they have the highest search results compared to other typical job advertisements sites in the country. This research uses the search term ‘BIM’ in the available search feature on those websites to identify the advertisements. This approach collects only advertisements that have ‘BIM’ in their list of skills to remove positions that have no requirement for BIM. In this process, only academic qualifications related to civil engineering, construction engineering, and construction management are collected. Additionally, only positions that do not require work experience besides internships are regarded as entry-level positions. The data collection involves collecting the name, company, location, summary of the positions, job tasks, and skills. The names, companies and locations are utilized to remove duplicate advertisements in the data while the summary of positions, job tasks, and skills are used for data analysis.

2.3.2 Data analysis: Skills possessed by individuals vs. skills listed in job advertisements

This analysis compares skills from the collected profiles and advertisements. The process of analysing those skills involves: (i) Identifying skills that are correlated with 'BIM' from those social networking profiles; (ii) Identifying skills that are commonly listed in those job advertisements that require 'BIM;' and (iii) Comparing the data that have been identified in (i) and (ii). This subsection describes the methods of analysing the skills from the profiles and advertisements. Figure 2 shows the steps performed in this analysis.

Skills correlated with BIM in social networking profiles

This research proposes a new method to identify skills that have a correlation with a particular skill from the social networking profiles. The method performs bivariate correlation analysis on the skills derived from the 'skills and endorsements' feature from LinkedIn. The same methodology could potentially be applied to any social network-based data source, but LinkedIn is chosen for its standing as the most prominently used social network in the American professional realm (Forbes, 2012; Statista, 2016). Furthermore, the skills in LinkedIn have endorsements from other individuals – a further validation over most other data sources which rely exclusively on self-assessment.

This research focuses on identifying skills that are correlated with 'BIM.' The bivariate correlation analysis computes the correlation coefficients between skills from their number of endorsements. This research considers skills that have at least low correlation coefficients (≥0.30) with BIM as those that are "correlated" with BIM. This threshold is adopted because variables with correlation coefficients that are smaller than 0.30 have little correlation if any (Asuero et al. 2006).

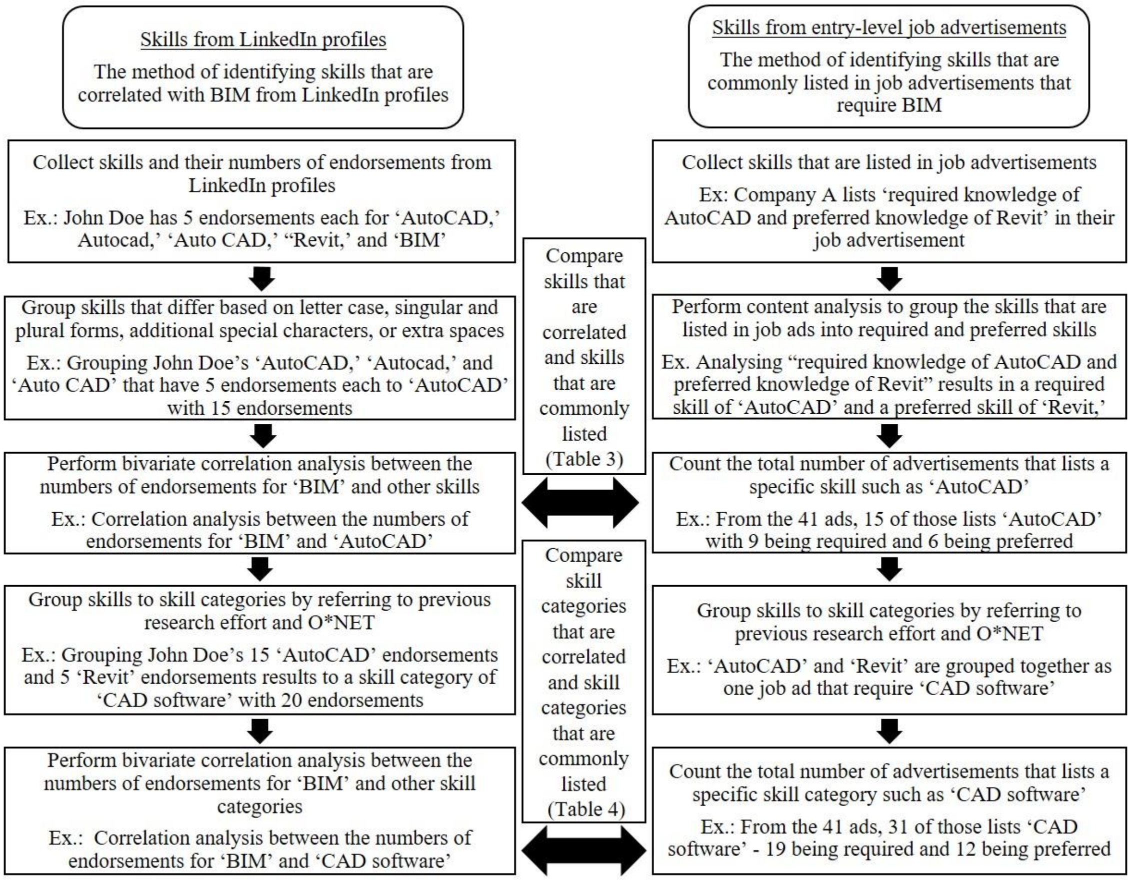

Figure 2 The process of analysing skills from social networking profiles and entry-level job advertisements

Skills commonly listed with BIM in job advertisements

This analysis focuses on identifying skills that are commonly listed in the collected job advertisements. This research considers "skills that are commonly listed" as those that are listed in at least 10% of total advertisements. This threshold was used by another paper that identified the common competencies of librarians from job advertisements (Harnett, 2014).

Additionally, this analysis groups the skills that are commonly listed into (i) skills that are necessary to acquire a particular position as ‘required skills;’ and (ii) skills that are not necessary, but would be an advantage in the acquisition of a specific position as ‘preferred skills.’ The required and preferred skills are identified using relational analysis. This research adapts the content analysis concepts on relational analysis and conceptual analysis from Carley (1990). Performing the conceptual analysis can illustrate the importance of a skill from a word’s number of occurrences. Conversely, the relational analysis may further explore the relationships between words, and the level of requirement of a skill by analyzing each original sentence. Therefore, this research adopts relational analysis to code the skills that are listed in the advertisements into required skills and preferred skills. The skills are coded in this analysis without interpreting their meanings. This research design is adopted from prior works of identifying the skills that are required and preferred in digital librarian positions (Choi & Rasmussen, 2009).

In other words, this analysis first groups the skills that are listed in the advertisements into two groups: (i) skills that are listed in at least 10%; and (ii) skills that are not listed in at least 10% of the total number of advertisements. Then, the skills in the first group are further grouped into: (a) skills that are required more than preferred; and (b) skills that are preferred more than required. Equation 1 and Equation 2 present the formula used to compute the percentage of being listed and being required, respectively.

$$\text{Percentage of being listed} = \frac{\text{No of job ads with skill listed}}{\text{Total number of job ads}} \times 100\% \qquad (1)$$

$$\text{Percentage of being required} = \frac{\text{No of job ads with skill listed as required}}{\text{No of job ads with skill listed}} \times 100\% \qquad (2)$$

Skills correlated with BIM in social networking profiles vs. skills commonly listed with BIM in job advertisements

This research first compares the skills that are obtained through data collection. In this initial analysis, all skills obtained are compared, without grouping any that might have similar meanings. To further compare the information from the profiles and advertisements, this research groups the skills into categories. Both comparisons omit the individual skills and skill categories that are endorsed to less than 2.5% of the profiles. These omissions remove those that represent a smaller portion of the profiles. Figure 3 shows the steps taken to perform these analyses.

Skills

This initial analysis compares skills from the profiles and advertisements without any interpretation of their meaning. This approach does not introduce any subjectivity into the process, but also means that similar skills may be analyzed individually. This limitation could potentially reduce the chance that a related group of skills would emerge as essential skills for industry positions because of the sub-divided nature of this raw data.

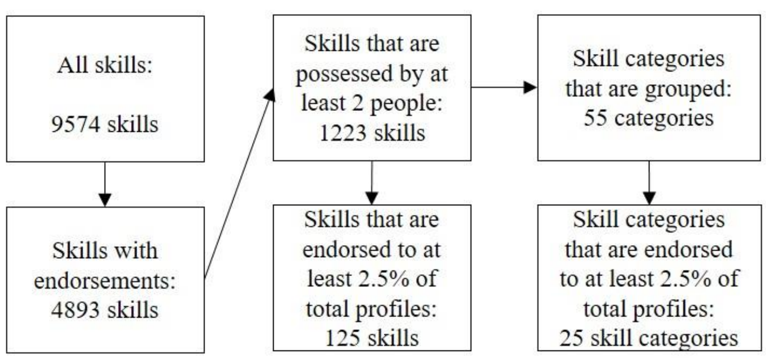

Figure 3 The process of grouping skills into skill categories

Skill categories

This subsequent analysis compares skills from the profiles and advertisements by grouping them into skill categories. The process of grouping skills is based on prior works, and the Occupational Information Network or O*NET's database on tools and technologies, and knowledge domains. This research groups those skills by using O*NET's data because the government funded database provides information on occupation-specific descriptors including the task of tools and technologies, and the relevant skills, knowledge, and abilities. This research design of using O*NET to group skills is similar to another prior work that categorized competencies when analyzing online job postings (Uhm et al., 2017). This research considers skills that are endorsed to only one individual as very uncommon. Therefore, the process of grouping skills involves only those that are endorsed to more than one individual.

The analysis groups the collected skills in the profiles and advertisements into skill categories. First, the soft skills are grouped by referring to the list of soft skills from prior works (Giesecke & McNeil, 1999; Rainsbury et al., 2002; Leicht et al., 2009). Then, the hard skills are grouped by referring to the list of tools and technologies in O*NET. However, O*NET lists certain tools and technologies in one or more categories. Therefore, skills that are listed in two or more categories are included in each categorization. This research then group leftover skills into the available tools, technologies and knowledge domains that are listed in O*NET. The leftover skills that are unrelated to any of those tools and technologies or domains are omitted from this process. The process of grouping the leftover skills requires interpretations that could potentially introduce some subjectivity into the process. To assess the reliability of the process, another researcher groups a randomly given portion (15%) from the leftover skills separately. The results of both researchers are compared to calculate the inter-rater reliability of the process.

In addition to grouping the skills, the analysis computes the endorsements of skill categories from those in the profiles. This process first identifies the number of endorsements for each skill that is grouped. Then, those endorsements are added up to compute the endorsements of their skill categories. The analysis also determines the level of requirement of skill categories from those in the advertisements. In this process, if any terms in a single advertisement are required, the skill categories are coded as required. Skill categories are coded as preferred only when all terms in the advertisement are listed as preferred. If those terms appeared as both required and preferred, the skill category is coded as required because an aspect of that skill would be necessary for an individual obtaining that job position.

Skills possessed by novice practitioners vs. skills listed in job advertisements

The initial social network data collection process enables the researchers to explore skills that are commonly listed from among all industry professionals who work with BIM. However, this sample set also includes individuals with many years of industry experience. Therefore, it is possible that, while this population may indicate what skills are needed for BIM implementation in general, they may not indicate a realistic set of expected goals for students pursuing entry-level positions. The data set is reduced to explore only individuals with three or fewer years of experience for subsequent analysis. This research adopts this threshold since prior works have suggested that those with three or more years of experience are much more likely to be experts in their fields (Kiziltas et al., 2010; Wang & Leite, 2014b).

2.3.3 Data analysis: Job tasks between positions in job advertisements

This analysis compares the job tasks between BIM-specialized positions and non-BIM-specialized positions from the collected advertisements. In this analysis, this research first categorizes the advertisements into those that are BIM-specialized positions and non-BIM specialized positions. Advertisements with 'BIM' in the title are considered as those of BIM-specialized positions. Conversely, advertisements without 'BIM' in the title are considered as those of non-BIM-specialized positions. This categorization is adopted from prior works that define 'BIM-specialized positions' as those with 'BIM' in the title (Barison & Santos, 2010; Wu & Issa, 2013; Davies et al. 2015).

The analysis then continues by coding the job tasks in the advertisements into simple sentences. This process of coding the job tasks groups similar tasks together. This research then counts the number of tasks that are grouped in each representative task. Several advertisements have multiple tasks that are grouped into the same task. Therefore, there are representative tasks that have a higher count compared to the number of advertisements. Finally, this analysis compares the job tasks between the BIM-specialized and non-BIM-specialized positions using those representative tasks and their counts.

In this analysis, the process of grouping the job tasks involves those that are in the advertisements. Theoretically, O*NET's database could have been used to group the job tasks. However, the database had no information on the BIM-specialized positions identified through the data collection such as BIM designers, BIM specialists, BIM technicians and BIM detailers. This research also considers interchanging those BIM titles to CAD titles, which are the alternative titles for 'architectural drafters,' according to O*NET. However, it is risky to consider all of those BIM-specialized positions as architectural drafters, particularly when those positions are construction industry positions that do not require architectural degrees. Therefore, this analysis codes similar job tasks individually as performed by prior works on analyzing job advertisement content (Choi & Rasmussen, 2009; Barison & Santos, 2011).

2.4 Results And Discussion

Table 1 and Table 2 shows the information of the collected data from the social networking profiles and the entry-level job advertisements, respectively. The data collection process occurred between February 27 and April 11, 2016, for the individual profiles, and between March 24 and March 31, 2016, for the job advertisements. The process of collecting data from social networking profiles includes those profiles that exist before the date of data collection.

For the social networking profiles, the data collection gathered 5,061 profiles (75%) from the 6,727 profiles available, ranging between 52% and 95% between the eight locations. From those profiles, 9,574 skills were identified. From those, 125 skills are endorsed to more than 2.5% of the total profiles. The process of grouping the skills resulted in 55 skill categories. From those, 25 skill categories are endorsed to more than 2.5% of the total profiles.

For the job advertisements, 41 job advertisements were gathered. From those, 24 are BIM-specialized positions, and 17 are non-BIM-specialized positions. Through the data analysis, 122 skills were identified. From those, 11 skills are listed in at least 10% of the advertisements. The process of grouping the skills resulted in 28 skill categories. From those, 14 skill categories are listed in at least 10% of the advertisements.

Table 1 Summary of data collected for the social network analysis

Characteristics	No of available profiles	No of collected profiles	No of novice profiles [a]	Characteristics	All profiles	Novice profiles [a]
Profiles	6727	5061	168	Skills		
City				All skills	9574	1355
Chicago	844	661	25	Endorsed to more than 2.5% individuals	125	84
Houston	664	599	27	Skill categories		
Jacksonville	114	76	2	All skill categories	55	35
Los Angeles	1280	872	20	Endorsed to more than 2.5%	25	25
New York	1478	770	15	Experience		
Phoenix	834	792	36	Average (years)	16.3	2.5
Seattle	654	566	28	Standard deviation (years)	9.48	0.65
Washington D.C.	859	725	15			

Table 2 Summary of data collected for the job advertisement analysis

Characteristics	Number of observations	Characteristics	Number of observations
Job advertisement	41	Skills	122
City		Listed to more than 10%	11
Chicago	3	Listed to less than 10%	111
Houston	2	Required > preferred	80
Jacksonville	4	Skill categories	28
Los Angeles	12	Listed to more than 10%	14
New York	11	Listed to less than 10%	14
Phoenix	2	Required > preferred	27
Seattle	2	Positions	41
Washington D.C.	5	BIM specialized	24
		Non-BIM-specialized	17

2.4.1 Skills possessed by individuals vs. skills listed in job advertisements

Table 3 lists and compares skills that are possessed by individuals related to BIM from social networking profiles and skills that are commonly listed in entry-level job advertisements that require BIM. The results illustrate the similarities and differences between the skills in the profiles and the advertisements. Overall, out of the eleven skills that are commonly listed in the advertisements, only three are correlated with BIM in the profiles. In other words, there are more differences than similarities between the skills in the profiles and the advertisements.

Additionally, the results also illustrate the existence of skills that are preferred in the advertisements. The results suggest that even though employers commonly list certain skills, employers are not frequently 'requiring' these skills for entry-level hires. For example, 'Revit' and 'Primavera' are the skills that are commonly listed but are only preferred in the advertisements. These results illustrate that there are common skills that are not necessary, but would be an advantage in the acquisition of BIM-specific positions.

Table 3 Comparison between the skills that are possessed by individuals related to BIM and the skills that are commonly listed in entry-level job advertisements that require BIM [a]

	Percentage of being listed from available job advertisements (n=41)		
	More than 10%		Less than 10%
	Required>Preferred	Required<Preferred	
Correlated with BIM (>0.30) (n=5061)	**AutoCAD** (36.59%, 60.00%. 0.344, 42.15%) **Navisworks** (19.51%, 75%, 0.563, 15.31%)	**Revit** (58.54%, 45.83%, 0.636, 30.33%)	**CAD** (7.32%, 100.00%, 0.558, 19.86%) **Architecture** (2.44%, 100.00%, 0.438, 8.54%)
Not-correlated with BIM (<0.30) (n=5061)	**Communication** (56.10%, 100.00%, N/A) **Microsoft Office** (43.90%, 88.89%, 0.014, 19.92%) **Organizational** (36.59%, 100.00%, 0.101, 0.77%) **Teamwork** (26.83%, 100.00%, -0.025, 1.38%) **Construction drawings** (24.39%, 80%, 0.288, 36.53%) **Self-starters** (19.51%, 100.00%, N/A) **Industry standards** (19.51%, 62.50%, N/A)	**Primavera** (29.27%, 41.67%, 0. 080, 32.88%)	[b]

[a] The meanings of the numbers in the parenthesis: (Percentage of being listed; percentage of being required; correlation coefficient; percentage of profiles having the skill)
[b] The skills that are either not-correlated with BIM in the profiles or are not-commonly listed in the advertisements are excluded in this table because those do not contribute to the scope of this research

2.4.2 Skill categories possessed by individuals vs. skill categories listed in job advertisements

Table 4 lists and compares skill categories that are possessed by individuals related to BIM from social networking profiles and skill categories that are commonly listed in entry-level job advertisements that require BIM. The process of grouping the skills into skill categories may introduce some subjectivity. To address this problem, this research performs an inter-rater reliability test that resulted in a level of agreement of 81.3%.

The results illustrate the similarities and differences between the skill categories in the profiles and those in the advertisements. Altogether, out of the fourteen skill categories that are commonly listed in the advertisements, only one is correlated with BIM in the profiles. In other words, there are more differences than similarities between the skill categories in the profiles and the advertisements.

Table 4 Comparison between the skill categories that are possessed by individuals related to BIM and the skill categories that are commonly listed in entry-level job advertisements that require BIM [a]

	Percentage of being listed from available job advertisements (n=41)		
	More than 10%		Less than 10%
	Required>Preferred	Required <Preferred	
Correlated with BIM (>0.30) (n=5061)	**CAD software** (75.61%, 61.29%, 0.639, 55.88%)	NIL	Design (2.44%, 100.00%, 0.396, 56.73%)
Not-correlated with BIM (<0.30) (n=5061)	**Communication** (56.10%, 100.00%, 0.050, 2.55%) **Planning and organizational** (43.90%, 94.44%, 0.095, 1.92%) **Office suite software** (43.90%, 88.89%, 0.015, 19.92%) **Building and construction** (43.90%, 55.56%, 0.150, 90.14%) **Initiative** (41.46%, 94.12%, N/A) **Teamwork** (31.71%, 100.00%, -0.025, 1.38%) **Engineering and technology** (31.71%, 61.54%, 0.186, 86.72%) **Analytical and problem-solving** (17.07%, 85.71%, -0.015, 0.91%) **Computer and electronics** (17.07%, 85.71%, 0.108, 3.12%) **Admin and management** (14.63%, 100.00%, 0.115, 85.89%) Graphics or photo imaging software (14.63%, 83.33%, 0.167, 11.99%) **Document management software** (12.02%, 80.00%, 0.092, 2.35%)	**Project management software** (31.71%, 46.15%, 0.080, 49.04%)	[b]

a The meanings of the numbers in the parenthesis: (Percentage of being listed; percentage of being required; correlation coefficient; percentage of profiles having the skill)

b The list of other skill categories are: analytical or scientific software; communications and media; customer and personnel service; development environment software; education and training; law and government; leadership; mechanics; personnel and human resources; presentation software; production and processing; sales and marketing; spreadsheet software; transportation; and word processing software

In addition to illustrating the overlapping skill categories, the results also illustrate the existence of skill categories that are preferred in the advertisements. The result suggests that there is a skill set that is commonly listed but is only preferred in the advertisements. The results also suggest that different skills in the same skill set have different levels of requirement. Specifically, 'Revit,' 'AutoCAD' and 'Navisworks' are from the same skill category of 'CAD software.' 'AutoCAD' and 'Navisworks' are commonly listed and are required in the advertisements. However, 'Revit' is commonly listed, but is only preferred in the advertisements. In other words, there are skills from the same skill set that have different levels of requirement in the advertisements.

2.4.3 Skills possessed by novice practitioners vs. skills listed in job advertisements

Table 5 Comparison between the skills that are possessed by novice practitioners related to BIM and the skills that are commonly listed in entry-level job advertisements that require BIM [a]

	Percentage of being listed from available job advertisements (n=41)		
	More than 10%		Less than 10%
	Required>Preferred	Required <Preferred	
Correlated with BIM (>0.30) (n=168)	**AutoCAD** (36.59%, 60.00%. 0.523, 48.81%) **Navisworks** (19.51%, 75%, 0.815, 8.93%)	**Revit** (58.54%, 45.83%, 0.646, 32.14%)	**CAD** (7.32%, 100.00%, 0.553, 12.50%) **SketchUp** (7.32%, 66.67%, 0.454, 8.33%) **Plumbing** (0.00%, 0.00%, 0.371, 5.36%)
Not-correlated with BIM (<0.30) (n=168)	**Communication** (56.10%, 100.00%, N/A) **Microsoft Office** (43.90%, 88.89%, -0.055, 41.67%) **Organizational** (36.59%, 100.00%, N/A) **Teamwork** (26.83%, 100.00%, -0.068, 9.52%) **Construction drawings** (24.39%, 80%, 0.237, 17.26%) **Self-starters** (19.51%, 100.00%, N/A) **Industry standards** (19.51%, 62.50%, N/A)	**Primavera** (29.27%, 41.67%, 0. 052, 21.43%)	[b]

[a] The meanings of the numbers in the parenthesis: (Percentage of being listed; percentage of being required; correlation coefficient; percentage of profiles having the skill)

[b] The skills that are either not-correlated with BIM in the profiles or are not-commonly listed in the advertisements are excluded in this table because those do not contribute to the scope of this research

Table 5 and Table 6 show the comparison of skills that are possessed by novice practitioners related to BIM from social networking profiles and the skills that are commonly listed in entry-level job advertisements that require BIM. Table 5 lists the skills, while Table 6 lists the skill categories for the comparison.

The results are similar to comparing those that are possessed by all individuals related to BIM and the advertisements. Specifically, the skills and skill categories that overlap those that are commonly listed in the advertisements are the same. Overall, less than a quarter of the skill and skill categories overlap those that are commonly listed in the advertisements. Therefore, these results suggest that there are more differences than similarities between the skills in the profiles and the advertisements.

Table 6 Comparison between the skill categories that are possessed by novice practitioners related to BIM and the skill categories that are commonly listed in entry-level job-advertisements that require BIM [a]

	Percentage of being listed from available job-advertisements (n=41)		
	More than 10%		Less than 10%
	Required>Preferred	Required <Preferred	
Correlated with BIM (>0.30) (n=168)	**CAD software** (75.61%, 61.29%, 0.791, 59.52%)	NIL	NIL
Not correlated with BIM (<0.30) (n=168)	**Communication** (56.10%, 100.00%, -0.028, 9.52%) **Planning and organizational** (43.90%, 94.44%, -0.053, 8.93%) **Office suite software** (43.90%, 88.89%, -0.055, 41.67%) **Building and construction** (43.90%, 55.56%, 0.061, 75.60%) **Initiative** (41.46%, 94.12%, N/A) **Teamwork** (31.71%, 100.00%, -0.068, 9.52%) **Engineering and technology** (31.71%, 61.54%, 0.108, 60.71%) **Analytical and problem-solving** (17.07%, 85.71%, -0.051, 2.38%) Computer and electronics (17.07%, 85.71%, N/A) Graphics or photo imaging software (14.63%, 83.33%, 0.291, 13.10%) **Admin and management** (14.63%, 100.00%, 0.029, 71.43%) **Document management software** (12.02%, 80.00%, -0.032, 4.17%)	**Project management software** (31.71%, 46.15%, 0.061, 37.50%)	[b]

[a] The meanings of the numbers in the parenthesis: (Percentage of being listed; percentage of being required; correlation coefficient; percentage of profiles having the skill)

[b] The list of other skill categories are: analytical or scientific software; communications and media; design; customer and personnel service; development environment software; law and government; leadership; mechanics; object or component oriented development software; personnel and human resources; presentation software; sales and marketing; spreadsheet software; and word processing software

Additionally, the results illustrate that there are differences between the skills possessed by the individuals and the novice practitioners. Specifically, the differences are between the skills and skill categories that are correlated with BIM but are not commonly listed in the advertisements. For skills, 'architecture' is correlated with BIM only in the profiles of all practitioners. 'Construction estimating' and 'SketchUp' are correlated with BIM only in the profiles of the novice practitioners. For skill categories, 'design' is correlated with BIM only in the profiles of all practitioners. In other words, the non-novice and novice practitioners have differences between their BIM skill set.

2.4.4 Job tasks between positions in job advertisements

Table 7 summarizes the results of the job tasks and their count for BIM-specialized positions and non-BIM-specialized positions. The results illustrate that certain tasks are exclusive to the BIM-specialized positions. These tasks are those that are related to the BIM-specialized positions but are not included in the non-BIM-specialized positions. These tasks include those such as 'educate other staff on BIM' and 'advance Virtual Design and Construction (VDC) flow.' However, this research questions the sustainability of these tasks when BIM has achieved maturity throughout the industry. The maturity should result in more staff that are educated in BIM and more companies with established VDC flows. Therefore, although the results illustrate that there are exclusive tasks for BIM-specialized positions, it is not clear if these tasks are likely to remain necessary in the future.

In addition to illustrating the exclusive tasks of BIM specialized positions, the results also illustrate the main tasks of these positions. The results suggest that 'create, update and maintain models,' and 'produce specific output using BIM' are the main tasks of BIM-specialized positions. These tasks have higher counts compared to all of the other tasks in BIM specialized positions. However, these tasks are similar to certain tasks related to CAD in O*NET. Those similar tasks include operating CAD equipment to perform engineering tasks, and produce designs, working drawings, charts, forms, and records. These tasks are similar to those of non-BIM-specialized positions such as architects, project managers, and project engineers in O*NET. In other words, the main tasks of BIM-specialized positions in the advertisements are similar to the current CAD tasks of non-BIM-specialized positions in O*NET.

2.4.5 Discussion

This research identifies skills that are related to BIM by analysing social networking profiles of individuals that are related to BIM and entry-level job advertisements that require BIM. Additionally, the skills from both sets of data are compared in this analysis. The results suggest that there are discrepancies between the skills that are related to BIM in this research. First, there are more differences than similarities between the skills and skill categories in the profiles and advertisements. The same findings are also illustrated when comparing the skills and skill categories that are possessed by novice practitioners from the profiles and the advertisements. Second, there are differences between the skills that are possessed by all individuals and novice practitioners. Lastly, there are different levels of requirement for the skills and the skill sets in the advertisements. It is also evident that certain skills from the same skill set have different levels of requirement in the advertisements. In other words, this research has identified skills that are related to BIM. These skills are commonly sought by employers, and they are commonly reported by current BIM professionals on social networking profiles. Therefore, preparing students with these skills may support their future career success. However, the skills that are reported on social networking and those that are sought by employers do not match exactly. Therefore, this creates a need to identify which skills are the most critical for educators to incorporate into their courses. This need for prioritization of skills will be addressed in future work that aims to interview current industry experts to obtain more in-depth feedback to identify the most critical skill sets necessary to resolve the most common and impactful BIM challenges in construction.

Additionally, this research analyses job tasks from the same entry-level job advertisements that were collected. The job tasks are also compared to BIM-specialized and non-BIM-specialized positions. The analysis helps to illustrate the existence of 'BIM tasks,' which are the exclusive and main tasks of the BIM-specialized positions. However, this research questions the sustainability of these BIM tasks. Specifically, there are BIM tasks that may no longer be needed when BIM has achieved maturity throughout the industry. Moreover, there are also BIM tasks in the advertisements that are similar to the current CAD-related tasks of the non-BIM-specialized positions in O*NET. These similarities suggest that BIM tasks might diffuse into the current tasks of those non-BIM-specialized positions in the future. This change may be similar to the transition between hand-drafted drawings to CAD in the past. In other words, BIM tasks will be distributed throughout an organization. If this proves to be the case, BIM skills may no longer be a differentiator among individuals, but may simply be an expected skill set for anyone. Therefore, this research suggests that while BIM skills may be a standard expectation in all positions in the future, there are BIM tasks that may disappear when BIM reaches maturity in the industry.

Table 7 Comparison of the job tasks between BIM-specialized and non-BIM-specialized positions in entry-level job advertisements that require BIM

Non-BIM-specialized positions			BIM-specialized positions		
Task	Count	Job Ads (n=17)	Task	Count	Job Ads (n=24)
Communicate and coordinate with others	26	12	Create, update and maintain models	53	22
Prepare construction documents	16	11	Produce specific output with BIM [c]	37	22
Oversight projects	10	10	Communicate and coordinate with others	20	16
Prepare reports and studies (ex. monthly reports, structural studies)	10	10	Prepare construction documents [a]	18	13
Review construction documents [a]	8	7	Resolve issues related to BIM	16	11
Create, update and maintain models	7	3	Provide quality control for BIM	12	11
Manage finance for projects	6	3	Perform related calculations	10	4
Perform related calculations	6	2	Inspect existing condition	6	3
Report issues to upper personnel	5	5	Represent the company in meetings related to BIM	5	5
Produce specific output using BIM [b]	5	5	Advance VDC flow in the company	4	4
Response to inquiries of construction documents [a]	5	4	Educate others staffs on BIM	4	3
Inspect existing condition	4	3	Partake in project submissions	3	3
Verify conformance to specifications	4	4	Identify issues in documents or model	3	1
Prepare estimates	4	4	Manage issuance of drawings	2	2
Gather construction documents	3	3	Manage construction documents [a]	2	2
Prepare presentations	3	3	Coordinate material requirements	1	1
Partake in LEED submissions	2	2	Review material requirements	1	1
Provide consulting services	2	2	Visualize building systems	1	1
Update project website	2	2	Distribute construction documents [a]	1	1
Represent company	2	2			
Update project schedule	2	2			
Procure and coordinate materials	2	2			
Negotiate pricing/proposals	2	2			
Motivate project team members	1	1			
Prepare proposals for new projects	1	1			
Make technical decisions	1	1			
Manage construction documents [a]	1	1			

[a] Construction documents represent designs, drawings, and specifications including request for information (RFI), submittals, shop drawings and change orders

[b] Output includes either quantity take-offs, site logistics and graphics contents

[c] Output includes clash reports, quantity take-offs, estimates, project schedules, drawings such as coordination drawings and formwork drawings, engineering documents, plans such as 3D floor plans, diagrams, RFIs, information from analyses and graphics contents

While this research provides several insights into the skills that may be required for new BIM professionals, the work does have a few limitations. For example, it is possible that the job advertisements identified may be seasonal or have other variations that could influence findings. Additionally, the study design performs content analyses, which could potentially produce bias in the data through subjective categorization. While this is theoretically possible, this research required minimal analysis and had a high level of agreement between the researchers performing the categorization. Also, interpreting the skills occurs only during the process of grouping skills that are unlisted from prior works on soft skills, and O*NET's database. The process groups leftover skills in general domains with specific definitions provided by the database. Some may argue that grouping certain skills may inflate those skills in having a higher percentage of being listed in the job advertisement analysis. However, from the results, even certain skills with more terms are listed at less than 10%. Additionally, the percentage of being listed is solely based on the number of job advertisements, therefore grouping multiple terms for a skill does not increase the percentage. This research can be repeated as a longitudinal study to explore the trends related to BIM skills possessed by individuals and job tasks listed in job advertisements. Also, future studies may further investigate the BIM-specialized and non-BIM-specialized positions by comparing the skills that are possessed by industry professionals or the skills that are listed in job advertisements.

2.5 Conclusion

This chapter identified the skills that are related to BIM by analysing social networking profiles and entry-level job advertisements. Additionally, job tasks in those advertisements were analysed to illustrate how the skills might be used in the industry. The analysis also compared the job tasks between the BIM-specialized and non-BIM-specialized positions to illustrate the different tasks between those positions further.

On the surface, it would seem logical that the skills sought by employers would closely match those that are currently possessed by individuals in the industry. However, it is noteworthy to observe that the results of this research suggest that there are differences between the skills that were identified. The results also suggest that while BIM skills may be a standard expectation in all positions in the future, there are BIM tasks that may disappear when BIM reaches maturity in the industry. Therefore, prioritizing the skills may prepare students with those that are more sustainable throughout their career.

CHAPTER 3 TEACHING STRATEGIES FOR THE NON-TECHNOLOGICAL SKILLS OF BIM

3.1 Introduction

BIM, as a set of technologies and processes, enables project team members to virtually represent information throughout a construction project (Eastman et al., 2011). The use of BIM has been extensively adopted and has transformed the AEC industry by generating information that is unachievable from conventional drawing-based design methods (Crotty, 2012). In fact, BIM provides major long-term benefits in procurement, construction, pre-fabrication and facility management (Bryde et al., 2013).

While implementing BIM has benefits, issues on the project, such as technical and managerial difficulties (Azhar, 2011), and the presence of unaligned stakeholders (Hamdi & Leite, 2013), can hinder the realization of the full benefits of implementing BIM (Ghaffarianhoseini et al., 2017). Furthermore, specific issues such as coordination between project activities and change resistance in individuals can inhibit the success of implementing BIM in construction projects (Tulenheimo, 2015). Therefore, having individuals with the skills for addressing or avoiding issues in BIM-based construction projects is necessary to reap the benefits of implementing BIM.

More than four-fifths of the issues that are recurring in BIM-based construction projects are related to the people an processes, i.e., the non-technological elements of BIM (Rahman & Ayer 2017a). Examples of people and process-related issues include unintentionally providing incorrect information to project participants, and inappropriate sequences of tasks that hinder the process of receiving updates from another party. Therefore, in addition to maintaining or improving the technological skills of using BIM among students, BIM curriculums should also prepare university graduates with the non-technological skills for managing the people and processes in a BIM environment.

Educators are already experimenting with different pedagogies, such as case studies (Russell et al., 2014) and project-based learning (Wang & Leite, 2014), to teach the non-technological skills for managing the people and processes of BIM. While the education community can continue experimenting, there are disadvantages if the experimented pedagogy is not providing the highest value to students. Continuous experimentation with low potential pedagogies could lead to students spending ineffective time and experiencing inefficient learning during their education. In other words, there are likely benefits in identifying pedagogies with high potential value for educators to prioritize when experimenting with alternate content to teach the non-technological elements of BIM.

The objective of this chapter is to address common issues in current industry BIM projects by enhancing the non-technological skills required for resolving those issues among students through efficient and effective education. To achieve this objective, the first portion of this chapter identifies the common issues that are recurring in BIM-based construction projects and the non-technological skills that are required for resolving those issues. After identifying those issues and skills, the latter or second portion of this chapter identifies the pedagogies that are most frequently reported to enhance the non-technological skills required for resolving common issues in BIM-based construction projects. Specifically, the first portion addresses research questions related to:

- Which of the project issues reported by prior work (Rahman & Ayer, 2017a) are also reported by industry practitioners from other companies? And

- What are the non-technological skills reported by industry practitioners as required for resolving those issues?

This research answer those two questions through an analysis of individual interviews with industry practitioners.

After addressing those two research questions, the second portion addresses the following research questions:

- Which pedagogies are frequently reported to enhance those skills identified in (1b)?

To answer that question, this research perform a structured analysis of peer-reviewed journal articles. In other words, the first portion explores the current need of the industry, while the second portion identifies pedagogies that are frequently reported as enablers for similar types of learning gains in other applications. Figure 4 shows the relationship between the issues, skills, and pedagogies (i.e., the two portions) in this chapter.

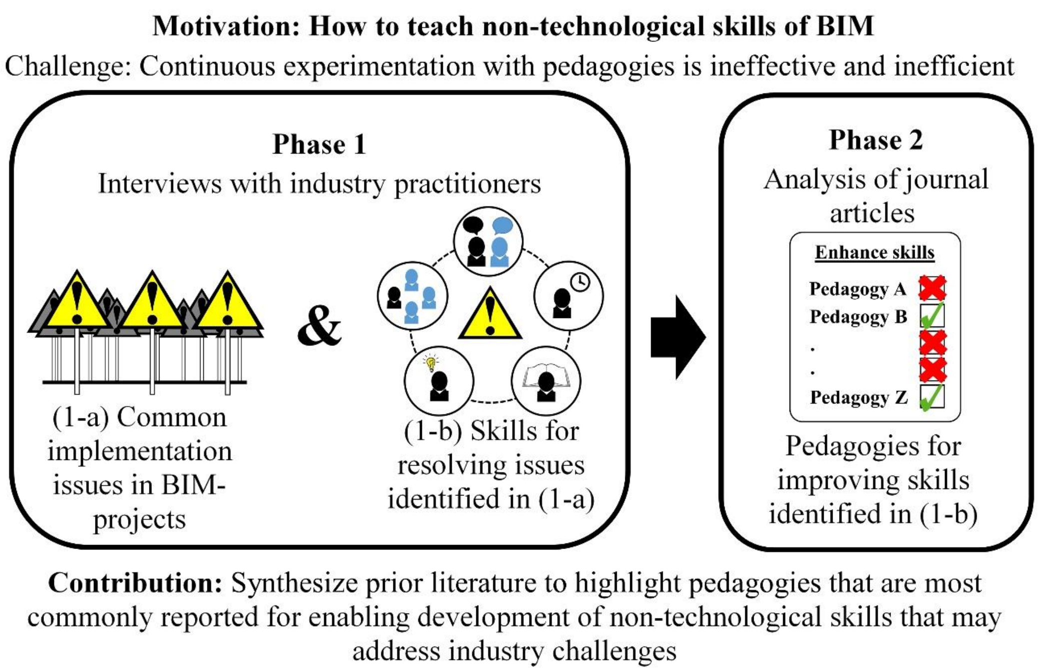

Figure 4 The relationship between implementation issues, skills, and pedagogies in this chapter

3.2 Background

3.2.1 Teaching BIM

Teaching BIM can be challenging for various reasons. Educators must not only teach BIM software applications to students, but they must also help the students to understand the underlying processes associated with implementing and using BIM in construction projects (Kymmell, 2008). Prior works have been experimenting with different pedagogies, such as case studies (Russell et al., 2014) and project-based learning (Wang & Leite, 2014), to teach the non-technological elements of BIM. While educators are experimenting with different pedagogies, a recent review of scholarly publications suggests that gaps exist in BIM education because designing strategies to teach BIM are complex and challenging as educators need to consider the trade-offs between challenges that are inherent with using a particular pedagogy and the advantages in educational outcomes (Abdirad & Dossick, 2016). Therefore, identifying pedagogies that show effectiveness in enhancing a targeted set of BIM skills can help educators to make decisions when experimenting with new teaching strategies in the classroom.

3.2.2 Skills Related to BIM

Prior works also provide an understanding of the appropriate skills related to BIM for students. Specifically, prior works have identified the necessary BIM skills for students through questionnaires (Ku & Taibat, 2011) and Delphi approaches (Wu et al., 2017). Although the works have defined the necessary BIM skills, some skills may not be identified because questionnaires limit participants' responses to the available information generated by researchers while the Delphi method limits the identified BIM skills to only those that are agreed among multiple experts (Woudenberg, 1991). This research's second chapter aimed at resolving this challenge by using methods that do not require individual responses to identify the skills that are related to BIM through collecting publicly available data on eight major cities throughout the United States. While that work provides a list of skills related to BIM, it does not indicate which skills educators should focus on when teaching BIM to students. To further refine the list of skills, this chapter identifies skills that are required for resolving common issues in BIM-based construction projects. Identifying these skills enables educators to prioritize pedagogies that specifically enhance skills that may address current challenges in the industry.

3.2.3 Issues in BIM-Based Construction Projects

Prior works provide insights on many challenges related to implementing BIM in practice through various methods, including literature reviews (Azhar, 2011), expert interviews and questionnaire surveys (Hamdi & Leite, 2013), and case studies (2008; Bryde et al., 2013). While these methods identify many BIM challenges, it is unclear how often those issues recur from project to project. This research have responded by analyzing issue logs of numerous BIM-based construction projects to identify the recurring issues on those construction projects (Rahman & Ayer, 2017a). However, the findings are from a single company and do not represent the recurring issues in other organizations. Comparing the findings with data from other companies would offer a method of validating the claim that the issues observed in that one company are similar or even identical to those found in other companies.

3.3 Methodology

To answer the research questions, this research analyzes data from two sources: (1) individual interviews with industry practitioners; and (2) peer-reviewed journal articles.

This research perform the thematic analysis on the interviews. Analyzing the journal articles involves extracting and summarizing the pedagogies and the skills that are reported to be enhanced by implementing the pedagogies described in those articles. The following subsections detail each step of the methodology.

3.3.1 Individual Interviews

This research performs interviews to identify issues and skills that are overlapping with the prevalent issues (Rahman & Ayer, 2017a) and the skills associated with BIM from this research's second chapter. The overlapping issues and skills represent: issues that are recurring in numerous projects and frequently faced by multiple organizations; and skills that are associated with BIM and reported as required for resolving common issues in BIM-based construction projects.

Data Collection

This research collects information through individual interviews because the interviews provide an understanding of individuals' perspectives and experiences. The interviews involve twelve individuals from different companies that this research selected because of their in-depth knowledge and experience with BIM in the industry. Six of them are from Phoenix, AZ, near this research' academic institution, while the other seven are from other states throughout the United States. This research purposefully selected the individuals to maintain a level of quality of the interviewees that took part in the activity.

This research use open-ended questions because these encourage participants to contribute as much detailed information as desired while allowing researchers to ask probing questions as a means to follow-up (Turner III, 2010). The interview include two questions: (i) What are the issues that you frequently face in BIM-based construction projects? And (ii) What are the skills required by project team members to resolve those issues? The participants addressed the questions while the author took notes and probed follow-up questions. Examples of the follow-up questions include "Can you please explain when you say 'coordination' is one of the issues that you frequently face in your projects?" and "What do you mean by 'individuals need to be effective communicators?'" The interviews are not recorded to reduce hesitancy to respond among participants. After the interview, the author summarized the notes and sent the summary to the participants for validation to avoid misinterpreting or misquoting the interviewee. The summary includes headings and narratives for each point discussed during the interview. The interviewees would then be able to confirm or modify the notes to accurately reflect their comments.

Data Analysis

This research analyzes the interviews by performing the thematic analysis as outlined by (Boyatzis 1998) to pinpoint, examine, and record patterns within the data (Gibson & Brown 2009). However, the thematic analysis could introduce some subjective bias. Therefore, the analysis uses the headings of each point in the summary of interviews as initial codes to reduce bias. Using the headings as initial codes for the analysis may reduce such bias because the headings reduce the scope of interpreting the data.

In addition to using the summaries, this research uses the same methodology of prior chapter to group the skills to enable consistency between the results. Specifically, the process uses the same information as the prior work: prior literature (i.e., Giesecke & McNeil, 1999; Rainsbury et al., 2002; Leicht et al., 2009); and the Occupational Information Network (O*NET). O*NET is a United States government database that provides information on occupation-specific descriptors including the tools and technologies, and the relevant skills, knowledge, and abilities. Using the O*NET to group the skills can be advantageous because the content is developed using: a large amount of data; and existing frameworks such as the functional job analysis and the position analysis questionnaire.

After identifying the skills and issues reported in the interviews, the results are compared to the prevalent issues (Rahman & Ayer, 2017a) and the skills associated with BIM to identify: issues that are recurring in numerous projects and frequently faced by multiple organizations; and skills that are associated with BIM and reported as required for resolving common issues in BIM-based construction projects. Specifically, the prevalent issues are: transfers of information; changes; individual personalities; human error; and technology breakdowns. The non-technological skills associated with BIM are: communication, planning and organizational, initiative, analytical and problem-solving, and teamwork. Figure 5 summarizes the process of collecting and analyzing individual interviews.

3.3.2 Peer-Reviewed Articles

After identifying the skills required for resolving common issues in BIM-based construction projects, this research analyzes peer-reviewed journal articles to identify pedagogies that are reported to enhance those skills. Specifically, this research analyzes articles from the American Society of Civil Engineers (ASCE) and the American Society for Engineering Education (ASEE) because these professional associations have various publications related to engineering and education as well as the specific discipline of interest.

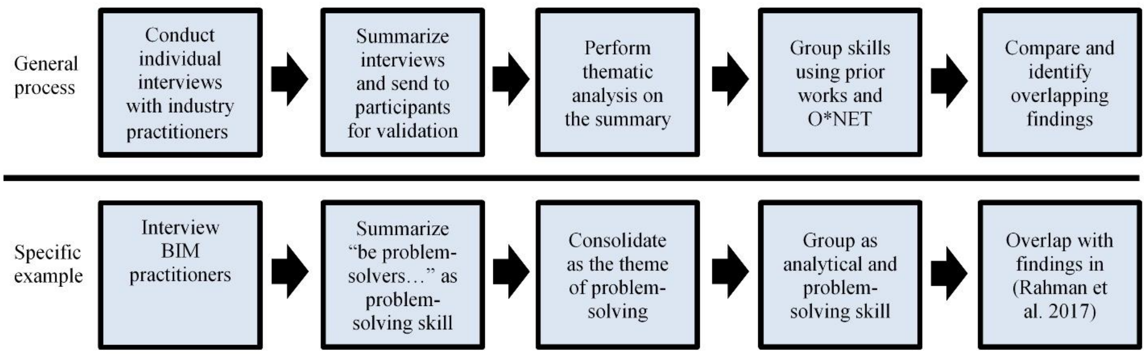

Figure 5 This research's approach in identifying the common issues in BIM-based construction projects and the non-technological skills required for resolving them

Data Collection

The data collection filters the journals in the ASCE database to those that have "education" in their aims and scope to gather articles that are related to education in the AEC realm. Also, the ASEE journals are filtered to exclude those that are specific to disciplines outside of the AEC domain such as chemical engineering and those that purely focus on technological advances in education.

This research uses the search feature in each of the journal's databases to identify articles that report the enhancement of skills due to implementing specific pedagogies. This process is followed by reviewing the collected articles to extract two types of information: (1) The implemented pedagogies; and (2) The skills that are reported to be enhanced due to the use of specific pedagogies. The methodology enables this research to identify publications that explicitly state enhancement of skills through a specific pedagogy without inferring improvement in skills unless stated in the findings. This process of not inferring improvement in skills unless explicitly stated in an article is done to reduce misinterpreting or over-extrapolating the findings of prior works. Furthermore, if a publication reports improvement in a skill, but does not state a specific assessment strategy, this is noted during data collection. These results are still included in this research, but because a specific assessment strategy is not stated, this research does not make assumptions about how the author(s) arrive at a specific conclusion.

Data Analysis

After collecting information from peer-reviewed journal articles, the data analysis groups the skills using the same resources (prior literature (i.e. Giesecke & McNeil, 1999; Rainsbury et al., 2002; Leicht et al., 2009) and O*NET) for grouping the skills identified through the individual interviews to have consistency between the findings. During this process, publications with multiple pedagogies are grouped for each reported pedagogy. For example, if a publication reports that using hands-on and cooperative learning can help students enhance their teamwork skills, the articles will be grouped in both "hands-on" and "cooperative learning." This approach may reduce misinterpreting the articles' contents. Finally, the summarized information is reported. For example, "cooperative learning" is reported as being able to enhance "communication," "analytical and problem-solving," and teamwork" skills. Figure 6 summarizes the process of collecting and analyzing the peer-reviewed publications.

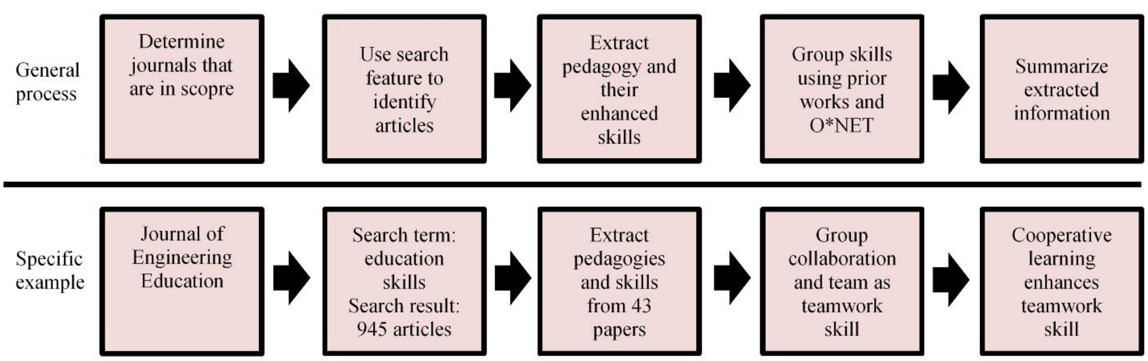

Figure 6 This chapter's approach in identifying the pedagogies that are most frequently reported for enhancing the skills identified

3.4 Results And Discussion

3.4.1 Common Issues in BIM-Based Construction Projects

Table 8 presents the issues that the industry practitioners frequently encounter in BIM-based construction projects. The results show five issues overlap with the issues that are commonly recurring on numerous BIM-based construction projects in (Rahman & Ayer, 2017a). The overlapping issues are those issues that are both commonly recurring in numerous projects and frequently faced by multiple companies. In other words, the findings suggest that the common issues in BIM-based construction projects are:

- transfers of information
- changes
- human error
- individual personalities
- technology breakdowns

In addition to validating the claim of prior works that these issues are common in BIM-based construction projects, these findings suggest the common issues are similar or even identical in other companies.

3.4.2 Skills Required for Resolving Common Issues in BIM-Based Construction Projects

Table 8 also presents the skills that the industry practitioners suggest as required for resolving the issues that the practitioners frequently encounter in BIM-based construction projects. The results show five skills overlap with the non-technological skills associated with BIM. The overlapping skills are:

- communication
- analytical and problem-solving

Table 8 The issues frequently faced and the skills indicated as required for resolving them from individual interviews with industry practitioners

Interviewee job title	Service sector	Issue	Skill
Director of VDC	General contractor	Inefficient, cost, individual personalities[a]	Communication[b], analytical and problem solving[b]
Director of Construction Piping Services	Piping	Individual personalities[a], transfers of information[a], insufficient training or experience	Initiative[b], communication[b], analytical and problem solving[b], CAD software, teamwork[b], building and construction
Director of VDC	Engineering	Insufficient resource, insufficient training or experience, cost, individual personalities[a]	Initiative[b], analytical and problem solving[b], CAD software, building and construction
Business Development Manager	General contractor	Individual personalities[a], transfers of information[a], insufficient resources, insufficient training or experience, miscommunication	Initiative[b], communication[b], CAD software
Project Engineer – Design	Concrete subcontractor	Inefficient, unclear process, insufficient training or experience, human error[a]	Communication[b], teamwork[b], accountability, planning and organizational[b]
Director of Operations	Electrical subcontractor	Unclear process, transfers of information[a], insufficient training or experience, miscommunication, individual personalities[a]	Engineering and technology, planning and organizational[b]
Digital Facility Integrator	Consultant	Technology breakdowns[a], unclear process, insufficient training or experience, individual personalities[a]	Communication[b], leadership, engineering and technology, analytical and problem solving[b], CAD software, building and construction
Assistant Virtual Design and Construction Manager	Heavy Civil	Inefficient, unclear process, insufficient training or experience, changes[a], miscommunication	Interpersonal, engineering and technology, CAD software, building and construction, planning and organizational[b]
Virtual Construction Engineer, Senior	General contractor	Inefficient, miscommunication	Engineering and technology, CAD software, building and construction
Virtual Construction Manager	General contractor	Transfers of information[a], insufficient resources, changes[a]	CAD software, building and construction
Manager, Facility Asset Management	Higher education (owner)	Unclear process, timing of BIM	Analytical and problem solving[b], intrapersonal, leadership, building and construction, engineering and technology, communication[b]
Virtual Construction Manager	General Contractor	Inefficient, individual personalities[a], transfers of information[a], unclear process, insufficient resources	Communication[b], leadership, building and construction, intrapersonal, leadership, engineering and technology

[a] Issues that overlap with the issues that are commonly recurring in numerous BIM-based construction projects in Rahman and Ayer (2017a).

[b] Skills that overlap with the non-technological skills in Chapter 2.

- planning and organizational
- initiative
- teamwork

In other words, the overlapping skills are those skills that are both suggested as required for resolving common issues in BIM-based construction projects by industry practitioners and associated with BIM from the analysis of social networking profiles and job-advertisements.

Also, the non-technological skills associated with BIM in are all overlapping with the skills indicated as required for resolving common issues in BIM-based construction projects by industry practitioners. While prior work has identified the list of non-technological skills that are associated with BIM, this chapter advances this research by suggesting the role of those skills in practice.

3.4.3 Pedagogies that Enhance the Skills Required for Resolving Common Issues in BIM-Based Construction Projects

In addition to analyzing individual interviews with industry practitioners, this research analyzed peer-reviewed journal articles to identify pedagogies that report enhancements of the non-technological skills required for resolving common issues in BIM-based construction projects. Table 9 presents the list of journals that are within this research's scope and the number of results from the search query. In summary, the data collection process reviews 2,866 articles that are published by March 2018 from six journals that are within the scope. Of the 2,866 articles initially reviewed, 43 articles reported pedagogies that specifically improved one or more of those skills.

Table 9 The number of search results and papers extracted from each journal in this research's scope

Journal title	Search results	Papers summarized
Journal of Architectural Engineering	56	0
Journal of Construction Engineering and Management	379	1
Journal of Management in Engineering	542	0
Journal of Professional Issues in Engineering Education and Practice	828	21
Journal of Engineering Education	945	19
Advances in Engineering Education	116	2

Table 10 presents the list of pedagogies that are reported to enhance any of those five non-technological skills required for resolving common issues in BIM-based construction projects. While the pedagogies report the enhancements of at least one of the skills, eight pedagogies are reported to enhance the highest number of those skills compared to other pedagogies. These findings suggest that these are the pedagogies that are frequently reported for enhancing those non-technological skills required for resolving common people-and process related issues in BIM-based construction projects. In other words, the pedagogies that educators should prioritize over other strategies when experimenting alternate content for their BIM curriculums when teaching the non-technological skills of BIM are:

- Cooperative learning
- Game-based learning
- Hands-on
- Problem-based learning
- Project-based learning
- Service-learning

- Student competition
- Undergraduate research

Also, the results show none of the pedagogies indicate enhancements in two of those five non-technological skills required for resolving common issues in BIM-based construction projects. Specifically, the two skills are planning and organizational, and initiative. These findings suggest that none of the thousands of articles reviewed in this research mentioned the enhancement of those two skills when using a particular pedagogy in their classrooms. Prior studies may not cover those skills for various reasons. First, assessing the two skills can be challenging. For example, an analysis of peer-reviewed articles did not suggest any appropriate strategies to evaluate those skills for PBL pedagogies (Rahman & Ayer, 2017b). Second, designing pedagogies to enhance the two skills are complex because educators need to: balance between being too directive and too noninterfering to teach initiative skills (Guavain & Huard, 1999); and create contingency and reward plans that are effective to teach planning and organizational skills (Langberg et al., 2008). In other words, designing and evaluating pedagogies that enhance planning and organizational, and initiative skills is a demanding task. Therefore, while the list of pedagogies in this research does not report the enhancement of all of the five skills, leveraging the findings of prior work to target learning gains through proven pedagogies strategically can be the most efficient approach when designing new modules to enhance the required skills for resolving common challenges in BIM-based construction projects among students.

Table 10 List of pedagogies that are reported to enhance any of the non-technological skills required for resolving common issues in BIM-based construction projects

Pedagogies v. Skills	n	Communication	Planning & organizational	Initiative	Analytical & problem-solving	Teamwork
Active learning	2	Yes	-	-	-	Yes
Capstone project	5	Yes	-	-	-	Yes
Collaborative learning	5	Yes	-	-	-	Yes
Cooperative learning	6	Yes	-	-	Yes	Yes
Game-based learning	3	Yes	-	-	Yes	Yes
Hands-on	3	Yes	-	-	Yes	Yes
Inquiry-based learning	1	-	-	-	Yes	-
Interdisciplinary methods	4	Yes	-	-	-	Yes
Problem-based learning	10	Yes	-	-	Yes	Yes
Project-based learning	4	Yes	-	-	Yes	Yes[c]
Service learning	4	Yes	-	-	Yes	Yes
Simulation	2	-	-	-	Yes	-
Situated learning	1	Yes	-	-	-	-
Student competition	2	Yes	-	-	Yes	Yes
Undergraduate research	1	Yes	-	-	Yes	Yes

Note: Total pedagogies (n=53) are higher than total publications (N=43) because publications with multiple pedagogies are grouped according to each reported pedagogy.

[c] Skills that are suggested to be enhanced without the specific information on the assessment strategies to evaluate them

3.4.4 Limitations

While this chapter provides insights on the effective pedagogies for teaching BIM, the study has a few limitations. First, this research uses individual interviews as a data source. While the individuals do not represent all stakeholders in the industry, this research uses the results only to prioritize the issues and skills. It does not aim to use it as a means to discredit the others.

Second, this research analyzes peer-reviewed journal articles to identify the effective pedagogies. While the process could omit materials outside of the chosen journal publications, ASEE and ASCE are preeminent sources for publishing research related to both BIM and engineering education. Therefore, this research maintains that these sources are sufficient to identify trends or lack of trends in related research.

3.5 Conclusions

The primary objective of this chapter is to address common issues in current industry BIM projects by enhancing the non-technological skills required for resolving those issues among students through efficient and effective education. This topic is addressed through analyzing individual interviews with twelve industry practitioners from different organizations in the AEC industry and analyzing peer-reviewed journal articles from six publications related to engineering and education. The analysis of the interviews identifies common issues in BIM-based construction projects and the non-technological skills required for resolving those issues. The analysis in the journal articles identifies pedagogies that are most frequently reported for enabling students to develop those non-technological skills. The major findings from the analyses include:

- The issues that are commonly recurring in multiple BIM-based construction projects of a single electrical subcontractor (i.e., transfers of information, changes, individual personalities, human error, and technology breakdowns) are also suggested as frequent issues by industry practitioners from other companies.
- The non-technological skills that are associated with BIM (i.e., analytical and problem-solving, planning and organizational, communication, initiative, and teamwork) are indicated as required for resolving common issues in BIM-based construction projects by industry practitioners.
- The pedagogies that are frequently reported for enhancing most of the non-technological skills for resolving common issues in BIM-based construction projects are cooperative learning, game-based learning, hands-on, problem-based learning,

project-based learning, service-learning, student competition, and undergraduate research.

CHAPTER 4 DEVELOPING A PBL MODULE FOR ENHANCING THE NON-TECHNOLOGICAL SKILLS OF BIM

4.1 Introduction

BIM is an integrative technology that alters the digital building representation process through the lifecycle of construction projects (Eastman et al., 2011). Implementing BIM in construction projects can provide major long-term benefits in procurement, construction, pre-fabrication and facility management (Bryde et al., 2013). Therefore, BIM is one of the most influential innovations in the AEC industry and has been extensively adopted in construction projects. In response to this increase of BIM in the industry, educators have been integrating BIM into the curriculum of postsecondary education and professional training over the years.

While implementing BIM has many potential benefits, issues on projects, such as technical and managerial difficulties (Azhar, 2011), and the presence of unaligned stakeholders (Hamdi & Leite, 2013), can hinder the realization of those benefits (Ghaffarianhoseini et al., 2017). Furthermore, specific issues such as coordination between project activities and change resistance among individuals can inhibit the success of implementing BIM in construction projects (Tulenheimo, 2015). Therefore, having project team members with the skills for resolving or avoiding issues in BIM-based construction projects is necessary to reap the benefits of implementing BIM.

More than four-fifths of the recurring issues in BIM-based construction projects are related to the people and processes (i.e., the non-technological elements of BIM) (Rahman & Ayer 2017a). Specifically, the most common people- and process- related issues are: transfers of information (ex. not updated with the latest information); changes (ex. sudden modifications in previously agreed details); individual personalities (ex. field personnel ignoring recommendations from modeling team); and human error (ex. misclicks in the model). Therefore, in addition to the technological skills required for using BIM, educators should also prepare university graduates with the non-technological skills required for managing the people and processes of BIM.

The non-technological skills required in project team members for resolving the common issues in BIM-based construction projects are analytical and problem-solving, communication, initiative, planning and organizational, and teamwork. While a meta-analysis of journal articles suggests that PBL is the most frequently reported pedagogy that enhances those skills, a process for developing a PBL module that targets those skills in BIM education is missing in the current literature.

This chapter's objective is to present a process for developing a PBL module that may be able to address common, people- and process-related, issues in BIM-based construction projects. To achieve this objective, this chapter addresses research questions related to:

- How can a problem be created for a PBL module that targets the non-technological skills required for resolving the common issues in current BIM-based construction projects?
- What is the process of developing a lesson plan for implementing the created problem(s) through PBL in BIM classrooms?

This research answer those two questions by outlining the steps taken to create the problems for this research' PBL module and develop the lesson plan to implement those created problems in their BIM course.

4.2 Background

4.2.1 Teaching non-technological skills of BIM

While implementing BIM in construction projects has various potential benefits, issues on the project can hinder the realization of those benefits in practice (Tulenheimo, 2015; Ghaffarianhoseini et al., 2017). Although BIM involves using technology, an analysis of problem-logs of multiple BIM-based construction projects suggests that the main causes of issues in BIM-based construction projects are people and processes (Rahman & Ayer, 2017a). To better prepare students to handle those people-and process-related issues, educational researchers have explored various pedagogies, such as case studies (Russell et al., 2014) and project-based learning (Wang & Leite, 2014). This research also attempts to address the common issues in current BIM-based construction projects by preparing university graduates with the non-technological skills associated with BIM.

4.2.2 PBL in BIM education

The results from this research's third chapter suggests that PBL is the most frequently reported pedagogy for enhancing those non-technological skills among students in other educational applications. While prior works are already experimenting with PBL in BIM education, there is a lack of literature on how to develop a PBL module that specifically targets those non-technogical skills in BIM education. Therefore, this chapter develops and presents the process for developing a PBL module that targets those non-technological skills to fill this knowledge gap.

4.3 Methodology

To answer the research questions, this chapter outlines the steps to create the problems for this research' PBL module; and develop the lesson plan to implement those created problems in their BIM course. The process of creating the problems involves determining the content, writing problem statements, developing focus questions, and validating the drafted problems. The process of developing a lesson plan involves identifying targeted skills, choosing an instructional model, choosing a motivation activity, and determining an evaluation strategy to assess success. The following subsections detail each of these steps.

4.3.1 Creating the problem

The actual 'problems' in PBL are critical to successfully implementing this mode of education (Duch et al. 2001). This research aimed to adhere to previously published guidelines, where possible but had to tailor this content to relate to a BIM education focus. Because this type of learning environment is new to BIM education, this research also added a 'validation' step with industry practitioners to ensure practical credibility to the developed problem. Figure 7 shows the general process and specific examples of the steps taken to create the problems for this research's PBL module.

The first step in creating a problem is determining the content to be incorporated. Educators can refer to a program's curriculum or national standards when determining the content of their PBL module (Delisle, 1997). However, for emerging educational needs related to BIM, established standards may not adequately guide educators in developing content that supports the current needs of the industry.

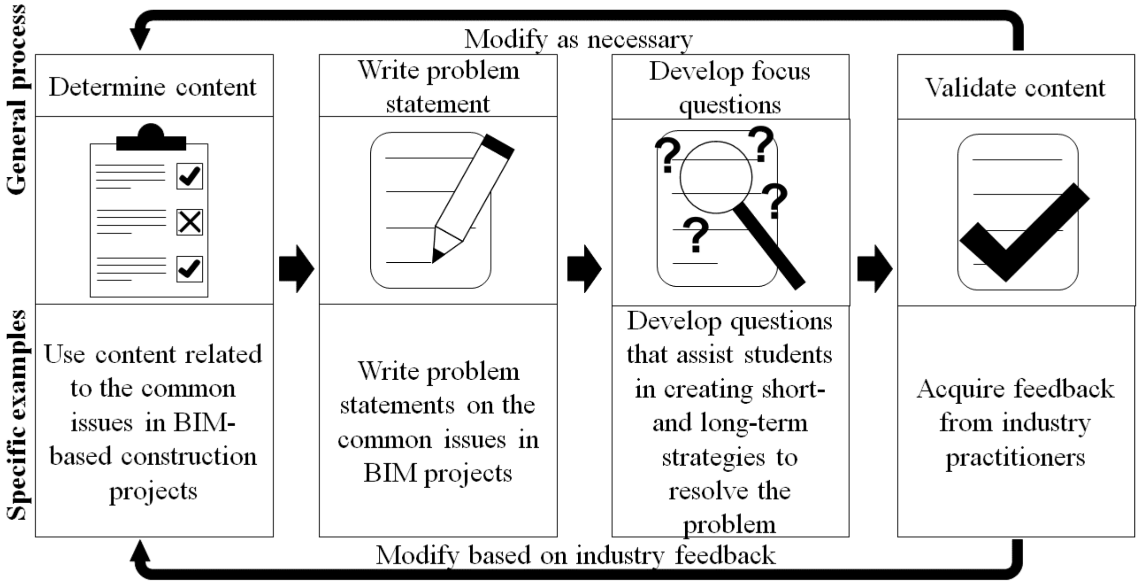

Figure 7 The steps taken to create the problems for this research's PBL module

Determining content

To address the common issues in current BIM-based construction projects, this research needed to develop problems that would adequately incorporate the real challenges faced by current practitioners. To achieve this objective, this research used a list of previously-identified issues that are common in BIM-based construction projects (i.e., changes, human error, individual personalities, and transfers of information). This prior work leveraged industry member input and actual project-related problem logs to identify the most common issues that are currently observed on BIM projects. In addition to providing practical validity to the learning content, this approach also helps to create content that: is timely to the current industry, which increases students' motivation (Palmer, 2007; Frey & Fisher, 2010); and provides students with the knowledge of contemporary issues.

Writing problem statements

After identifying the targeted learning content for problem development, this research needed to create the actual problem statement to provide to the students. According to Delisle (1997), a problem statement should be:

- Developmentally appropriate
- Grounded to students experience
- Curriculum based
- Ill-structured

In this research, the list of common issues that are commonly recurring in BIM-based construction projects is developmentally appropriate for the targeted students because the course is a senior-level undergraduate course focused on BIM planning and management. The students in the targeted course all have some industry experience through internships, and most will enter the construction industry full-time within one or two semesters after completing the course. While the students may not have experienced the specific issues that are presented during their internships, the developed problems relate to people and process issues that they may have experienced from their internship experiences and group projects. This helps to ground the module on their experience, and the focus on BIM for this particular course helps to base the developed problems well within their targeted curriculum. Finally, the people- and process-related issues that were developed into problems were selected because in all cases, they do not have a single solution. This helps to ensure that the problems are ill-structured, which requires the students to determine the best solution, given the challenges presented.

Developing focus questions

After defining the problem statements for the learning modules, focus questions were developed for the module. Focus questions assist students in focusing on their task after they become interested in the problem (Delisle, 1997). For this research, it was of particular interest to focus the students' attention to resolving the people- and process-related challenges that were a part of the problem presented to them.

To accomplish this aim, the study targeted two required focus questions for the students. They were required to generate a list of strategies to resolve the provided issue in the immediate short-term and justify their chosen strategy. They were also required to create a list of strategies to avoid the provided issue from recurring in the future and defend their chosen strategy. To assist the instructor and students to achieve the module's learning objective, the focus questions were developed to relate to each problem specifically. This focus helped to guide the students' thought process to plan for how to resolve the specific issue provided in the near- and long-term.

Validating the drafted problems

The final step of creating a problem in this study involves validating the relevance and plausibility of each problem. If irrelevant problems are identified by students, it can demotivate them and also reduce the probability of them benefiting from the module (Major & Palmer, 2001). Therefore, while the previously published PBL development guidelines (Delisle, 1997; Duch et al. 2001) do not formally include this step, the authors added this step to ensure that the drafted problems are relevant and plausible to BIM-based construction projects in industry. This step will likely be especially important for future educational researchers who aim to create this type of learning module for more cuttingedge applications that may not have a wealth of previously published literature documenting the industry problems targeted.

This validation step was completed by bringing the drafted problem statements to industry practitioners who have BIM experience for them to provide input on the plausibility of the developed statements. Specifically, these industry practitioners were asked to read each problem, state whether or not they believed it was a realistic problem as written, and also provide specific suggestions for modifications that might make the problem statements more plausible. Based on the discussion, this research modified the problems based on their recommendations to: add detail to clarify the content; and remove implausible content.

4.3.2 Developing the lesson plan

Once the problems were created, a lesson plan for implementing the problems was developed. Figure 8 shows the general process for developing this lesson plan and also specific examples of the steps taken to develop the lesson plan for implementing the developed PBL module. This phase involves gathering information on approaches to designing the lesson plan through prior guidelines, such as Delisle (1997), Duch et al. (2001) & Kenney (2008). It also required this research to tailor this prior content to provide an implementation strategy that would be appropriate to the targeted BIM-based education module.

Selecting skills

Before educators can determine whether or not a developed BIM-based problem has had a beneficial impact on student learners, it is necessary to determine the skills that they aim to improve upon completion of the module. For this particular work, this research leveraged prior works that were completed to identify the skills reported by industry practitioners as being necessary to resolve the identified people- and process-related issues for BIM projects. These skills included: analytical and problem-solving, communication, initiative, planning and organizational, and teamwork. By using these previously identified skills, it enabled this research to target the types of learning gains that may be most needed among construction professionals.

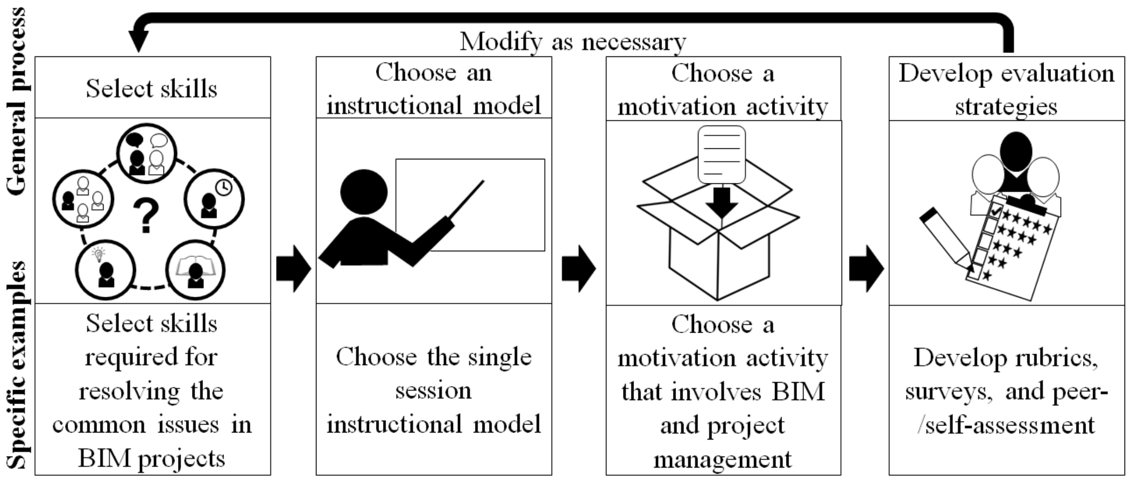

Figure 8 The steps taken to develop the lesson plan for implementing the developed PBL module.

Choosing an instructional model

To incorporate PBL effectively within an existing course, an instructional model must be selected that will support the specific needs and constraints of the given course. This decision may be based on several factors including the size of the class, the intellectual maturity of students, course objectives, preference of instructor, and availability of undergraduate peer tutors or graduate teaching assistants (Duch et al. 2001).

This particular study adopts the single session PBL model by Kenney (2008) because the targeted class involves a weekly two-hour practicum session where students are provided with hands-on BIM education. This session enabled adequate time for students to dedicate to this learning activity and also provided an opportunity to align with the existing activity-based nature of this practicum session. The single session model involves students: analyzing the problem; identifying, locating, and evaluating further information for solving the problem; consulting with team members on approaches for solving the problem; making decisions on the final approach for solving the problem; and reviewing own performance with respect to the overall activity (Kenney, 2008).

Furthermore, from a practical perspective, this single-session model offered plausibility to replicating the types of decision-making challenges that construction project leaders must face day-to-day when unforeseen problems arise due to people- or process-related BIM issues. In these instances, project leaders do not have the benefit of having a semester to determine a solution. Instead, they may need to define a resolution to a problem within a matter of hours. This single-session approach enabled this research to replicate this type of decision-making challenge more accurately.

Choosing a motivation activity

Defining an effective motivation activity helps to ensure that students feel that the problem that they are tasked with resolving is important and worth their time and attention. Therefore, this step requires the instructor to think of ways to introduce the subject and make the links explicit (Delisle, 1997). This research needed to target a motivation activity that would directly relate to the targeted student learners.

For this research, the motivating activity involved students participating in a hypothetical BIM-based 3D coordination meeting. Coordination meetings involve comparing various contractor models to determine where clashes arise in the modeled content to resolve challenges before construction. These types of meetings are among the most common in construction (Kreider et al. 2010; Alsafouri et al. 2015), most taught in schools (Ghosh et al. 2013), and considered to be among the most important BIM-related meetings in construction (Mayo et al. 2012). Furthermore, coordination meetings frequently involve different project participants, which make them likely events for people- and process-related problems to arise. Students were told that they would play the role of project manager for this meeting and would be able to determine solutions and policies to resolve the presented BIM problems. To further replicate the uncertainty of challenges that may arise in the students' subsequent careers, different problems that were developed were randomly selected by students. In all cases, once a student selected their problem, they were required to define solutions to resolve the problem for the following coordination meeting and policies to resolve that problem for all future coordination meetings to the best of their ability.

Determining evaluation strategies

Evaluation strategies for PBL can vary substantially. For each problem, educators must integrate an assessment approach that can be used to evaluate mastery of content, skills, and the process of problem-solving itself. The process of evaluation in a PBL classroom is encompassing in its methods, procedures, and goals. (Delisle, 1997). This research identified assessment strategies that would support the evaluation of the specific BIM educational goals.

The assessment strategies that have been suggested for evaluating the non-technological skills required for resolving the common BIM-based construction issues include rubrics, surveys, interviews, reflective journals, and peer-/self-assessments

(Rahman & Ayer, 2017b). From those assessment strategies, this research adopts rubrics, surveys, and peer-/self-assessments. Rubrics provide an approach to consistently evaluate student performance (Arter & McTighe, 2000). Surveys provide opportunities for students to provide feedback on the module's impact on developing their skills (Richardson, 2005). Self- and peer-assessments provide a platform for critical reflection before providing feedback on the module's impact through the survey (Nicol & Macfarlane-Dick, 2006).

4.4 Results And Discussion

This chapter developed a PBL module for BIM education according to the methodology presented in the prior sections. The resultant content is presented in the subsequent sections to illustrate how this process was implemented to support other educators interested in leveraging this mode of education for other BIM-based educational topics.

4.4.1 The problem

Several BIM-based 3D coordination meeting problems were developed in this research to target the skills needed to resolve common people- and process-related issues that occur in construction projects. Figure 9 shows an example of a learning module as it evolved through the methodology described in this chapter. The initial content is from industry-generated problem logs. Then, this research developed the problem logs into a dialogue between project team members to simulate the types of discussions that might be had in weekly BIM-based 3D coordination meetings. As mentioned in the methodology, this research implemented a validation step that iteratively elicited feedback from industry practitioners during this problem development phase. The figure illustrates the types of changes that were suggested by the industry practitioners. This process of eliciting industry member feedback helped to add clarity to the problem statements and also to present content that is realistic to the problems currently faced in the industry.

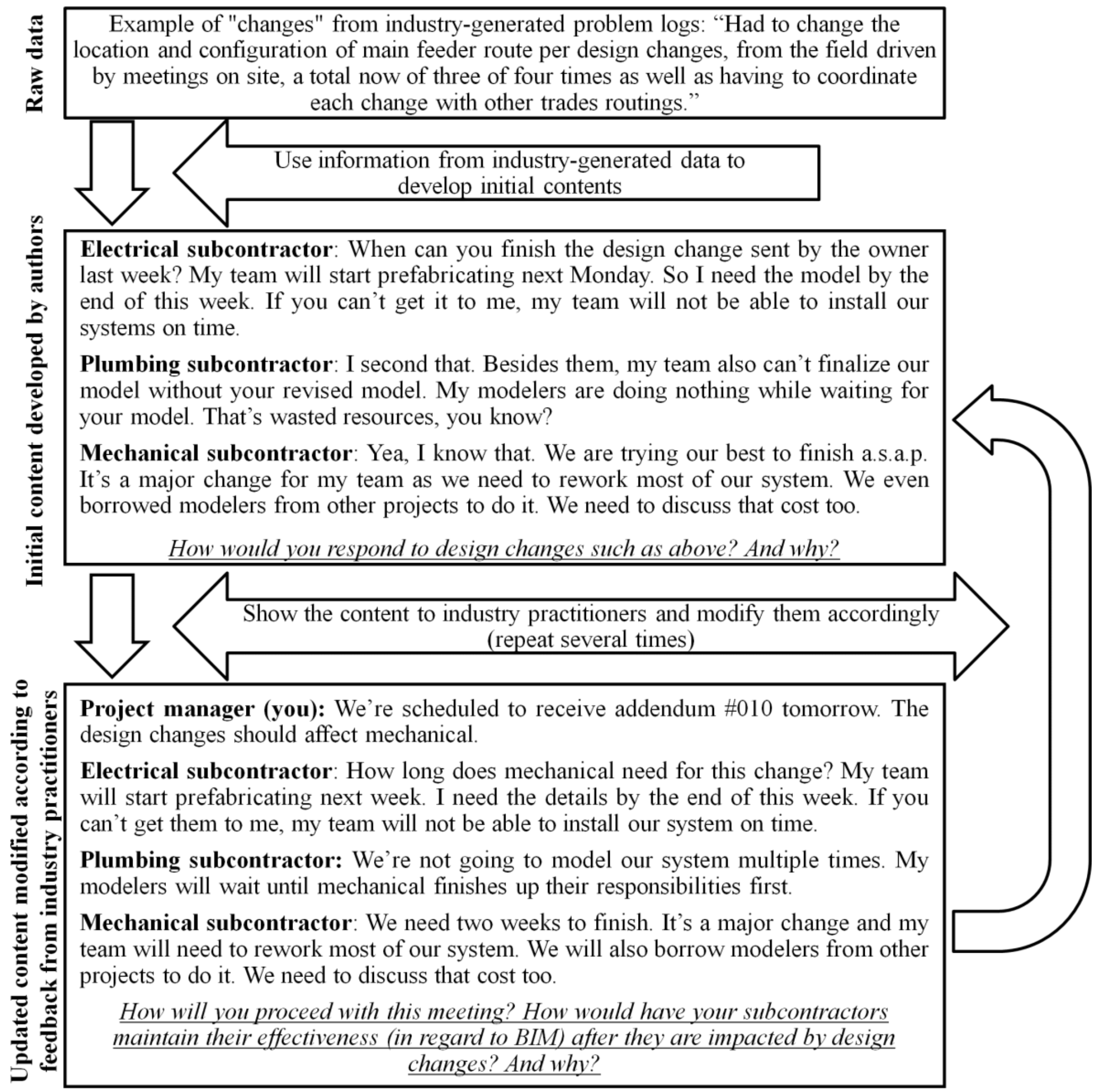

Figure 9 An example of the learning module’s content

Initially, eight problems were developed based on the four most common types of people- and process-related challenges observed on BIM-based construction projects. The four types of issues are transfers of information, individual personalities, changes, and human error (Rahman & Ayer, 2017a). Table 11 defines each of those issues. While all interviewees agreed that the common types of problems are indeed relevant to their work, one of the specific problem descriptions was suggested to be implausible by several interviewees. Therefore, even though this problem was created based on previously observed problem logs, this research did not pursue the development of that particular problem because they aimed to target common industry problems.

These findings suggest the process can assist educators in adding clarity to the module and removing content that is implausible in the industry. These changes can benefit the module because content that is timely and relevant to real life increase students' motivation (Palmer, 2007; Frey & Fisher, 2010). In the near-term, this process benefits the development of the module. In the long-term, this chapter provides an approach that is repeatable as BIM evolves. Educators can use the approach to develop content that is relevant to the industry for their PBL modules.

Table 11 Definition of the common people-and process-related issues

Issue	Definition
Transfers of Information	Instances on projects when individuals needed to exchange some type of information.
Changes	Complications that are caused by any acts or instances which something becomes different at any time during the project.
Human error	Something that has been done that was not the intention of an individual. Providing incorrect or incomplete information, misinterpreting information, making mistakes during modeling, and "misclicks" in the model are included in the scope of human error.
Individual personalities	Difficulties that are either a combination of individual characteristics and qualities or one of those elements respectively. However, this issue excludes "human error."

4.4.2 The lesson plan

This research's learning module involves students role-playing as project managers for a hypothetical weekly BIM-based 3D coordination meeting, which they must lead.

Issues will emerge during that meeting, and each student will receive a problem statement in the form of problem cards randomly. The problem cards present students with one of the specific problem narratives developed in this research. The activity requires students to generate two outputs: (1) approaches to solve the problem during the meeting (i.e., solutions); and (2) approaches to avoid the problem from recurring in the future (i.e., policies). To develop these outputs, the activity involves students:

- brainstorming up to three solutions and three policies without referring to any resources nor discussing with other individuals;
- determining the best solution and the best policy from the ideas that were brainstormed;
- searching the internet to identify other resources to generate up to three new solutions and three new policies or to modify those created in the prior phases;
- discussing their developed concepts with other students who selected the same problem card to determine the group's best solutions and policies; and
- generating a final solution and a final policy to resolve the problem in the short- and long-term, respectively.

Figure 10 summarizes the learning module's activity.

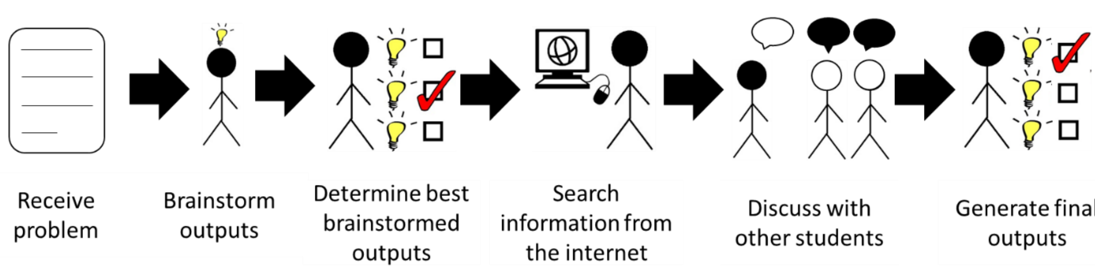

Figure 10 The learning module's activity

4.4.3 The assessments

Appendix and Appendix B shows the questionnaire survey and peer-/self-assessment adopted in this research after gathering assessments from prior works, removing overlapping and unrelated assessments, and modifying the assessments to fit this research's module. The feedback form adopts assessments are from two studies (i.e., Werth, 2009; El-adaway et al. 2014). The self- and peer-assessments adopt evaluations from three studies (i.e., Chin & Chia, 2004; Papinczak et al. 2007; Yoon et al. 2014). Additionally, this research adopts a four-point Likert-scale without a "neutral" response from another study. That study uses the scale for two reasons: (1) to avoid participants from providing a neutral reaction; and (2) to statistically evaluate the feedback results (Werth, 2009).

This research also adopts rubrics for evaluating the S.M.A.R.T. criteria from prior works to evaluate the module's impact among students. While the S.M.A.R.T. criteria are not required for resolving the common issues in current BIM-based construction projects, the criteria can be associated with the non-technological skills required for resolving those issues. Specifically, prior works suggest the following links between S.M.A.R.T. and the targeted learning skills:

- Specific can be associated with the ability to identify and solve problems and implement effective solutions (i.e., problem-solving skills) (Leicht et al. 2009).
- Measurable can be associated with the ability to predict changes (i.e., organizational skills) (Giesecke & McNeil, 1999)
- Assignable can be associated with the ability to allocate resources to implement initiatives appropriately (i.e., organizational skills) (Giesecke & McNeil, 1999).

- Realistic can be associated with practical intelligence (i.e., analytical skills) (Rainsbury et al. 2002)
- Time-based can be associated with the ability to plan (i.e., analytical skills) (Rainsbury et al. 2002)

In other words, S.M.A.R.T. can be used as a proxy for measuring the non-technological skills required for resolving the common issues in current BIM-based construction projects. Appendix C presents the S.M.A.R.T. rubric adopted in this research.

This research's approach in developing the evaluation strategies helped to define assessments that have a theoretical basis for evaluating the targeted BIM skills. Specifically, the results indicate that assessments from prior studies have already undergone validation in other educational contexts when evaluating those skills. Using assessments that are validated may ensure reliability and quality of the evaluation process. Therefore, adopting assessment from prior studies, where possible, can enable educators to develop "new" evaluations that have already undergone extensive validation in other educational contexts.

4.4.4 Limitations

This chapter provides insights on the approaches for developing a PBL module that targets the non-technological skills required for resolving the common issues in current BIM-based construction projects, but it does not evaluate the module's learning impact through testing with students. Therefore, this research does not make claims about the specific learning gains or drawbacks associated with implementing their developed learning modules. Subsequent chapter will test the developed modules and present the specific findings related to their impact. While this research cannot make claims regarding the modules impact, they do maintain their claim that their proposed process can successfully enable the development of a BIM-based PBL module that targets skills to resolve current industry problems. This claim is supported by the industry members who confirmed the practicality of the developed modules and also by the prior literature that specifically relate the targeted learning outcomes to the chosen implementation methodology.

4.5 Conclusion

This chapter’s primary objective is to present a process for developing a PBL module that may be able to address common, people- and process-related, issues in BIM-based construction projects. This research addressed this topic by outlining the steps taken to create the problems for this research’ PBL module and developing the lesson plan to implement those created problems in their BIM course. The process of creating the problems involves determining the content, writing problem statements, developing focus questions, and validating the drafted problems. The process of developing a lesson plan involves selecting skills, choosing an instructional model, choosing a motivation activity, and determining an evaluation strategy. The major findings from these processes include:

- The process can assist educators in creating problems that are plausible and relevant to current industry practitioners.
- Prior works can assist educators in creating assessments that have already undergone validation in another educational context.
- The S.M.A.R.T criteria can be used as a proxy to assess the non-technological skills required for resolving common issues in current BIM-based construction projects.

CHAPTER 5 PBL'S LEARNING IMPACT ON THE NON-TECHNOLOGICAL SKILLS OF BIM

5.1 Introduction

BIM, as a set of technologies and processes, enables project team members to virtually represent information throughout the lifecycle of a construction project that supports efficient design, information storage and retrieval, model-based data analysis, decision making, and communication among project stakeholders (Eastman et al., 2011). The use of BIM is becoming a standard practice in major construction projects in the United States (Dodge Data and Analytics 2015; McGraw-Hill Construction 2014). AEC companies are adopting BIM because of its benefits, which include cost reduction and control through a project life cycle, time savings (Bryde et al. 2013), and potentially high return on investment (Azhar, 2011; Giel & Issa, 2011).

While implementing BIM has many potential benefits, issues on projects, such as technical and managerial difficulties (Azhar, 2011), and the presence of unaligned stakeholders (Hamdi & Leite, 2013), can hinder the realization of those benefits (Ghaffarianhoseini et al., 2017). Furthermore, specific issues such as coordination between project activities and change resistance among individuals can inhibit the success of implementing BIM in construction projects (Tulenheimo, 2015). Therefore, having project team members with the skills for resolving or avoiding issues in BIM-based construction projects is necessary to reap the benefits of implementing BIM.

Technology, people, and processes can all influence the impact of implementing BIM in construction projects (Arayici et al. 2011). However, people and processes are the primary causes of issues that lead to problems or difficulties in BIM-based construction projects (Rahman & Ayer, 2017a). Specifically, the most common people- and process-related issues are: transfers of information (ex. not updated with the latest information); changes (ex. sudden modifications in previously agreed details); individual personalities (ex. field personnel ignoring recommendations from modeling team); and human error (ex. misclicks in the model). In other words, while new and emerging technologies are a core component of effective BIM implementation, the majority of problems are not the result of technology, but instead the result of people and processes related to those technologies.

To solve those common issues in BIM-based construction projects, industry practitioners indicate that project team members require the non-technological skills associated with BIM (i.e., communication, analytical and problem-solving, planning and organizational, initiative, and teamwork); A meta-analysis of peer-reviewed journal articles suggests that PBL is the most frequently reported pedagogy for enhancing those non-technological skills among students in other educational applications. While Chapter 4 has developed a learning module that targets those skills, the actual impact of implementing the module is still missing in this research. Therefore, this chapter presents the results of implementing the PBL module to fill this knowledge gap.

This chapter addresses the following research questions:

(1) What is the learning impact of a PBL module on the non-technological skills required for resolving the common issues in current BIM-based construction projects?

(2) How does the learning module impact the students' ability to demonstrate improvement in these skills?

This research answer these two questions by implementing the learning module in a BIM course and analyzing the collected data from the implementation.

5.2 Background

5.2.1 The non-technological skills associated with BIM

While implementing BIM in construction projects has various potential benefits, issues on the project can hinder the realization of those benefits in practice (Tulenheimo, 2015; Ghaffarianhoseini et al., 2017). Although BIM involves using technology, an analysis on problem-logs of multiple BIM-based construction projects suggests that the main causes of issues in BIM-based construction projects are people and processes (Rahman & Ayer, 2017a). To resolve those issues, industry practitioners indicate that project team members require those non-technological skills associated with BIM (i.e., communication, analytical and problem-solving, planning and organizational, initiative, and teamwork).

5.2.2 PBL in BIM-education

The results from this research's third chapter suggests that PBL is the most frequently reported pedagogy for enhancing those non-technological skills among students in other educational applications. Prior work has used PBL to introduce numerous technologies and processes, and integrate project scope, team collaboration, and project planning in a BIM course (Forsythe et al. 2013). Another study developed PBL modules to have students gain knowledge of the concept of implementing BIM throughout a lifecycle of a building (Leite, 2016).

5.2.3 The learning module

While Chapter 4 has developed a learning module that targets those skills, the actual impact of implementing the module is still missing in this research. Therefore, this chapter presents the results of implementing the PBL module to fill this knowledge gap. The learning module involves students role-playing as project managers for a hypothetical weekly BIM-based 3D coordination meeting, which they must lead. Issues will emerge during that meeting, and each student will receive a problem statement in the form of problem cards randomly. The problem cards present students with one of the specific problem narratives developed in this research (An example of the problem cards is presented in Appendix D). The activity requires students to generate two outputs: (1) approaches to solve the problem during the meeting (i.e., solutions); and (2) approaches to avoid the problem from recurring in the future (i.e., policies). To develop these outputs, the activity involves students:

(a) brainstorming up to three solutions and three policies without referring to any resources nor discussing with other individuals;
(b) determining the best solution and the best policy from the ideas that were brainstormed;
(c) searching the internet to identify other resources to generate up to three new solutions and three new policies or to modify those created in the prior phases;
(d) discussing their developed concepts with other students who selected the same problem card to determine the group's best solutions and policies; and
(e) generating a final solution and a final policy to resolve the problem in the short- and long-term, respectively.

The assessment strategies that have been suggested for evaluating the non-technological skills required for resolving the common BIM-based construction issues include rubrics, surveys, interviews, reflective journals, and peer-/self-assessments (Rahman & Ayer, 2017b). From those assessment strategies, the learning module adopts rubrics, surveys, and peer-/self-assessments. Surveys provide opportunities for students to provide feedback on the module's impact on developing their skills (Richardson, 2005). Self- and peer-assessments provide a platform for critical reflection before providing feedback on the module's impact through the survey (Nicol & Macfarlane-Dick, 2006). The module's feedback form and self-peer assessments are shown in Appendix A and B.

Rubrics provide an approach to consistently evaluate student performance (Arter & McTighe, 2000). Specifically, this research's learning module adopts rubrics for evaluating the S.M.A.R.T. (specific, measurable, assignable, realistic, and time-based) criteria from prior works to evaluate the module's impact on students. While the S.M.A.R.T. criteria are not required for resolving the common issues in current BIM-based construction projects, the criteria can be associated with the non-technological skills required for resolving those issues. Specifically, prior research suggests the following links between S.M.A.R.T. and the targeted learning skills:

- Specific can be associated with the ability to identify and solve problems and implement effective solutions (i.e., problem-solving skills) (Leicht et al. 2009).
- Measurable can be associated with the ability to predict changes (i.e., organizational skills) (Giesecke & McNeil, 1999)
- Assignable can be associated with the ability to allocate resources to implement initiatives appropriately (i.e., organizational skills) (Giesecke & McNeil, 1999).
- Realistic can be associated with practical intelligence (i.e., analytical skills) (Rainsbury et al. 2002)
- Time-based can be associated with the ability to plan (i.e., analytical skills) (Rainsbury et al. 2002)

In other words, this research uses the S.M.A.R.T. criteria as a proxy for measuring the non-technological skills required for resolving the common issues in current BIM-based construction projects. Appendix C presents the S.M.A.R.T. rubric adopted in this research. Figure 11 outlines the learning module.

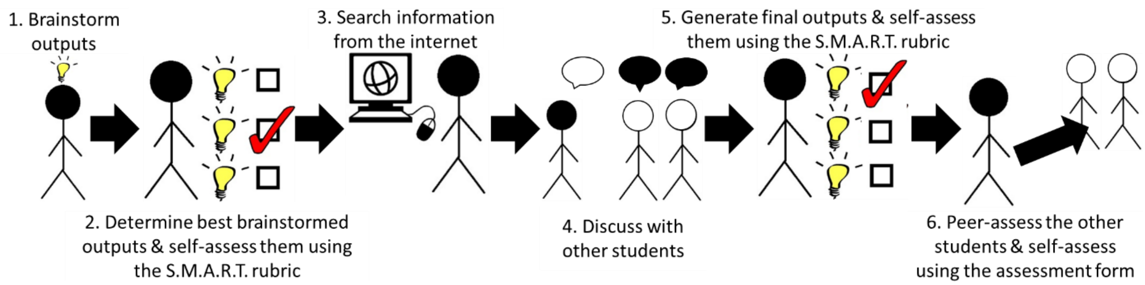

Figure 11 Overview of this research's learning module

5.3 Methodology

To answer the research questions, this research: collects data from implementing the learning module with students and also collects feedback about the student responses from industry practitioners; and analyzes the collected data for trends and changes in performance. The following subsections detail each of these steps.

5.3.1 Data collection

In order to collect data for this research, students enrolled in a BIM-focused Project Management were studied during the Fall 2017 and Spring 2018 semesters at Arizona State University. Subsequently, the responses and feedback generated by the students were reviewed by industry practitioners that have responsibilities directly related to BIM to help provide an external assessment of the behaviors and performance of the students.

As detailed in the background section, a previously developed PBL module related to the non-technological aspects of BIM was implemented over these semesters. In both semesters, students were tasked with selecting a random problem card that would illustrate a potential people- or process-related BIM problem that they would have to solve. For example, they could receive a card stating that one of their subcontractors failed to deliver an updated model for a BIM coordination session as required. After receiving problem cards, students would conduct the thought exercises involved in the module to determine their best possible solution and policy for resolving the selected problem in the immediate and distant future.

While the problems and general format of the activities were consistent between both Fall 2017 and Spring 2018, some differences were present in the sessions related to the researchers' data collection strategy. These differences are presented in the subsequent sections. Figure 12 also summarizes the data collection procedure for both the Fall 2017 and Spring 2018 students.

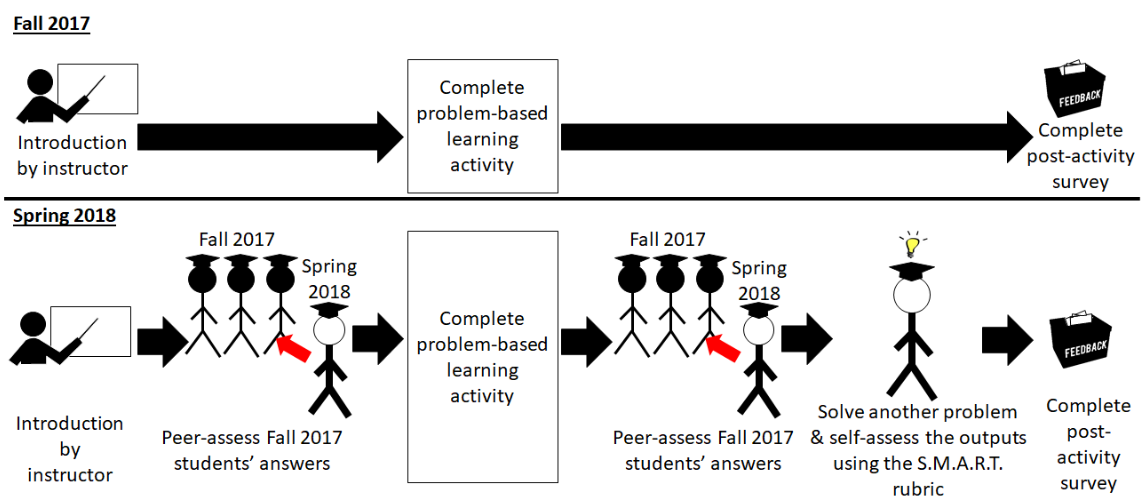

Figure 12 The procedure for collecting data from the Fall 2017 and Spring 2018 students

Students from fall 2017

When implementing the module for the Fall 2017 session, students provided their:

- Best solution and best policy from the ideas that were brainstormed (i.e., initial answers)
- Final solution and final policy to resolve the problem (i.e., final answers)
- Self-evaluation using the S.M.A.R.T. rubric for each of their answers.

Collecting those responses with their self-evaluated S.M.A.R.T. evaluations allows this research to provide the students' answers to other individuals for evaluation purposes, and also to compare the self-evaluated initial and final scores.

Students from spring 2018

For the Spring 2018 session, in addition to implementing the learning module, this research required the students to: evaluate the Fall 2017 students' answers using the S.M.A.R.T. rubric; and solve another problem and self-evaluate their answers to that new problem using the S.M.A.R.T. rubric. These additions provide the study with peer-evaluations of the Fall 2017 students' responses using the S.M.A.R.T. rubric. This also helped to provide an opportunity for the researchers to see if students' self-evaluations were different when evaluating a newly created solution and policy to a new problem card after completing the sequential thought exercises included in the original PBL module.

To facilitate these additions, this research provided the Spring 2018 students with the answers provided by Fall 2017 students for two different problem statements. All Spring 2018 students were provided with responses to a problem that was different from the type they had selected. For example, if a student addresses a problem with an issue associated with 'individual personalities' during the activity, the student will not evaluate answers that problem or any other problems associated with individual personalities before or after the activity. This setup reduces the chances of Spring 2018 students from being able to directly use the answers provided by the Fall 2017 students when addressing their problem. Also, the Fall 2017 students' answers were arranged randomly so that students would not know whether the answers they were evaluating came from the beginning or end of the PBL activity. Theoretically, if students knew that a response came from the end of the activity, they could be inclined to rate it more highly because they believe it is supposed to be better from this fact alone. This helped to reduce the chances of bias from the student evaluations.

In addition to collecting the Spring 2018 students' evaluations of the prior semesters' students' responses, the Spring 2018 students were also tasked with trying to resolve a follow-up problem without following the structured PBL module thought process. After the students completed the learning module, they were asked to provide a solution and policy to a problem card other than the one they were originally assigned. To reduce the tendency in students from remembering prior semester' answers when evaluating answers for the new problem, the students were not informed that they would need to address a second problem during the activity. This was done to determine the extent to which the types of behaviors demonstrated during the initial activity might be observed for a second problem.

Industry practitioners

To provide this research with expert-evaluations on the students' answers, industry practitioners evaluated the Fall 2017 students' initial and final answers using the S.M.A.R.T. rubric. The practitioners included individuals from different companies and various stakeholders that have responsibilities directly related to BIM. The selected practitioners were asked to evaluate verbatim responses generated by the students during the activity. To reduce any potential bias from industry experts knowing whether a student answer was provided at the beginning or end of the session, the Fall 2017 students' answers are arranged randomly. This meant that the practitioners would only be able to evaluate the students' responses based on their content and did not know whether the responses were initial and which were final.

The practitioners were given the same set of responses that were given to the Spring 2018 students. This allowed this research to identify any differences between the practitioners' and Spring 2018 students' evaluations. Furthermore, it would help to determine the extent to which students and practitioners evaluate the responses similarly or differently.

5.3.2 Data analysis

Scores from evaluations using the S.M.A.R.T. rubric

The S.M.A.R.T. rubric (Appendix C) shows a scoring system of minimum 1 point and maximum 3 points for each criterion. Because there are five components to S.M.A.R.T., the minimum and maximum total scores for answers are 5 points and 15 points, respectively. This study uses this scoring system's overall scores and each criterion scores to compare the module's impact on the S.M.A.R.T. scores among students' answers when addressing: the same problem throughout the activity; and another problem post-module. Table 12 presents the data points used for those comparisons. For each comparison S.M.A.R.T. evaluations of various student-developed solutions and policies are compared. The comparisons also include evaluations generated by students in both semesters and also industry practitioners. For each comparison presented, a rationale is also included to explain why the authors specifically studied each pair of data points. For all comparisons, the Wilcoxon signed-rank test was used to identify any statistical difference in the comparisons. The authors use that test because the S.M.A.R.T. rubric produces ordinal variables in nature and the test compares two dependent samples with ordinal variables for the difference in population means (Gibbons and Chakraborti, 2011).

Table 12 Type of comparisons and their rationale when analyzing the S.M.A.R.T. scores

Comparison between		Rationale of comparison
Data Point 1	Data Point 2	
Fall 2017 self-evaluation: initial answers	Fall 2017 self-evaluation: final answers	Identify the module's perceived impact on the S.M.A.R.T. scores
Spring 2018 self-evaluation: initial answers	Spring 2018 self-evaluation: final answers	
Spring 2018 peer-evaluation: Fall 2017 initial answers	Spring 2018 peer-evaluation: Fall 2017 final answers	Identify the module's impact on the S.M.A.R.T. scores with theoretically removing any potential bias in the evaluations
Practitioners' evaluation: Fall 2017 initial answers	Practitioners' evaluation: Fall 2017 final answers	
Spring 2018 self-evaluation: initial answers	Spring 2018 self-evaluation: post-module answers	Identify the module's perceived impact on the S.M.A.R.T. scores when solving a similar type of problem post-module
Spring 2018 self-evaluation: final answers	Spring 2018 self-evaluation: post-module answers	Identify the perceived impact of the module's PBL process on the S.M.A.R.T. scores

Students' feedback from the post-activity survey

In addition to analyzing the scores for the S.M.A.R.T. critertia, this research analyzed the students' feedback of the learning activity from the post-activity survey. The analysis involves comparing students' feedback on the activity's impact on the non-technological skills required for resolving common issues in BIM-based construction projects from the post-activity survey (i.e., Appendix A). Comparing the students' feedback on the Likert-like scale questions provides an indicator of the activity's impact towards the enhancement of those non-technological skills in themselves from a student's perception. Also, the open-ended questions were analyzed to identify any feedback from the students that demonstrate the module' strengths in enhancing those non-technological skills.

5.4 Results And Discussion

This section presents the results from analyzing the data collected from the Fall 2017 students, Spring 2018 students, and industry practitioners. The Fall 2017 students include 55 students with each student self-evaluated their outputs (initial solution, initial policy, final solution, and final policy) providing 220 self-evaluation data points. The Spring 2018 students include 46 students with each student self-evaluated their outputs (initial solution, initial policy, final solution, final policy, post-module solution, and post-module policy) providing 276 self-evaluation data points. Also, the Spring 2018 students peer-evaluated the Fall 2017 students' outputs twice providing 368 peer-evaluation data points. The industry practitioners include 11 individuals with each practitioner externally-evaluated the Fall 2017 students' output six times providing 264 external-evaluation data points.

The Fall 2017 and Spring 2018 students are primarily Seniors, with several Juniors students. Most students have multiple internships or at least one internship experience prior to taking the class. The industry practitioners are individuals of different companies that this research selected because of their in-depth knowledge and experience with BIM in the industry. Five of them are from Phoenix, AZ, near this research' academic institution, while the other six are from other states throughout the United States. This research purposefully selected the individuals to maintain a level of quality of the external-evaluators.

5.4.1 Module's impact on S.M.A.R.T. scores

Table 13 presents the changes between the S.M.A.R.T. scores' mean between the initial and final answers. The results show a significant increase in the overall scores by all evaluators (i.e., students' self-evaluation, students' peer-evaluation, and industry practitioners' external-evaluation). The finding that students' evaluate their own work more highly after completing the exercise is largely intuitive. Students knew that they were participating in a research activity aimed at improving BIM education. Therefore, it is possible that they consciously or subconsciously inflated their S.M.A.R.T. scores toward the end of the activity because they believed they were supposed to see improvement in their performance. However, when examining the scores received by their peers in a different semester and also by industry practitioners who did not know which responses came from the beginning or end of the activity, it was noteworthy to see that these scores also illustrated an increase in the overall S.M.A.R.T. scores. This suggests that PBL leads to improved scores related to the S.M.A.R.T. criteria among students' answers for addressing a problem statement related to common issues in BIM-based construction projects.

While the results show increases in the overall scores and scores for all S.M.A.R.T. criteria regardless of the evaluator, there is a lack of significant changes in certain specific elements within these criteria. For example, the researchers did not observe a significant shift in students' self-evaluations related to the 'realistic' criterion. Realism often relates to the practical ability for a solution or policy to be implemented (Doran, 1981). This may be influenced by the attributes of a project or team that fall outside the scope of the specific problem statement that was presented to the students. This means that students may have to make what they believe to be logical assumptions about this context. If a student evaluates his or her own responses based on this category, that individual would likely maintain the same assumptions through the activity, which may explain the comparatively high mean scores associated with this criterion throughout the activity. As a result, this high mean does not indicate a significant shift in the students' self-evaluations of this S.M.A.R.T. criterion.

Table 13 S.M.A.R.T. scores from all evaluators for the Fall 2017 students' answers

Evaluator	Self (Fall 2017 students)			Peer (Spring 2017 students)			Industry practitioners		
Initial or final answers	Initial ($S^{17}{}_I$)	Final ($S^{17}{}_F$)	$S^{17}{}_F - S^{17}{}_I$	Initial (P_I)	Final (P_F)	$P_F - P_I$	Initial (I_I)	Final (I_F)	$I_F - I_I$
Specific	2.72	2.92	0.20**	2.27	2.54	0.27**	1.97	2.21	0.24**
Measurable	2.53	2.85	0.32**	2.00	2.39	0.39**	1.94	2.06	0.12
Assignable	2.60	2.85	0.25**	2.20	2.55	0.35**	2.07	2.13	0.06
Realistic	2.80	2.92	0.12	2.32	2.52	0.20**	1.88	2.10	0.22**
Time-based	2.43	2.85	0.43**	1.99	2.37	0.38**	1.78	2.08	0.30**
Overall	13.07	14.39	1.32**	10.78	12.36	1.58**	9.65	10.58	0.94**

* Final scores that are significantly different from the initial scores at $p < 0.05$ from the Wilcoxon signed-rank test.

** Final scores that are significantly different from the initial scores at $p < 0.01$ from the Wilcoxon signed-rank test.

In addition to a lack of significance in realism among students' self-evaluations, the researchers also did not observe significant shifts in practitioners' evaluations of the 'assignable' and 'measurable' criteria. This may be attributed to the different behaviors of individuals with industrial experience (i.e., the industry practitioners) and without industrial experience (i.e., the students) (Walker et al. 2005; Gruenther et al. 2009). Also, students with limited industrial experience through internships may have behaviors that are more similar to those without any industrial experience than individuals with years of industrial experience (Bailey 2007). Therefore, the students and industry practitioners may have different thought process or standards when evaluating the assignable and measurable criteria resulting in the discrepancies between the significant increase in those criteria.

5.4.2 Module's impact on S.M.A.R.T. scores for another problem

Table 14 presents the differences in the students' self-evaluation of their S.M.A.R.T. scores between the initial answers and: final answers for the same problem; and post-module answers for another problem. The scores for the final answers have significant increases in the overall S.M.A.R.T. scores and all S.M.A.R.T. criteria. While the scores for the post-module answers only have significant increases in the overall S.M.A.R.T. scores and some of the S.M.A.R.T. criteria (i.e., specific, measurable, and time-based), the scores for the leftover S.M.A.R.T. criteria (i.e., assignable and realistic) has also increased. In other words, the learning module has a positive impact on the overall S.M.A.R.T. scores for both the original problem provided and other similar problems post-module. In this research, those scores are the proxy for assessing those non-technological skills required for resolving the common issues in current BIM-based construction projects. Therefore, these findings suggest PBL enhances those non-technological skills when addressing problems related to the common issues in BIM-based construction projects.

5.4.3 PBL's process of problem-solving and the S.M.A.R.T. scores

Table 14 also presents the differences in the students' self-evaluation of their S.M.A.R.T. scores between the final answers and the brainstormed: initial answers for the same problem; and post-module answers for another problem. The overall scores and most scores of the S.M.A.R.T. criteria for the final answers are significantly higher compared to the brainstormed answers. In other words, the students perceived that the answers generated through this research's process of problem-solving (i.e., analyzing the problem identifying, locating, and evaluating further information for solving the problem; consulting with peers on approaches for solving the problem; making decisions on the final approach for solving the problem; and reviewing own performance) are better compared to the brainstormed answers. Therefore, these findings suggest that in addition to receiving PBL's benefit as a pedagogy, educators should inform students that understanding the pedagogy's process of problem-solving can assist themselves in creating better outputs for a problem.

Table 14 Students' self-evaluation of their responses using the S.M.A.R.T. rubric for the Spring 2018 session

Answer	Initial	Final	Post-module	$S^{18}{}_F - S^{18}{}_I$	$S^{18}{}_{2nd} - S^{18}{}_I$	$S^{18}{}_F - S^{18}{}_{2nd}$
Problem	1st problem ($S^{18}{}_I$)	1st problem ($S^{18}{}_F$)	2nd problem ($S^{18}{}_{2nd}$)			
Specific	2.70	2.92	2.84	0.22**	0.14*	0.08*
Measurable	2.39	2.85	2.66	0.46**	0.27**	0.19**
Assignable	2.65	2.91	2.72	0.26**	0.07	0.19**
Realistic	2.73	2.92	2.82	0.19**	0.09	0.10*
Time-based	2.45	2.68	2.62	0.23**	0.17*	0.06
Overall	12.91	14.29	13.65	1.38**	0.74**	0.64**

* Scores that are significantly different from the initial scores at $p < 0.05$ from the Wilcoxon signed-rank test.

** Scores that are significantly different from the initial scores at $p < 0.01$ from the Wilcoxon signed-rank test.

5.4.4 The learning module's impact on students

Table 15 presents the students' feedback on the activity through the Likert-scale questions in the post-module survey. The results show that students generally agree that the activity can enhance problem-solving, analytical, and communication skills, and ability to work as a team member. These findings are similar to the findings of prior works suggesting that most students perceived that PBL could enhance analytical and problem-solving, teamwork, and communication skills. While this illustrates perception of value by the students, it is possible that they simply rated this process as effective because they knew it was part of a research activity. In other words, these findings suggest that students perceived the activity to enhance some of the non-technological skills required for resolving common issues in BIM-based construction projects.

Table 15 Students' feedback from the Likert-like scale questions

The activity has enhanced my:	Semester (Fall 2017, n=37; Spring 2018, n=46)	Feedback			
		Strongly agree	Agree	Disagree	Strongly disagree
Problem-solving skills	Fall 2017	45.7%	39.1%	6.5%	8.7%
	Spring 2018	34.5%	49.1%	9.1%	7.3%
Analytical skills	Fall 2017	47.8%	37.0%	8.7%	6.5%
	Spring 2018	23.6%	61.8%	7.3%	7.3%
Ability to work as a team member	Fall 2017	45.7%	32.6%	10.9%	10.9%
	Spring 2018	29.1%	47.3%	16.4%	7.3%
Communication skills	Fall 2017	43.5%	34.8%	15.2%	6.5%
	Spring 2018	25.5%	50.9%	16.4%	7.3%

In addition to the Likert-like scale questions, this research analyses the open-ended questions in the post-module survey. Several students responded that the module had made them use some of the targeted skills. For example, the following responses can be associated with communication, and analytical, and problem-solving skills, respectively:

- "Makes you think outside the box, communicate with your team effectively."

- "Having to come up with more than one solution because it made me try to think outside the box."
- "The activity forces you to think about problems in a different way and use problems solving skills to find solutions."

Also, several students responded that the module had made them understood the S.M.A.R.T. criteria (i.e., the proxy used to assess the targeted skills):

- "The activity forces you to use the S.M.A.R.T. lens over and over again, so I now know what is clearly expected of me when answering these types of questions."
- "To understand S.M.A.R.T. answering."

Several students also responded that the module had given them some idea on real contemporary problems of the current industry:

- "You get to see how you can use BIM in the real world and how it affects others."
- "Putting yourself in a real-world situation and figuring out how to deal with the problem."
- "Get enough idea how to behave in the future to avoid those mistakes that may happen in the field of a project."

While the students may rate the module as effective because they knew it was part of a research activity, the open-ended questions require students to input information such as their feelings and attitudes towards the learning module. These findings from the open-ended questions suggest that the learning module can be associated with the non-technological skills required for resolving common issues in BIM-based construction projects.

5.4.5 Limitations

While this research provides insights on the learning impact of PBL on the non-technological skills required for resolving the common issues in current BIM-based construction projects, the study has a few limitations. First, there are differences in the significant increment in the individual S.M.A.R.T. criteria between the evaluators. For example, there is only a significant increase in the measurable and assignable criteria by only the students (both self and peer-evaluations) but not the industry practitioners. While these findings suggest there are discrepancies between the evaluators' thought process on which individual S.M.A.R.T. criteria have increased, this research does maintain the claim that the learning module has a positive impact on those non-technological skills. This claim is supported by the results showing that the final answers have higher scores for both the overall and each S.M.A.R.T. criterion compared to the initial answers regardless of the evaluator.

Second, this research uses only self-evaluations when comparing the S.M.A.R.T. scores for the students' initial answers and post-module answers. While self-evaluations could raise doubts about their value and accuracy, prior works suggest that self-evaluation can produce valid and reliable information on students' performances (Dochy et al. 1999; Ross, 2006). Also, the self-evaluations in this research do not affect the students' grades, which can further enhance the strengths of self-evaluation (Ross, 2006). Therefore, this research does maintain the claim the information from the self-evaluations have validity and reliability to facilitate this research in identifying the learning impact of PBL on the non-technological skills required for resolving common issues in current BIM-based construction projects.

5.5 Conclusion

This chapter's primary objective is to present the learning impact of a PBL module that targets the skills required for addressing common, people- and process-related, issues in BIM-based construction projects. This research addressed this topic by implementing the learning module in a BIM course and analyzing the collected data from the implementation. The analysis of the S.M.A.R.T. scores indicates the learning impacts of the module. The analysis of the students' feedback identifies the perceived learning impacts of the module. The major findings from the analyses include:

- PBL enhances scores for the S.M.A.R.T. criteria (i.e., criteria used as a proxy to assess the non-technological skills required for resolving common issues in BIM-based construction projects) among students' answers in addressing problems related to the issues that are commonly recurring in BIM-based construction projects.
- Similar to prior studies, students in a BIM classroom environment perceived a PBL module could enhance their analytical and problem-solving, teamwork, and communications skills (i.e., the non-technological skills required for resolving common issues in BIM-based construction projects).
- Students perceived that the PBL process of solving a problem generates better outputs than brainstorming in addressing problems related to the common issues in current BIM-based construction projects.

CHAPTER 6 RESEARCH CONTRIBUTION

In summation, this research identifies the common issues in current BIM-based construction projects, the skills required for resolving those issues, and the pedagogies that have high potential in enhancing those skills. This research has demonstrated the process of developing a PBL module that targets the non-technological skills required for resolving the common issues in BIM-based construction projects and identified the impact of that learning module.

6.1 Summary of Reseach Contributions

This research contributes to the existing body of knowledge related to the pedagogical value of PBL in education as well as the process for creating this type of learning module.

6.1.1 Understanding of the pedagogical value of PBL

Through the implementation of the learning module, this research has helped to expend the current understanding of PBL in BIM education. It has observed several key benefits to using this type of pedagogy including: PBL can enhance the non-technological skills required for resolving the common issues in current BIM-based construction projects; and the structured thought process that is incorporated in a PBL module results to improvements in students' self-evaluations of their outputs. Future research will benefit from the identification of the aspects of the learning process that benefitted from using PBL as well as the aspects of learning where no benefit was observed. This contribution allows future research to develop learning modules that may support educators in preparing students for their future careers by enhancing the skills that are most likely required for effectively implementing BIM in the current industry.

In addition to enhancing the non-technological skills required for resolving the common issues in current BIM-based construction projects, the PBL process of producing new and original outputs (i.e., the solutions and policies to address the project issues) can be associated to "creating," the most complex function in human cognition, as according to the revised version of Bloom's taxonomy (Anderson et al. 2001). Specifically, "creating" involves putting different parts together from numerous elements with emphasis on creating a new meaning or structure (Anderson et al., 2001). Having students "creating" new and original outputs have its benefits including long-term knowledge retention on the particular subject and development of transferable skills (Albanese et al. 1993; Hmelo-Silver, 2004; Kong et al. 2014). Also, university graduates from four-year university programs are expected to enter the current industry with the ability to "create" (De Graaf and Kolmos, 2003; Brown et al. 2013; Connor et al. 2015). Therefore, in addition to enhancing those targeted skills in this research, creating PBL modules for a BIM curriculum can provide students with opportunities to carry out the most complex function in human cognition that are being sought after in individuals by the industry.

6.1.2 Documentation of the learning module's development process

The development process for creating the learning module has been detailed in this research to help future research by creating alternate content that attempts to satisfy the current needs of the industry. Specifically, the development process of the learning module may also be beneficial to other non-BIM-educational researchers because the types of problems in this research are not necessarily different from non-BIM educational researchers. While the learning module was only developed as a proof of concept, the documentation of the process used to create the learning module helps to illustrate a functional process for developing a new learning module like this research's learning module. The documentation presents a repeatable methodology that will enable others to create a similarly structured learning module for BIM education. Also, the documentation will support future researchers by providing methods for identifying the common issues in the current industry, skills required to solve those issues, pedagogies reported to enhance those skills, process for creating and implementing a learning module that uses one of those pedagogies. In addition to the documentation of the process used for creating the learning module, several limitations associated with the chosen development process have also been discussed. These will help educators in avoiding some of the potential problems observed to avoid some of the limitations observed in this research. Also, all assessments administered are included in the appendix of this document to illustrate the learning module.

6.2 Recommended Future Research Directions

The research presented has provided several contributions to the body of knowledge related to the pedagogical understanding of PBL in BIM education, but also has several limitations. This section explores possible directions for future work based on the findings of this research.

6.2.1 Streamlining evaluators' thought process on the S.M.A.R.T. criteria

While the results of this research show that industry practitioners and students evaluations are different that can be caused from the different thought process between expert and novice practitioners; future work can reduce those differences by adding additional steps to reduce different interpretations of the criteria in the S.M.A.R.T. rubric during the evaluation process. For example, future research can provide examples that specifically illustrate the different level of evaluations in that rubric. Providing those examples may reduce the misinterpretation that can result in evaluations with higher agreements between evaluators regardless of their level of experience. Also, future research can compare the level of agreements between evaluators, for example between industry practitioners, between students, and between industry practitioners and students, to identify any differences in the thought process of evaluators after providing those examples.

6.2.2 Development of alternate learning modules and assessments

Future work will compare the results of implementing the other pedagogies (i.e., cooperative learning, game-based learning, hands-on, project-based learning, service-learning, student competition, and undergraduate research) that target the non-technological skills required for resolving the common issues in BIM-based construction projects. Specifically, researchers and educators can use the same assessment strategy used in this research when identifying the alternate learning module's impact among students to have a direct comparison with the impact of this research's learning module. The comparison can provide insights on which teaching strategy is more efficient and effective in enhancing those non-technological skills.

6.2.2 Identify differences in the common issues between construction projects with and without BIM

In addition to future work related to developing alternate assessments and learning modules, there are also opportunities to further examine the differences in the common issues between construction projects with and without BIM. For example, the key findings of this research include breakdowns, changes, human error, individual personalities, and transfers of information as the common issues in BIM-based construction projects, and these issues might also be the common issues in non-BIM-based construction projects. Therefore, identifying the common issues in construction projects without BIM and comparing the results to the common issues in construction projects with BIM will provide insights on the benefits and new challenges of adopting BIM into construction projects.

Additionally, it would be of value for future work to target those issues that specifically occur from implementing BIM when developing alternate content for current BIM curricula. Reducing the scope of BIM curricula that prepares university graduates with the specific skills for implementing BIM successfully might reduce unnecessary overlaps with the outputs of other courses in AEC programs. This additional information could also determine how the content should be provided to students to illustrate the new challenges when implementing BIM in construction projects in addition to the conventional challenges that are occurring in construction projects without BIM.

6.2.3 Leveraging findings for use outside of academic institutions

Through informal discussions with different industry practitioners about the learning module, a common question that frequently was raised was related to whether PBL or the learning module could be used to offer benefits to the current workforce in the AEC industry. While this research could answer that question if structured differently, the findings would be out of the scope of this research. Therefore, this limitation could provide a valuable direction for future research. Although this research's PBL module was intended to educate students in academia, the development process from this research may be able to be transitioned to enhance the non-technological skills of newcomers in the BIM realm. Enhancing the non-technological skills among the newcomers could allow a smoother adoption of BIM in their projects.

6.3 Closing Remarks

The experience of developing and implementing an alternative learning module for BIM education has been hugely rewarding. The findings from this initial development of the PBL module are highly encouraging for the potential of further exploring high potential pedagogies in education.

However, the initial development of the learning module also results to an unexpected findings. Specifically, the common issues in BIM-based construction projects are likely to be the common issues in non-BIM-based construction projects. Also, the non-technological skills required for resolving the common issues in BIM-based construction projects are the non-technological skills required in university graduates for project management. This situation means that although BIM can be seen as a new process or technology that are being adopted in construction projects, the issues, and skills that are associated with implementing BIM can be associated to the general situation of construction projects. Therefore, preparing university graduates and project team members with those skills and also resolving project issues related to people and process can resolve the common project issues in non-BIM-based construction projects, BIM-based construction projects, and also other future construction projects that are adopting the latest technology or processes at that time.

Also, while this research identified the pedagogies that are reported to enhance the non-technological skills required for resolving the common issues in current BIM-based construction projects, the results did not illustrate any teaching strategies that are reported to enhance two skills – planning and organizational; and initiative. Besides required for resolving the common issues in BIM-based construction projects, these skills are the also critical skills required for individuals to become successful in their career. While initiative can be associated with nurture instead of education; and planning and organizational can be difficult to assess, this research expects prior studies to illustrate the impact of different pedagogies on those skills although the results may not be positive. Therefore, it is surprising that none of the thousands of literature reported the impact of the pedagogy that was used in their studies on those skills.

Finally, on the surface, the targeted skills in this research (i.e., analytical and problem-solving, communication, initiative, planning and organizational, and teamwork) could be applied to other contexts of BIM because those skills are sought after in each university graduates from the AEC programs. Additionally, while the learning module's content was developed using the common issues in current BIM-based construction projects, those issues can also be the common issues in non-BIM-based construction projects. Furthermore, the learning module was developed using the general theories of PBL, and the module does not involve students using any software associated with BIM. In other words, the learning module in this research is not BIM-specific. Therefore, while the objective of this research is to develop a learning module that targets the non-technological skills required for resolving the common issues in BIM-based construction projects, the findings of this research on PBL can be generalizable to other curricula throughout the AEC education.

This work has made a first step toward advancing the development of alternate content that targets the non-technological skills for managing people and processes of BIM in an engineering education context to prepare students with the skills that may support their future career success. This research illustrates that much more can be done and future developments will undoubtedly determine other benefice aspects of these high potential pedagogies not only for engineering students but also for other disciplines. As technology evolves, the possibility of creating alternate content will only increase. It is exciting to consider how this research may serve as a starting point for some of these new and innovative approaches to education.

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APPENDIX

APPENDIX A

THE LEARNING MODULE'S FEEDBACK FORM

I feel that:	Strongly disagree	Disagree	Agree	Strongly agree
The activity has enhanced my problem-solving skills	1	2	3	4
The activity has enhanced my analytical skills	1	2	3	4
The activity has enhanced my ability to work as a team member	1	2	3	4
The activity has enhanced my communication skills	1	2	3	4
The content reflected real-world issues that will help with future professional experience	1	2	3	4
Overall, I was satisfied with the quality of the activity	1	2	3	4
The activity should be used in future BIM courses	1	2	3	4

APPENDIX B

THE LEARNING MODULE'S PEER- AND SELF-ASSESSMENTS

When performing the activity, I felt that I/______ (insert name of team member)	Strongly disagree	Disagree	Agree	Strongly agree
Was able to share ideas clearly with the group	1	2	3	4
Actively participated in the group discussion	1	2	3	4
Gave input which was relevant to the problem	1	2	3	4
Actively tried to think how to use resources to solve the problem	1	2	3	4
Was able to solve the problem	1	2	3	4

APPENDIX C

THE LEARNING MODULE'S S.M.A.R.T RUBRIC

Criterion/Score	3 points	2 points	1 point
<u>S</u>pecific	Has a strong connection to solving the problem	Has some connection to solving the problem	Has no connection to solving the problem
<u>M</u>easurable	Has clear criteria for measuring progress	Has unclear criteria for measuring progress	Has no criteria for measuring progress
<u>A</u>ssignable	Has tasks that are clearly assigned to certain individuals or groups	Has tasks that are somewhat assigned to certain individuals or groups	Has tasks that are not assigned to any individuals or groups
<u>R</u>ealistic	Can be executed	Can probably be executed	Cannot be executed
<u>T</u>ime-related	Has a clear time-frame for accomplishing certain goals	Has an unclear time-frame for accomplishing certain goals	Has no time-frame for accomplishing certain goals

APPENDIX D

AN EXAMPLE OF THE LEARNING MODULE'S PROBLEM CARDS

Project manager (you): We're scheduled to receive addendum #010 tomorrow. The design changes should affect mechanical. **Electrical subcontractor:** How long does mechanical need for this change? My team will start prefabricating next week. I need the details by the end of this week. If you can't get them to me, my team will not be able to install our system on time. **Plumbing subcontractor:** We're not going to model our system multiple times. My modelers will wait until mechanical finishes up their responsibilities first. **Mechanical subcontractor:** We need two weeks to finish. It's a major change and my team will need to rework most of our system. We will also borrow modelers from other projects to do it. We need to discuss that cost too. *How will you proceed with this meeting? How would have your subcontractors maintain their effectiveness (in regard to BIM) after they are impacted by design changes? And why?*